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Announcement from the U.S. Naval Observatory

The availability of large astrometric catalogs and the admirable acumen of users has led to the republishing of the same measures and identification of the same "new" systems by multiple data-miners. This has significantly increased the amount of work needed to properly incorporate these data into the USNO double star catalogs. Therefore, in the future, data mining results will be added to the WDS and WDSS at the discretion of the catalogers. Furthermore, preference will be given to data prepared by those specifically associated with the original catalog project.

Double Star Measures Using the Video Drift Method - XII

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Abstract: Position angles and separations for 254 multiple star systems are presented using the video drift method. A proposed new double star, not currently in the WDS, is shown with nearly identical Gaia proper motions and parallaxes for the components.

Introduction

This is Paper XII in our continuing series on double star measurements using the video drift method first proposed by Nugent and Iverson 2011. We continue our practice of preferentially measuring multiple star systems listed in the Washington Double Star Catalog (WDS) that have not been measured for a minimum of 10-15 years and have less than 10 measurements. Measurements are limited to systems with a separation greater than 3.47". This separation represents the current minimum resolution of the video drift method with our equipment.

Methodology

The techniques used in this paper are the same as in our previous paper (Nugent and Iverson, 2018). All measurements were made with a pair of Meade 14-inch LX-200 telescopes (focal length 3556 mm at f/10, scale factor 0.6"/pixel). Astronomical video data collection systems require a onetime aspect ratio calibration. The reader is referred to our previous discussion of the problem and calibration procedure (Nugent and Iverson, 2014).

For systems in which either the primary and/or secondary star is faint, image enhancement techniques were employed. Co-author Iverson used a variation of the drift method employing an integrating video camera (Iverson and Nugent 2015) while co-author Nugent used a Collins I3 image intensifier with a non-

integrating camera. The faintest system measured in Table 1 had primary/secondary magnitudes of +10.61, +15.3. Thirty-two systems had WDS magnitudes in the +13.5 to +15.3 range.

Occasionally we would come across systems in which there was a large magnitude difference between the components. At a nominal gain setting for our video cameras the fainter (secondary) component was usually not visible thus no measurements could be acquired of its position. If it was visible, the primary (brighter) component was overly saturated on the video chip sensor and thus too large to be measured by the restricted size of the measurement aperture in the Limovie program. The solution is to make two separate drift runs at different gain settings so that each component was visible and thus could be measured; then combine the measurements from both runs to derive a position angle and separation.

Other systems had very close separations causing the components to merge at our nominal scale factor of 0.6"/pixel. This issue was resolved by using a magnification script on the video. The video was enlarged significantly into three sections (typically scale 0.2"/pixel or less) allowing the components to be resolved and measured. Both of the above techniques are described in detail in Paper 11 of this series (Nugent and Iverson 2018).

(Text continues on page 502)

Double Star Measures Using the Video Drift Method - XII*Table 1. Results of 254 double stars using the video drift method*

Object	Designation	PA °	PA SEM °	Sep "	Sep SEM "	Avg. Date	Mag 1	Mag 2	Samples	Nights
00002-2519	COO 273	10.6	1.15	8.70	0.160	2017.24	10.13	10.20	3	1
00042+2701	SMA 1	161.4	0.09	13.44	0.017	2018.77	9.96	10.84	15	3
00043+4235	HJ 1932AB	306.0	0.06	7.02	0.011	2018.77	8.64	9.50	25	5
00043+4235	WAL 4AC	188.1	0.04	47.19	0.052	2018.77	8.64	9.83	25	5
00093+2517	FYM 132AC	161.7	0.02	62.52	0.022	2018.83	7.77	12.4	30	6
00093+2517	GIC 2AB	236.3	0.03	29.69	0.016	2018.83	7.77	11.46	30	6
00118+1952	HJ 1943AB	236.5	0.10	12.22	0.019	2018.83	10.03	11.5	15	3
00118+1952	HJ 1943AC	47.8	0.12	15.32	0.095	2018.83	10.03	13.7	3	1
00118+1952	HJ 1943AD	248.0	0.04	55.58	0.055	2018.83	10.03	13.89	20	4
00187+2545	HJ 1015AB	286.9	0.27	5.35	0.042	2018.82	9.78	10.95	3	1
00187+2545	HJ 1015AC	252.0	0.23	27.97	0.298	2018.77	9.78	13.57	5	1
00379-2740	BRT2845	334.7	1.58	5.72	0.156	2017.78	10.35	12.	3	1
00391-2533	SKF 759	107.6	1.30	7.70	0.172	2017.78	11.4	11.8	6	1
00408-3246	HJ 3384	265.9	0.79	5.88	0.086	2017.78	10.09	10.83	7	1
01025-2137	SEE 10	312.2	1.06	5.76	0.118	2017.78	8.05	10.89	5	1
01130+3004	STT 26AC	340.8	0.05	117.69	0.057	2018.83	6.34	13.59	20	4
01172+0201	HDO 45	103.6	0.03	38.23	0.044	2018.93	7.36	9.65	20	4
01227+1712	STTA 16	137.2	0.04	72.03	0.083	2018.93	7.22	10.19	20	4
01428+2421	GRF 1	4.1	0.04	46.93	0.058	2018.93	9.45	9.68	20	4
02002+0641	STF 198	117.9	0.03	45.56	0.040	2018.93	9.22	9.80	20	4
02110+2912	CHE 66	161.7	0.03	37.18	0.023	2018.93	9.81	10.64	15	3
02415+4015	AG 46	344.1	0.04	39.39	0.033	2018.87	9.59	10.18	10	2
02521+3718	STF 316	135.1	0.03	14.36	0.016	2018.93	9.46	9.74	15	3
03015+0513	BAL2604	14.2	0.06	11.37	0.023	2018.93	9.4	9.5	15	3
03090+4415	STF 351	115.4	0.05	27.10	0.035	2018.93	9.18	9.87	15	3
03143+2057	HJ 2178	213.7	0.070	17.86	0.019	2018.93	9.8	10.6	15	3
03254-0109	SCJ 2	183.1	0.02	16.92	0.023	2018.93	9.03	9.96	15	3
04254+0221	HJ 2230	324.9	0.01	34.73	0.029	2018.93	9.65	9.88	15	3
04494+4414	SKF1383	272.0	0.04	54.15	0.051	2018.93	8.32	9.79	15	3
05264-1210	GAL 384	192.9	0.06	12.07	0.021	2018.87	9.3	9.5	10	2
05378+0245	SKF1528	127.4	0.04	41.91	0.054	2018.93	9.20	10.16	15	3
05400+2232	AG 99	143.6	0.13	7.61	0.026	2018.87	9.62	10.17	5	1
05499+2259	ARN 91A	132.4	0.08	112.19	0.405	2018.87	8.37	8.99	5	1
05499+2259	POU 789	251.0	0.10	12.66	0.028	2018.87	8.99	10.7	5	1
05504+1422	SKF2490	236.0	0.05	53.03	0.027	2018.87	8.99	10.21	5	1
08025-2447	J 1507	323.6	0.60	6.96	0.075	2018.77	9.76	11.06	9	1
08026-2733	HJ 4037AB	244.6	0.55	6.52	0.066	2018.72	7.22	8.41	7	1
08026-2733	HJ 4037AC	74.4	0.26	64.46	0.293	2018.89	7.22	9.22	3	1
08036-2213	B 2163AB	219.9	1.75	8.08	0.235	2018.89	10.08	10.8	3	1
08036-2213	B 2163AC	173.4	0.83	41.52	0.633	2018.55	10.08	13.78	3	1

Table 1 continues on the next page.

Double Star Measures Using the Video Drift Method - XII*Table 1 (continued). Results of 254 double stars using the video drift method*

Object	Designation	PA °	PA SEM °	Sep "	Sep SEM "	Avg. Date	Mag 1	Mag 2	Samples	Nights
08039-3133	LDS 201AB	240.5	0.44	46.11	0.339	2018.72	8.80	9.71	2	1
08053-1802	ARA 208	127.1	1.41	8.91	0.246	2018.89	10.41	11.24	3	1
08074+0012	BAL1132	265.0	0.52	6.62	0.064	2018.72	9.33	10.9	8	1
08098-2449	JAW 5AB	284.8	0.55	26.89	0.277	2018.55	9.22	10.85	3	1
08098-3822	HJ 4049AB	322.3	1.39	9.44	0.204	2018.89	9.82	11.1	3	1
08104+0020	BAL1133	316.1	0.54	6.45	0.066	2018.77	9.42	10.7	9	1
08108-3236	COO 68AB	155.0	1.49	7.58	0.227	2018.22	8.74	9.11	3	1
08108-3236	COO 68AC	21.2	1.19	15.71	0.283	2018.22	8.74	13.02	3	1
08151-2819	LDS 208	173.3	1.60	8.96	0.242	2018.22	10.80	11.5	3	1
08156-1859	ARA 397	308.7	1.76	6.53	0.252	2018.89	10.57	11.1	3	1
08189-2311	ARA1728	67.2	1.42	9.33	0.233	2018.55	10.52	11.32	3	1
08226-1041	HJ 784AC	11.1	0.71	18.09	0.233	2018.22	10.23	10.88	3	1
08296-3836	SKF1454AB,C	234.5	0.42	58.52	0.364	2018.22	8.62	9.27	2	1
08313-1938	J 1524AB	316.9	1.03	5.94	0.124	2018.22	10.83	11.3	8	1
08313-1938	J 1524AC	219.6	0.84	13.04	0.176	2018.22	10.83	13.4	7	1
08317-1640	LDS 222	256.8	0.67	6.75	0.109	2018.22	10.91	11.05	12	1
08366-1846	ARA 402	152.1	1.19	11.80	0.242	2018.22	10.40	10.9	3	1
08385-2502	B 161	317.9	0.66	7.70	0.111	2018.22	9.23	10.78	9	1
08405-2101	ARA1058	141.9	0.86	11.59	0.166	2018.22	7.88	10.95	3	1
08417-2018	J 2645	306.2	1.82	6.81	0.242	2018.22	10.9	11.2	3	1
08457-2121	J 1531	14.9	2.53	7.68	0.362	2018.22	10.51	10.98	3	1
08531-2718	JRN 7	139.3	4.01	7.55	0.513	2019.22	11.0	11.5	2	1
08591-3203	PRO 79	47.1	2.44	8.32	0.285	2018.22	11.3	11.3	3	1
09023-2724	B 173	283.0	0.77	7.01	0.106	2018.22	9.67	11.2	6	1
09050+1134	TOK 125AC	244.3	0.15	140.73	0.392	2018.22	8.67	9.33	2	1
09050-2512	BRT2964AB	226.5	1.12	5.65	0.107	2018.22	10.85	11.1	8	1
09065-3213	HJ 4173AB	301.1	2.17	13.01	0.410	2018.22	11.1	12.2	2	1
09065-3213	HJ 4173AC	243.5	2.07	14.09	0.445	2018.22	11.1	11.5	2	1
09119-3814	WFC 80	224.4	1.73	7.32	0.192	2018.22	9.94	10.70	3	1
09153+0531	HJ 124AB	70.8	1.32	15.40	0.435	2018.22	9.16	11.54	2	1
09153+0531	HJ 124AC	242.4	0.39	62.05	0.456	2018.22	9.16	11.45	2	1
09153+0531	SKF1841AD	274.3	0.91	17.62	0.318	2018.22	9.21	13.78	2	1
09155-3815	SWR 69AB	300.9	1.02	23.52	0.361	2018.22	11.06	11.36	3	1
09188-1025	A 125AC	80.3	0.42	51.74	0.400	2018.22	8.48	10.86	2	1
09200-2747	HJ 4199AB	110.5	0.72	11.60	0.147	2018.22	8.29	9.48	8	1
09238-2340	HDO 123AC	188.8	0.46	53.65	0.481	2018.22	8.07	11.01	2	1
09257-1917	XMI 92AB	44.8	1.43	16.62	0.421	2018.22	11.32	11.42	2	1
09257-1917	XMI 92AC	271.3	0.61	30.15	0.424	2018.22	11.32	11.28	2	1
09327-2826	I 1616AB	236.4	0.76	33.06	0.463	2018.22	9.44	9.74	2	1
09327-2826	I 1616AC	280.0	1.86	14.24	0.467	2018.22	9.44	13.03	2	1

Table 1 continues on the next page.

Double Star Measures Using the Video Drift Method - XII*Table 1 (continued). Results of 254 double stars using the video drift method*

Object	Designation	PA °	PA SEM °	Sep "	Sep SEM "	Avg. Date	Mag 1	Mag 2	Samples	Nights
09387-2644	HJ 2501AC	94.0	1.81	10.80	0.470	2018.22	10.05	10.47	2	1
09387-2644	HJ 2501CD	135.8	1.36	25.80	0.643	2018.22	10.47	12.24	2	1
09413+0256	GRV 796AB	250.8	1.26	36.07	0.771	2018.22	10.58	13.84	2	1
09413+0256	DAM 805AD	82.0	0.15	159.21	0.470	2018.22	10.58	10.9	2	1
09425-2108	HJ 4233	310.5	1.41	12.74	0.389	2018.22	8.27	10.98	2	1
09451-3835	HJ 4239	195.2	2.02	9.40	0.280	2018.22	8.62	9.94	2	1
09470-3228	HJ 4244A,BC	29.4	1.45	11.75	0.289	2018.22	10.05	10.05	3	1
09504-3320	HJ 4253AB,C	36.7	1.82	11.99	0.371	2018.22	10.27	10.53	2	1
09504-3320	TOB 5AB,D	286.5	0.69	40.93	0.456	2018.22	10.27	11.23	2	1
10013-2246	HDO 124AB	8.4	1.22	12.99	0.260	2018.22	7.83	9.96	3	1
10013-2246	HDO 124AC	54.8	0.51	42.70	0.346	2018.22	7.83	12.36	3	1
10271+1804	STF 1434	282.2	0.41	6.44	1.356	2018.29	9.49	9.68	8	1
10336+1513	STF 1446	249.6	0.18	5.48	0.045	2018.29	9.29	10.03	3	1
10374-1103	J 2075	61.3	0.55	6.61	0.069	2018.22	8.32	10.55	7	1
10535-2008	HO 533BC	131.9	1.72	13.53	0.450	2018.22	9.60	10.7	3	1
10535-2008	HO 533BD	297.4	0.89	40.13	0.627	2018.22	9.60	13.50	3	1
11035-3245	TRC 3	345.7	2.623	10.06	0.387	2018.35	11.2	13.7	3	1
11037-2941	HDS1577	3.3	1.21	10.74	0.266	2018.35	10.00	12.79	3	1
11062-2850	LDS4059AB	234.5	2.44	13.51	0.533	2018.35	10.61	15.3	3	1
11062-3827	HJ 4402AB	121.0	2.24	9.46	0.352	2018.35	10.1	11.1	3	1
11062-3827	HJ 4402AC	77.7	1.92	15.29	0.418	2018.35	10.1	14.2	3	1
11074-0114	BAL 865	219.4	2.45	9.22	0.417	2018.22	10.9	10.9	5	1
11090-3625	SKF1214	155.2	2.25	8.61	0.308	2018.35	11.0	11.2	3	1
11118-3045	BRT2985	252.6	1.29	4.46	0.133	2018.35	11.0	11.3	7	1
11121-1224	WFC 292	310.0	1.34	10.88	0.254	2018.35	9.58	13.0	3	1
11144-0225	HJ 178AB	34.3	1.24	18.46	0.368	2018.35	12.07	11.0	3	1
11144-0225	HJ 178AC	196.6	0.50	42.16	0.346	2018.35	12.07	13.28	3	1
11144-0225	HJ 178BC	201.9	0.57	59.84	0.574	2018.35	11.0	13.28	3	1
11145+0516	STF1518BC	353.8	1.96	3.47	0.127	2018.36	11.26	11.5	3	1
11164-2200	B 2274	359.4	0.31	9.63	0.173	2018.35	8.67	11.7	3	1
11244-0158	BAL 535	116.1	0.914	7.64	0.134	2018.35	11.10	13.1	9	1
11248-0829	TDS7844	319.7	1.61	15.95	0.460	2018.35	10.55	11.61	3	1
11251-2320	ARA1787	204.7	2.32	10.50	0.381	2018.35	11.65	13.8	3	1
11272-1604	LDS4100AB	158.8	0.59	49.95	0.522	2018.35	10.80	14.43	3	1
11273-3044	I 76	50.4	1.17	7.23	0.123	2018.35	11.57	12.0	9	1
11276-2343	HJ 4437AB	318.8	1.74	11.43	0.343	2018.22	10.95	11.0	3	1
11296-2428	JC 16AB	81.8	0.26	8.23	0.037	2018.22	5.82	8.60	9	1
11296-2428	JC 16AC	112.4	0.08	166.14	0.262	2018.22	5.82	8.86	3	1
11301+2958	STTA 111	33.8	0.04	66.84	0.098	2018.37	6.95	9.49	15	3
11309-2012	B 2280	31.2	1.08	9.33	0.162	2018.35	7.90	11.52	3	1

Table 1 continues on the next page.

Double Star Measures Using the Video Drift Method - XII*Table 1 (continued). Results of 254 double stars using the video drift method*

Object	Designation	PA °	PA SEM °	Sep "	Sep SEM "	Avg. Date	Mag 1	Mag 2	Samples	Nights
11316-3338	I 1543AC	160.1	0.84	26.75	0.370	2018.35	9.85	12.6	3	1
11360-1050	J 1577AB	274.4	1.65	7.86	0.294	2018.35	10.85	13.5	3	1
11360-1050	J 1577AC	83.9	1.06	19.94	0.395	2018.35	10.85	13.6	3	1
11368-2426	HJ 4456AB	118.6	1.06	13.25	0.330	2018.35	7.15	10.82	1	1
11368-2426	HJ 4456AC	339.3	0.06	38.77	0.046	2018.35	7.15	13.29	3	1
11401-0326	DAM 73AB	11.1	1.48	18.53	0.466	2018.35	12.32	13.85	3	1
11416+3145	STT 575AB	311.1	0.03	43.96	0.040	2018.37	5.79	9.75	30	6
11489-3556	SEE 136	255.3	1.38	7.08	0.154	2018.35	11.3	12.7	8	1
11495-1937	LDS 368AB	91.3	1.34	9.11	0.331	2018.35	12.1	12.9	3	1
11495-1937	DAM 75BC	77.2	0.99	14.98	0.246	2018.35	13.3	13.6	9	1
11512+3322	ARG 101	272.9	0.08	45.76	0.081	2018.36	6.27	9.28	20	4
11529+3050	STF 1576	240.7	0.12	5.33	0.035	2018.37	9.11	9.45	18	3
11534-2434	HJ 4479	94.3	1.39	6.93	0.260	2018.22	8.86	9.92	3	1
11567-3216	DUN 116AC	37.6	0.47	29.96	0.231	2018.35	7.67	11.60	3	1
11567-3216	DUN 116BC	122.8	0.52	21.63	0.179	2018.35	7.83	11.60	3	1
12269-3728	HJ 4510AB	41.8	1.12	19.39	0.336	2018.36	9.73	10.38	2	1
12440-2727	UC 2393AC	330.0	0.47	40.55	0.364	2018.36	10.19	9.60	3	1
13112+3050	STF 1729AB,C	274.9	0.10	8.61	0.105	2018.36	9.61	11.06	5	1
13189+0030	A 2585BC	233.5	0.71	12.87	0.200	2018.36	9.38	13.9	3	1
13216-0926	BRT 447	54.4	2.23	7.94	0.319	2018.35	11.84	12.5	3	1
13225-1703	GWP1995AB	86.3	0.20	136.93	0.527	2018.36	12.3	12.5	3	1
13300-1430	HJ 2654	319.0	1.30	19.00	0.423	2018.36	11.37	13.00	3	1
13307-2327	HJ 2655	270.1	0.916	11.40	0.216	2018.36	10.00	13.3	3	1
13344+2617	STF 1760	64.2	0.07	8.73	0.014	2018.37	8.77	9.12	15	3
13385-0325	GWP2049	262.5	2.08	15.27	0.570	2018.36	12.2	12.5	3	1
13407+2804	BUP 151	223.1	0.04	89.74	0.074	2018.36	6.36	12.4	5	1
13451+1822	STF 1782AB	185.3	0.03	30.38	0.032	2018.37	7.98	9.81	15	3
13493+1742	S 655AB	85.9	0.03	46.27	0.038	2018.37	8.96	9.98	25	5
13493+1742	S 655AC	10.9	0.05	57.39	0.019	2018.37	8.96	13.93	13	3
13493+1742	S 655BC	326.4	0.03	63.64	0.045	2018.37	9.98	13.93	15	3
14095+3549	HJ 540	211.1	0.08	8.95	0.009	2018.37	9.39	10.04	10	2
14510+0943	SLE 1028AD	105.2	0.01	193.17	0.038	2018.37	8.44	12.40	10	2
14510+0943	STF 1886AB	224.1	0.07	7.89	0.025	2018.37	7.61	9.73	18	3
17594+2929	STF2247AB	188.4	0.05	11.62	0.011	2018.55	9.17	9.88	20	4
17594+2929	WAL 88AC	230.4	0.03	56.07	0.022	2018.55	9.17	12.49	20	4
18434+3533	SLE 688AD	16.3	0.05	109.77	0.085	2018.55	8.91	12.71	5	1
18434+3533	STF2378AB	189.9	0.04	11.47	0.021	2018.55	8.91	9.88	20	4
18434+3533	STF2378AC	243.2	0.02	210.24	0.049	2018.54	8.91	12.1	10	2
18434+3533	STF2378BC	245.8	0.03	203.54	0.063	2018.54	9.88	12.1	10	2
18445+3400	STTA172	5.3	0.03	64.88	0.047	2018.55	7.91	8.66	20	4

Table 1 continues on the next page.

Double Star Measures Using the Video Drift Method - XII*Table 1 (continued). Results of 254 double stars using the video drift method*

Object	Designation	PA °	PA SEM °	Sep "	Sep SEM "	Avg. Date	Mag 1	Mag 2	Samples	Nights
19039+3409	BU 1285AB	288.8	0.36	11.16	0.083	2018.62	7.30	12.8	15	3
19039+3409	BU 1285AC	208.1	0.06	41.78	0.047	2018.62	7.30	10.7	25	5
19201+2639	STTA181AB	359.5	0.03	63.48	0.057	2018.62	7.39	7.50	25	5
19201+2639	STTA181AC	169.5	0.05	31.61	0.053	2018.62	7.39	12.8	25	5
19201+2639	STTA181BD	42.6	0.02	94.04	0.075	2018.62	7.50	12.10	25	5
19434+3158	AG 235	199.0	0.05	12.64	0.029	2018.51	8.57	9.6	15	3
19500+1757	ABH 126AE	143.4	0.02	71.01	0.048	2018.60	7.99	13.42	15	3
19500+1757	H 4 99AB	83.2	0.03	25.64	0.018	2018.60	7.99	11.07	25	5
19500+1757	H 4 99AC	255.5	0.03	68.76	0.048	2018.60	7.99	9.10	25	5
19500+1757	H 4 99AD	339.6	0.03	44.05	0.040	2018.60	7.99	13.23	25	5
19517+3108	STT 389AC	182.2	0.03	13.30	0.037	2018.54	7.12	9.53	10	2
20014+1045	STF2613AB	354.3	0.79	3.50	0.050	2017.24	7.48	8.02	9	2
20035+3601	STF2624AC	326.8	0.04	42.32	0.038	2018.60	7.09	9.26	25	5
20035+3601	STF2624AD	171.1	0.04	28.97	0.052	2018.60	7.09	12.90	25	5
20057+3536	ES 24BC	241.4	0.26	11.31	0.181	2018.59	8.82	13.8	10	2
20057+3536	ES 24BD	85.6	0.94	17.12	0.243	2018.58	8.82	13.11	5	1
20057+3536	SHJ 316AB	322.8	0.03	69.44	0.053	2018.60	7.79	8.82	25	5
20106+3338	S 738AB	106.2	0.03	42.15	0.030	2018.55	7.76	8.43	20	4
20123+3205	STF2649AB	151.4	0.04	21.59	0.032	2018.60	7.86	9.85	25	5
20123+3205	STF2649AC	283.8	0.01	130.97	0.013	2018.60	7.86	11.41	25	5
20123+3205	STF2649AD	36.1	0.01	175.89	0.029	2018.60	7.86	10.63	25	5
20133+3502	ARY 23AB	28.2	0.03	81.55	0.058	2018.55	8.48	8.89	20	4
20133+3502	ARY 23BC	339.4	0.01	65.01	0.010	2018.55	8.89	10.56	20	4
20133+3502	SKF2392BD	345.5	0.23	13.95	0.102	2018.54	8.89	12.8	5	1
20140-0052	ABT 15AE	224.6	0.03	80.98	0.054	2018.78	7.87	12.83	5	1
20140-0052	BU 1485A,BC	105.0	0.02	74.95	0.044	2018.78	7.87	10.12	5	1
20140-0052	BU 1485BC,D	65.2	0.13	23.15	0.026	2018.78	10.12	12.2	5	1
20462+1554	STF2725AB	11.7	0.83	6.10	0.090	2017.78	7.54	8.20	6	2
20482-1303	HJ 2997	195.5	1.68	8.39	0.262	2018.75	10.42	11.3	3	1
20484-1812	S 763AB	293.6	0.73	15.43	0.206	2018.75	7.24	7.79	3	1
20484-1812	S 763CD	332.6	1.68	9.14	0.276	2018.75	11.72	12.0	4	1
20489-2037	HJ 2998AB	141.2	1.81	5.55	0.260	2018.75	9.72	9.96	3	1
20510+0211	BAL1573	225.3	1.24	5.64	0.117	2018.75	12.82	12.84	9	1
20532-0240	BRT 508	208.0	2.04	8.21	0.290	2018.75	10.46	14.2	1	1
20557-1625	DAM 219	117.3	0.92	8.20	0.144	2018.75	11.3	12.5	9	1
20577-3248	ENO 6	23.8	0.80	13.60	0.163	2018.75	10.14	13.8	12	1
20582+1038	LBU 11AC	151.6	0.21	72.46	0.279	2018.75	9.04	11.82	3	1
20584+1050	BUP 220BD	224.2	0.24	67.39	0.294	2018.75	9.88	12.01	3	1
20586-0434	BRT 511	82.4	1.21	4.04	0.107	2018.75	10.8	11.5	9	1
20588-0921	BU 764AB,D	140.8	0.11	134.05	0.283	2018.75	9.80	9.18	3	1

Table 1 continues on the next page.

Double Star Measures Using the Video Drift Method - XII*Table 1 (continued). Results of 254 double stars using the video drift method*

Object	Designation	PA °	PA SEM °	Sep "	Sep SEM "	Avg. Date	Mag 1	Mag 2	Samples	Nights
20588-0921	BU 764AB,C	109.6	0.14	102.80	0.291	2018.75	9.80	9.60	3	1
20588-0921	BU 764AB,E	86.1	0.35	54.52	0.346	2018.75	9.80	12.1	3	1
20588-0921	BU 764CE	311.9	0.33	57.32	0.348	2018.75	9.60	12.1	3	1
20588-0921	BOO 1DF	195.3	0.72	18.32	0.248	2018.75	9.18	14.5	4	1
20595-2212	ARA1937	124.3	1.93	11.48	0.389	2018.75	12.6	12.9	3	1
21017-1032	AOT 96	104.3	1.39	10.94	0.304	2018.75	10.73	13.0	3	1
21021+1016	J 158	163.2	1.72	4.76	0.140	2018.75	10.93	13.1	5	1
21069+3845	SMR 40AP	289.1	0.13	154.70	0.450	2017.78	5.35	12.84	1	1
21069+3845	SMR 40AO	279.8	0.19	162.47	0.350	2017.78	5.35	12.65	1	1
21140-2513	BRT3098	341.7	1.58	4.54	0.134	2018.62	13.02	13.06	9	1
21146-2935	B 2492	239.3	1.10	6.54	0.149	2018.62	10.21	10.91	9	1
21162-0003	LYS 41	234.2	2.43	6.35	0.289	2018.62	11.0	13.0	3	1
21215-2442	SEE 441AC	316.5	0.17	102.76	0.269	2018.75	9.31	10.94	3	1
21216-1825	ARA 502	123.2	2.55	6.79	0.460	2018.75	12.3	13.2	3	1
21223-3500	HJ 5264	46.6	1.44	16.26	0.348	2018.75	9.47	12.9	3	1
21247-3106	HJ 5266	256.2	1.10	10.74	0.183	2018.75	8.72	11.7	3	1
21255+0203	STT 439AB,C	221.9	0.91	14.63	0.242	2018.75	7.53	11.33	3	1
21264-0117	BAL 623	217.1	1.47	14.31	0.337	2018.75	11.03	12.11	3	1
21274-1112	J 2347	32.8	1.73	14.06	0.420	2018.75	10.62	14.0	3	1
21275-1112	J 2348	38.4	1.82	9.36	0.269	2018.75	11.0	12.3	3	1
21334+3058	KU 132AB	256.4	0.12	53.63	0.125	2018.62	10.15	10.69	1	1
21358+3101	HJ 939AB	175.8	0.24	15.59	0.130	2018.60	8.06	12.78	10	2
21358+3101	HJ 939CD	343.8	0.19	15.07	0.128	2018.62	11.07	14.67	10	2
21358+3101	STF2808AC	286.3	0.08	42.83	0.099	2018.62	8.06	11.07	10	2
21358+3104	HJ 940	329.2	0.13	20.97	0.099	2018.62	10.75	11.90	1	1
21416-2813	HJ 3046AB	56.9	0.71	28.97	0.302	2018.75	10.72	12.64	3	1
21416-2813	UC 4530AC	246.1	0.30	79.92	0.346	2018.75	10.72	13.88	3	1
21420-2439	SEE 453	325.2	0.89	11.47	0.166	2018.75	8.40	12.3	3	1
21429-1551	ARA 130	49.8	2.13	8.72	0.289	2018.75	12.6	13.6	3	1
21442+0953	S 798AC	317.7	0.12	143.91	0.676	2018.83	2.53	8.74	5	1
21452-0616	HDO 167AC	37.3	0.91	12.03	0.189	2018.75	8.26	12.3	3	1
21452-0616	HDO 167AD	111.6	0.74	27.77	0.387	2018.75	8.26	13.5	3	1
21519+0905	STF2833	337.5	0.12	8.95	0.029	2018.82	7.84	10.20	5	1
22038+6438	STF2863AB	275.4	0.84	8.20	0.060	2017.78	4.45	6.40	5	2
22218+1515	STF2897	98.4	0.15	16.89	0.029	2018.82	9.48	10.37	5	1
22485-0536	LDS4997AB	255.3	0.33	86.53	0.499	2018.75	9.43	14.13	2	1
22499-2154	ARA1943	295.0	1.82	11.59	0.381	2018.75	11.60	12.55	3	1
22558+4334	HDS3262	166.7	0.12	28.78	0.060	2018.83	8.00	9.54	5	1
22568-3856	WG 285	343.2	1.58	14.72	0.327	2018.75	10.37	12.8	3	1
22579-2250	RST4115	42.6	0.97	13.81	0.212	2018.75	9.17	14.0	3	1

Table 1 concludes on the next page.

Double Star Measures Using the Video Drift Method - XII

Table 1 (conclusion). Results of 254 double stars using the video drift method

Object	Designation	PA °	PA SEM °	Sep "	Sep SEM "	Avg. Date	Mag 1	Mag 2	Samples	Nights
23000-1024	BU 9025AC	272.1	1.57	14.51	0.477	2018.75	12.7	13.7	3	1
23033+0653	HJ 3161	254.5	1.72	11.41	0.354	2018.75	10.78	13.8	3	1
23088+1058	A 1238AB,CD	291.7	0.24	75.15	0.319	2018.75	7.67	11.16	3	1
23112+0500	HJ 980AB	190.0	0.93	50.90	0.391	2018.75	12.68	12.79	3	1
23112+0500	HJ 980BC	201.8	1.64	9.13	0.258	2018.75	12.68	12.79	4	1
23145+2027	HJ 982AB	172.3	0.07	39.61	0.051	2018.77	7.16	13.63	20	4
23145+2027	HJ 982AC	217.2	0.05	46.51	0.031	2018.77	7.16	13.18	20	4
23147-1041	FOX 271AC	224.7	0.86	31.38	0.309	2018.76	6.14	12.5	3	1
23147-1041	FOX 271AD	131.0	0.01	114.09	0.043	2018.82	6.14	12.95	20	4
23228+2034	STF3007AB	92.4	0.76	5.50	0.090	2017.78	6.74	9.78	6	2
23299-2035	HJ 3196AB,C	18.8	0.49	20.70	0.160	2017.24	8.34	10.63	3	1
23482-1642	TOK 354AB	60.6	0.09	110.00	0.170	2017.24	7.59	10.12	3	1
23483-2624	B 618AB	78.1	1.90	6.10	0.190	2017.24	9.76	12.2	3	1
23483-2624	B 618AC	170.8	0.69	12.60	0.150	2017.24	10.89	10.91	3	1

Table 1 Notes

- All magnitudes taken from the WDS catalogue. All position angle/separation measurements are for the Equator and Equinox of date.
- SEM is the standard deviation (SD) of all the drift run PA's and Sep's divided by the square root of the number of nights: $SEM = SD / \sqrt{nights}$
- The column "samples" is the number of separate drift runs made using both the video drift and modified video drift methods. An individual "drift run" contains hundreds to thousands of video frames. Each video frame produces a unique PA and Sep measurement. "Nights" is the number of nights drift runs were made for that system.

Table 2. Gaia Position, magnitudes, proper motions (pm), and parallaxes of new double star components

RA	DEC	mag	pm RA mas/yr	pm RA error mas/yr	pm DEC mas/yr	pm DEC error mas/yr	parallax mas	parallax error mas	measured PA	measured SEP "	Date
13h 22m 23.2s	-17° 02' 41.9"	13.39	4.1609	0.0428	1.8318	0.0349	2.128	0.025	330.3	10.8	2018.36
13h 22m 23.6s	-17° 02' 51.1"	13.35	4.1713	0.0422	2.1125	0.0341	2.158	0.024			

Double Star Measures Using the Video Drift Method - XII

(Continued from page 494)

New Double Star

A POSS2 image (epoch 1988.29) of a double star system not currently in the Washington Double Star Catalog is shown in Figure 1. Overlaid on the components are the Gaia proper motions (errors less than 2% in direction and magnitude) which show a common motion for the pair. The Gaia parallaxes are small at 2.158 and 2.128 mas with an 11% quoted error (0.025 mas). Distances are thus 463 ± 55 pc and 470 ± 51 pc for the components. Within the error margins of the Gaia distances and proper motions, the components could very well be a physically connected system. The coordinates, magnitudes, position angle, separation, their Gaia proper motions and parallaxes are given in Table 2. Our measurements for this system are PA = 330.3 deg, separation = 10.8", date of measurement 2018.36. This double star system is given the preliminary designation NUG 1.

Acknowledgements

This research makes use of the Washington Double Star Catalog maintained at the US Naval Observatory and the Aladin Interactive Sky Atlas, Centre de Données Astronomiques de Strasbourg: <http://aladin.u-strasbg.fr/java/nph-aladin.pl>. This work has made use of data from the European Space Agency (ESA) mission Gaia (<https://www.cosmos.esa.int/gaia>), processed by the Gaia Data Processing and Analysis Consortium (DPAC, <https://www.cosmos.esa.int/web/gaia/dpac/consortium>).

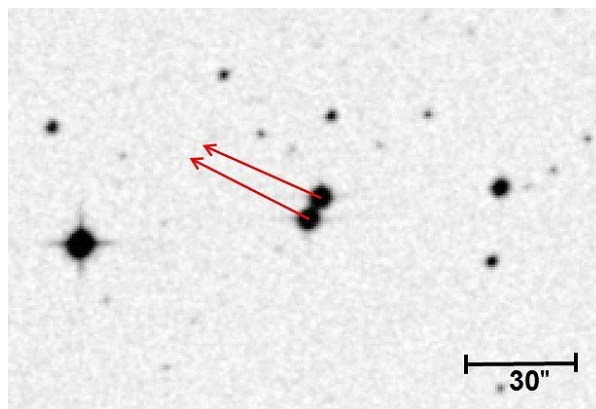


Figure 1. New double star. RA = 13h 22m 23.6s, DEC = -17° 2' 51.1". Proper motion components from the Gaia catalog. Palomar Digital Sky Survey image from the Aladin Interactive Sky Atlas.

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Lunar Occultation Observations of Double Stars – Report #7

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Abstract: Reports are presented of lunar occultations of close double stars observed using video techniques. Included are cases where a determination of the position angle and separation of the pair can be made as well as instances where no duplicity has been observed of known or reported double stars. Twenty-six double stars discovered as a result of a lunar occultation are also included together with the light curves for the discovery event.

This paper continues the series of reports of double star measurements made at lunar occultations of the star (see refs [2-7] for the previous reports). The majority of the observations date from early 2017 through 2018 to the end of March 2019. There are also a few observations made considerably earlier.

The principle and general method of calculation are

explained in Herald (2009) and Loader (2010).

Occultations presented in this paper have been observed using video cameras, mostly at either 25 frames, 50 fields per second (Australasia and Europe) or 30 frames, 60 fields per second (USA, Brazil and Japan). A video time inserter has been used to time-stamp each video field to millisecond precision. The limit of tim-

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ing accuracy is usually about ± 0.02 seconds, where analysis has been carried out using video frame measures and ± 0.01 seconds using field measures. An error of 0.01 seconds in time will typically translate to an angular error of 4 milliarcsecond.

Video records of double star occultations have been analyzed using the Limovie program developed by K. Miyashita. This program measures the light flux of the occulted star from the video record allowing a light curve for the event to be generated.

Occultations of double stars result in a stepped light curve, see e.g. Herald (2009). The duration of the step gives a measure of the separation of the pair in a direction perpendicular to the moon's limb at the point of occultation. The relative heights of the steps allow an estimate of the magnitude difference of the two stars to be made. Limovie has a facility to do this and to add the results to the light curve. Observations are normally made with an unfiltered CCD video camera.

Normally the separate occultations of the two stars of a pair will take place at slightly different points on the moon's limb. An angular separation of $1''$ at the mean distance of the moon is equivalent to about 1.86 km.

The heights of the moon's limb at the two points of occultation of the two stars may differ. Any difference will have an effect on the interval between the two events.

For each observation an estimate of the effective slope of the moon's limb between the two points of occultation is therefore needed for calculations of the position angle and separation angle of a pair of stars. For this paper, use has been made of the new limb data from the Lunar Reconnaissance Orbiter, Lunar Orbiter Laser Altimeter.

The Observations Reported

Table 1 continues the series of measures of known double stars for which a solution for the position angle and separation of the system has been calculated. In order to produce a solution, at least two observations are required with the occultations well separated on the moon's limb. A minimum separation of 10° round the moon's limb is needed to obtain a reliable result.

Ideally the observations would all be made on the same date but this is rarely possible. In most cases the occultation observations have been made on different dates, with an interval between them sufficiently short for any change in relative position of the pair of stars to be small. Besselian dates of each observation and the mean date of the combined observations are shown. An estimate of any change in the expected position angle and separation of the pair, as indicated by Washington

Double Star (WDS) data, is given in the notes. The changes shown cover the period in which the observations were made. The observed magnitude differences, as calculated by Limovie, are also shown.

Table 2 shows a number of occultation observations of double stars listed in the WDS for which only one observation is available. For many of them, no further occultations will occur for some years.

With only one observation the actual position angle and separation of the pair of stars cannot be determined. Only a vector separation in the direction of the position angle of the moon's limb at the point of observation can be found.

From a single observation an apparent magnitude difference of the two stars can be determined. The cataloged difference and the observed difference are shown. The resulting magnitudes of the pairs are also listed, based on the published combined magnitude.

Tables 3A and 3B present details of previously unknown double stars discovered as a result of stepped lunar occultations.

Table 3A shows cases where more than one occultation of the new double has been made, enabling the position angle and separation of the pair to be established. Similar data to Table 1 is presented.

Table 3B shows the far more numerous cases where only one observation has been made of the new double, resulting in the determination of a vector separation of the pair. In some cases two or more observations were made, but the separation of the occultation events on the moon's limb was too small to generate a reliable solution.

Only cases where the resulting light curve shows a reasonably well defined step have been included. Discovery light curves are presented for the events at the end of this paper. The captions for the curves give some further details.

Table 4 presents observations of stars which have been reported as possibly double as a result of earlier visual occultation observations. More recent video observations of occultations for the stars listed have shown no sign of a stepped event, that is, no indication that it is double. Only cases with two or more observations with event position angles (the vector angle) separated by at least 10° have been included. The stars in Table 4 all have an entry in the Interferometric Catalog.

While the most likely reason for the failure to detect a companion star is simply that the star is in fact single, other possible reasons are:

- i. The vector separation was small so that the interval between the two events was too short to detect. This possibility is largely eliminated by

(Text continues on page 510)

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Table 1 Known double stars: PA and separation measured

WDS name	XZ	Position RA Dec	Measured PA° & Sepn"	Mean Date	Mag. diff.	Observn. Date	Observers	Note
HDS 61	505	00266-0003	285.89±3.36° 0.498±0.016"	2017.04	2.46 n/a 2.21	2016.639 2016.864 2017.612	RS MI BL	1.
STF 291AB	3594	02411+1848	112.17±0.63° 2.240±0.026"	2006.10	-0.03 -0.11	2006.097	SM, RS	2.
BU 537	4891	03471+2449	222.6±2.4° 0.529±0.050"	2006.70	1.29 0.9	2005.727 2007.672	DG SM	3.
STF 449	4907	03474+2440	329.34±0.25° 6.600±0.025"	2008.38	n/a n/a	2007.672 2009.096	SM SM	4.
STF 572AB	5948	04385+2656	193.67±0.01° 3.133±0.016"	2007.64	0.18 0.17	2007.226 2008.049	SM RS	5.
BU 1044	5983	04399+1631	202.00±0.41° 0.637±0.014"	2016.18	n/a	2015.753 2016.127 2016.651	HA HA AA	6.
HO 226AB	6952	05270+2737	266.77±0.30° 0.700±0.007"	2006.07	0.04 0.45	2005.135 2007.005	RS SM	7.
STF 813	7838	05544+1854	139.55±0.72° 2.152±0.030"	2010.25	0.28 0.53 0.13	1999.225 2013.738 2017.777	RS MI JG	8.
HO 238	9774	06463+1812	120.65±13.29° 0.300±0.056"	2017.13	n/a	2016.882 2017.255	MI MI, HW	9.
STT 156	9812	06474+1812	135.98±2.48° 0.182±0.005"	2016.69	n/a 0.24, 0.28 n/a n/a	2015.160 2016.806 2016.882 2017.256	DG SM, RS MI HA, WH	10.
BU 899AB	10199	06592+1843	268.21±4.30° 0.764±0.020"	2015.93	1.25 1.27 n/a	2014.115 2016.283 2017.406	BL DH YA	11.
HO 253	14778	09478+1004	294.36±2.19° 1.310±0.026"	2015.53	2.89 n/a, 2.07 n/a, n/a	2015.160 2015.469 2015.843	BL DG, DH AA, MI	12.
STF1670AB	18692	12417-0127	4.88±2.77° 2.278±0.183"	2017.18	0.61 n/a	2016.527 2017.348	GK YA, MI, AA, WH	13.
MCA 38AaAb	19147	13099-0532	352.81±0.80° 0.446±0.010"	2016.15	n/a 2.36	2016.005 2016.304	AA AP	14.
HU 141	20639	14492-1050	308.63±2.24° 0.461±0.016"	2017.98	0.73 1.94 1.64, 1.5, 2.3	2016.609 2017.431 2018.627	BL DH DG, JB, SK	15.
HDS2210	21550	15394-1355	164.48±0.37° 0.146±0.003"	2017.28	n/a, 0.53 0.41	2016.612 2018.630	DH, DG BL	16.
BU 958	42128	17165-1920	204.40±0.60° 1.970±0.024"	2016.77	ca 1.7 0.61	2014.673 2018.860	BD DG	17.
BU 246AB	25003	18177-1940	111.82±2.55° 0.486±0.019"	2014.15	0.79, -, 0.28 0.73	2012.804 2018.190	DH, CC2, DG DG	18.
B 1887	25499	18340-1929	283.01±0.26° 2.236±0.009"	2015.24	n/a 0.55	2012.730 2017.743	DH DH	19.
KUI 88	25902	18488-1836	147.85±2.50° 0.398±0.012"	2014.64	n/a n/a	2013.554 2015.725	DH HY	20.
HU 262	45748	19167-1739	31.30±0.29° 3.999±0.038"	2016.77	0.31, 0.26	2016773	BL, SK	21.
FIN 336	28531	20311-1503	50.67°±1.34° 0.181±0.005"	2013.91	0.48 n/a, n/a	2010.865 2015.430	DH HA, MI	22.
4H 1 47	49923	21124-1500	308.75±2.44° 4.301±0.233"	2017.38	n/a, n/a 0.15, 0.13	2017.003 2017.751	MI, HW DG, DH	23.
HU 282	30282	22006+1345	49.08±1.07° 0.220±0.004"	2014.16	n/a 1.61, 1.85	2006.832 2017.829	BL AP, TH	24.
CHR 111	30765	22313-0633	356.28±0.30° 0.097±0.001"	2008.78	2.5, 2.5, n/a	2008.779	DG, DH, BL	25.

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Table 1 Notes

1. HDS 60 (10 Ceti), any change in relative positions likely to be small in 1 year .
2. STF 291AB, very slow rate of change, observations on same date
3. BU 537, recently received report, little change in position expected in 2 years, separation change ca 0.01".
4. STF 449 little change in position expected over ca 19 months.
5. STF 572AB, little position change expected over 10 months.
6. BU 1044, little position change expected over 11 months.
7. HO 226 AB, known orbit period 374 years, expected PA change in 2 years less than 1 degree.
8. STF 813, observations wide spaced in time, little position change in period.
9. HO 238, little position change expected over 5 months.
10. STT 156, WDS orbital period 205.3 years, PA changing ca 10° per year, separation changing slowly.
11. BU 899 AB, position changing very slowly.
12. HO 253, Any change in position insignificant in 10 months.
13. STF1670 AB, WDS orbit period 169.1 years. Rate of change in 2017: ca 1.8° in PA, 0.14" in separation per year.
14. MCA 38 Aa,Ab, orbital period 695 years, change in PA in 2016 ca 0.9° in PA and < 0.01" in separation per year.
15. HU 141, Orbital period 173.9 year, change in PA 0.4° per year, separation near constant
16. HDS2210, WDS shows only 2 or 3 observations, with considerable variations in PA and separation.
17. BU 958, little change in PA and in separation expected in 4 years.
18. BU 246AB, changes expected during 5+ years very small
19. B 1887, little change expected during 5 years.
20. KUI 88, orbital period 909.7 years, expected rate of change in 2 years of PA ca 0.6°, separation < 0.01"
21. HU 262, observations on same date. SK observed a near graze.
22. Orbital period 50.66 year, change in PA between observations ca 10°, separation near constant. HA and MI observations very close in limb PA, result very dependent on DH's earlier observation.
23. Orbital period shown as 4890 years, so no significant position change in 9 months.
24. Only 5° separate observation by AP and TH, so result largely dependent on BL 11 years earlier.
25. Short orbital period, 1.7309 years, observations all on same date.

Lunar Occultation Observations of Double Stars – Report #7*Table 2. WDS: Single observation, Vector separation and magnitudes determined*

WDS Star	XZ number	RA Dec	Observed Vector		Mag difference		Mags	Date	Obs
			Angle	Sepr	Catalog	Observed			
BU 777	376	00211-0015	297.6°	2.55"	1.19	1.27	9.78+11.05	2017.387	BL
CHR 200	3623	02425+1045	272.4°	0.336"	0.2	0.87	6.70+7.57	2018.592	DG
STF 412AB	4598	03344+2428	44.3°	0.436"	0.26	0.28	6.61+6.89	2008.047	RS
HO 324	4956	03490+1459	36.0	0.447"	0.19	n/a	n/a	2016.047	HA, AA
STT 64AB	4984	03500+2351	206.8°	2.94"	3.34	2.11	6.91+9.02	2006.550	RS
STF 559	5862	04335+1801	71.9°	8.81"	0.05	0.15	6.89+7.04	2018.074	BL
CHR 154	5998	04404+1631	299.4°	0.174"	1.75	n/a	n/a	2016.653	MI
STF 598	6174	04486+1748	334.4°	7.42"	1.86	n/a	n/a	2017.184	BL
BU 1047 BC	6595	05098+2802	221.4°	0.080"	0.60	0.03	9.36+9.39	2006.180	RS
COU 470	7257	05384+1808	108.7°	0.214"	1.40	n/a	n/a	2017.253	HA, YA
HU 39	7590	05472+2153	235.7°	0.180"	0.1	0.33	8.67+9.00	2019.125	BL
HDS 824	8190	06038+1816	88.9°	0.91"	1.10	1.19	8.04+9.23	2017.254	AP
STT 160	10040	06544+2110	110.5°	0.069"	2.26	3.39	6.65+10.04	2019.203	AP
STF1083	11061	07256+2030	100.9°	3.71"	0.91	0.67	7.37+8.04	2018.156	DH
HU 845	104753	07470+2045	212.6°	0.216"	0.47	0.99	1.49+10.48	2018.307	DH
COU 772	11679	07471+1847	86.5°	0.326"	0.19	0.24	8.96+9.20	2017.184	BL
COU 929	11911	07560+2342	238.9°	0.193"	0.67	1.36	7.70+9.06	2007.384	RS
COU 956	13372	08481+1836	66.5°	0.178"	0.3	0.33	10.19+10.52	2018.309	DH
COU 384	14098	09183+1847	34.8°	0.034"	0.1	0.04	8.62+8.66	2001.331	RS
HU 869	14273	09252+1449	287.4°	0.743	0.10	0.26	9.70+9.96	2017.413	BG
COU 936	14363	09290+1917	123.5°	0.154"	1.54	1.09	8.59+9.68	2005.819	RS
STT 220	15705	10292+1009	111.9°	0.462"	1.44	1.36	7.45+8.81	2017.267	DH
STF1450	15851	10350+0839	121.6°	1.78"	2.1	2.07	5.75+7.82	2017.342	AP
J 87	17572	11409+0457	80.5°	1.07"	4.58	2.8	8.36+11.16	2017.420	DH
AG 178	124037	12310+0207	309.6°	1.252"	0.1	0.43	9.64+10.07	2018.545	BL
BU 607	18685	12412-0127	265.9°	0.711"	2.2	n/a	n/a	2017.349	YA
HDS1881	19358	13244-0419	328.2°	0.243"	3.87	3.28	7.04+10.32	2017.351	DH
CHR 221	20105	14133-0827	161.9°	0.035"	1.1	0.37	7.18+7.55	2017.354	DH
RST3898	20687	14515-1033	238.1°	0.653"	0.54	n/a	n/a	2018.627	DG
HDS2167	39439	15245-1322	124.9°	0.125"	0.17	0.69	10.76+11.45	2018.704	DH
HLD 25	39817	15403-1432	300.1°	1.469"	0.19	n/a	n/a	2018.630	SK
RST3950	22363	16283-1613	89.7°	0.199"	1.08	1.12	7.61+8.73	2017.661	DH
A 2242	23446	17232-1807	17.8°	0.175"	2.5	2.32	9.55+11.87	2017.814	BL
HJ 2806	23593	17297-1748	84.8°	2.77"	0.64	0.75	8.77+9.52	2017.218	BL
CHR 235	25181	18228-1843	301.6°	0.152	0.9	n/a	n/a	2016.172	HA
HLD 144AB	43966	18257-2102	309.9°	0.187"	0.07	0.53	9.12+9.65	2019.162	DH
I 1030	160315	18462-2046	104.0°	4.27"	2.99	2.65		2018.715	DH
BU 154	29006	20528-1610	57.4°	2.99"	1.00	1.57	8.63+10.20	2017.825	SK
BU 1262	050164	21223-1455	62.9°	1.221"	1.05	0.82	8.72+9.54	2017.900	DG
RST4105	30710	22281-1153	227.5°	0.89"	0.41	0.4	9.0+9.4	2017.980	CE
RST4712	31173	23006-0704	288.5°	0.39"	1.90	2.09	9.85+11.94	2017.308	DG
STF2981	184816	23095-0850	57.3°	1.191"	0.05	0.43	9.80+10.23	2018.879	DH

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Table 3A: Occultation Discoveries: Separation and Position Angle Determined

Star name	OCC #	XZ	Position RA Dec	Measured PA° & Sepn.	Mean Date	Mag. diff.	Observn Dates	Observers
TYC 1387-00971-1	1672	12883	08317+1928	296.78±1.46° 0.189±0.016"	2009.41	0.3 0.24	2000.430 2018.383	RS DH
TYC 6171-00196-1	1789	21196	15210-1533	158 ± 20° 0.10±0.02"	2015.11	3.19 n/a	2014.742 2015.490	SK HW
TYC 6239-01058-1	1827	142496	17300-1755	232.59 ± 0.07° 0.423 ± 0.000"	2017.02	0.19 0.94 0.63	2016.768 2017.141 2017.141	BL DH BL
TYC 6348-01744-1	1847	28920	20484-1812	46.31±3.47° 0.630±0.027"	2018.87	3.37 3.98	2018.871 2018.871	DG DH

Table 3B: Occultation Discoveries: Vector separation only measured

Star name	OCC #	XZ	RA Dec	Vector Angle	Vector Sep.	Mag. diff.	Observn. Date	Obs.	Fig.
TYC 0604-01110-1	1850	1066	00496+0757	79.1°	0.061"	0.90	2007.664	SM	Fig 1
TYC 1215-00520-1	1832	3229	02235+1644	305.6°	0.028"	0.80	2012.083	RS	Fig 2
TYC 1253-00461-1	1864	5187	03589+1654	84.0°	0.035"	1.09	2019.120	DH	Fig 3
TYC 1320-01983-1	1838	79423	05536+1937	217.4°	0.201"	0.74	2017.179	DG	Fig 4
TYC 1342-01830-1	1861	92793	06464+2110	97.9°	0.035"	1.04	2018.4.21	DH	Fig 5
TYC 1902-00526-1	1860	95864	06578+2637	263.9°	0.545"	1.13	2007.571	SM	Fig 6
TYC 0283-00658-1	1842	122998	12070+0255	131.5°	0.042"	1.02	2017.496	DH	Fig 7
TYC 0290-00520-1	1844	124516	12341+0100	250.7°	0.204"	0.29	2017.573	BL	Fig 8
TYC 6217-00770+1	1836	137098	16426-1645	219.3°	0.158"	2.07	2017.138	DH	Fig 9
TYC 6256-01444-1	1862	42587	17363-1932	33.2°	0.021"	0.11	2018.758	BL	Fig 10
TYC 6269-03059-1	1837	155991	18232-1823	101.9°	0.100"	0.15	2017.144	DH	Fig 11
TYC 1320-01983-1	1838	79423	18262-1823	101.9°	0.100"	0.15	2017.180	DG	Fig 12
TYC 6270-00109-1	1857	44022	18273-1814	59.0°	0.371"	1.46	2016.771	SK	Fig 13
TYC 6274-01331-1	1853	157882	18318-1910	96.8°	0.027"	0.70	2017.743	BL	Fig 14
TYC 6275-00749-1	1851	44271	18359-1927	145.1°	0.039"	0.22	2017.825	DH	Fig 15
TYC 6289-02180-1	1859	161543	18529-1929	83.3°	0.255"	0.22	2017.893	DH	Fig 16
TYC 6294-00379-1	n/a	45164	18594-2123	301.3°	0.023"	0.40	2019.238	BL	Fig 17
TYC 6305-01605-1	1858	26920	19242-2018	269.0°	0.059"	0.09	2017.895	CE	Fig 18
TYC 6321-01088-1	1863	47100	19539-2023	292.9°	0.197"	0.86	2018.868	DG	Fig 19
TYC 6332-01468-1	1855	28346	20236-1813	265.4° 265.2° 265.1°	0.089" 0.100" 0.107"	0.24 -0.45 0.18	2017.749	YA MI HA	Fig 20 Fig 21 Fig 22
TYC 5784-00577-1	1839	49915	21121-1411	146.1°	0.023"	0.62	2017.303	BL	Fig 23
TYC 5784-00642-1	1852	29433	21137-1439	10.8° 8.7°	0.091" 0.091"	0.89 0.61	2017.751	DH DG	Fig 24 Fig 25
TYC 5241-00846-1	1840	52763	22561-0715	297.0°	0.020"	0.21	2017.308	BL	Fig 26

Lunar Occultation Observations of Double Stars – Report #7*Table 4: Companion not observed (possible double star, entry in WDS &/or IF Catalog.)*

Star name	OCC #	XZ	RA Dec	Vector angle	Resolution limit	Limiting Mag. diff.	Observn Date	Observer
HD 12281	429	2796	02008+1323	35.2°	0.027"	n/a	2004.973	DG
				75.2°	0.030"	2.7	2004.973	BL
HD 16802	588	3612	02420+1033	244.5°	0.037"	2.0	2018.592	DG
				171.9°	0.011"	3.0	2018.592	BL
HD 23288	1213	4813	03448+2417	278.1°	0.032"	3.0	2006.774	RS
				216.0°	0.028"	2.3	2007.672	SM
HD 29150	888	5915	04362+2132	115.5°	0.016"	2.7	2012.164	RS
				216.0°	0.025"	1.7	2012.613	JB
HD 38558	986	7602	05474+1744	245.2°	0.022"	2.3	2015.756	HW
				245.2°	0.022"	3.0	2015.756	MI
				77.5°	0.036"	2.1	2016.280	RS
HD 39357	206	7791	05533+2737	117.6°	0.038"	2.5	2007.379	RS
				220.5°	0.027"	2.7	2007.678	SM
HD39393	882	7796	05533+2132	236.1°	0.032"	2.9	2011.793	JM
				324.8°	0.014"	2.0	2018.751	BL
				157.8°	0.011"	2.5	2019.126	DH
				149.2°	0.016"	2.8	2019.126	DG
HD 49345	1130 (9127)	9863	06492+2711	50.1°	0.019"	2.3	2004.242	RS
				207.1°	0.035"	1.5	2016.934	SM
HD 60820	1368	11417	07371+2009	140.2°	0.031"	2.7	2010.303	EI
				271.4°	0.035"	2.1	2018.755	RS
BD +20 1912	815	11731	07492+2015	125.1°	0.033"	2.5	2018.307	DH
				99.0°	0.036"	1.5	2018.307	JB
HD 153727	40	22959	17019-1853	64.8°	0.043"	2.2	2013.699	BL
				148.8°	0.017"	3.3	2018.709	DG
				120.6°	0.024"	2.9	2018.709	JB
				106.1°	0.024"	2.3	2.018.709	SK
HD 164438	1523	24425	18019-1906	132.9°	0.019"	3.2	2017.666	DH
				126.8°	0.021"	3.5	2017.666	DG
				40.6°	0.027"	2.6	2017.866	DH
HD 168608	1542	25129	18214-1852	68.2°	0.033"	2.7	2013.628	DH
				65.4°	0.033"	3.3	2013.628	DG
				60.5°	0.024"	3.3	2017.592	BL
HD 174115	455	25924	18496-1909	24.9°	0.018"	3.3	2012.656	DG
				30.6°	0.021"	3.3	2012.656	DH
				80.5°	0.033"	2.5	2012.656	BL
				79.6°	0.025"	2.5	2016.622	SM
				233.2°	0.026"	1.8	2017.444	DH
HD 2196888	1639	31446	23179-0911	126.1°	0.010"	n/a	2003.916	BL
				72.3°	0.031"	1.8	2018.730	AP

[The 'Resolution limit' is set at no less than two frame intervals [0.080s (PAL) or 0.067s (NTSC)] times the vector rate of motion.]

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Table 5. Companion not observed (definite double star, listed in WDS)

Star name	XZ	RA Dec	Predicted-Mags	Predicted delta T	Limiting Mag. diff.	Observn Date	Observer
COU475AB	11356	07354+1950	9.2+11.5	0.48 s	3	2017.782	DG
RST49448	17224	11279-0142	6.2+8.2	0.24 s 0.35 s 0.30 s	2 2.7 1.5	2009.416 2010.014 2013.431	RS MI MI
TDS 8625	35595	12590-0146	10.9+11.1	1.00 s	2.4	2017.499	DH
TDS8701	35802	13078-0227	9.5+10.1	0.75 s	3 2.3	2017.650 2017.650	DG DH
JC 6	25260	18254-2033	5.0 + 7.4	3.85 s	3.5	2018.788	BL

(Continued from page 504)

- having two or more observations of the star at different position angles round the moon.
- ii. The magnitude difference of the two component stars is too large for the fainter star to be detected at the occultation.

Table 5 contains data similar to Table 4 for stars with entries in the Washington Double Star Catalog, but which have failed to show any double star nature during lunar occultations of the star. Those listed in the table have the predicted intervals between the two occultations shown and the component magnitudes showing it is likely the occultation would have separated the pair.

The names of all contributing observers are listed at the head of this paper and are referred to by the two letter code in the tables.

The XZ identifier refers to the XZ80Q catalog, available at Vizier as catalogue I/291. It includes all stars to magnitude 12.5 within 6° 40' of the ecliptic, that is, all stars which can be occulted by the moon.

OCC# is the number assigned to the possible double at the discovery.

This research has made use of the Washington Double Star Catalog (WDS) and the Interferometric Catalog, both maintained by the United States Naval Observatory, Washington.

Extensive use has been made of the Occult program written by D. Herald, including the solutions for the position angle (PA) and separation of pairs shown in Table 1 and Table 3A.

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- Loader B. “Lunar Occultations of Double Stars – Report #4”, *JDSO*, **10** No 2, 2014.
- Loader B. “Lunar Occultations of Double Stars – Report #5”, *JDSO*, **12** No 2, 2016.
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- Loader B. “A Possible New Double Star from Lunar Occultation, SAO 163677”, *JDSO*, **10**, No 1, 2014.
- Gault D. “A New Double Star Observed During Lunar Occultation, HIP 18473”, *JDSO*, **10**, No 1, 2014.
- Dave Herald’s “Occult” can be downloaded from: www.lunar-occultations.com/iota/occult4.htm.
- The program “Limovie” by K. Miyashita can be downloaded from: http://astro-limovie.info/limovie/limovie_en.html.

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The Figures

The following figures present the discovery light curves of stars found to be double at a lunar occultation. In most cases there is only one observation, although a few have more but no solution was possible. The curves have been generated using Kazuhisa Miyashita's Limovie program to analyze the video record.

The horizontal axes, effectively time, show the frame number of the video. The vertical axes show the light intensity of the star as measured by pixel brightness. In some cases measures have been made for each frame of the video recording, that is 30 frames per second for NTSC videos, 25 fps for PAL videos. Otherwise measures have been made for each field of the video, with two fields in a frame, giving 60 fields per second for NTSC or 50 for PAL. Which has been used is indicated at the top of the plot, usually following the name of the observer.

The step in the light curve occurs when only one of the pair of stars is visible, the other being hidden by the moon. In most cases the step is clear. The points on the step which are used to measure the light intensity are marked with a red cross. The points used to measure the light intensity when both stars are visible and those used to measure the background, both stars hidden, are colored green. Usually the results from the measures, including the calculated magnitudes of the two stars have been added to the diagram.

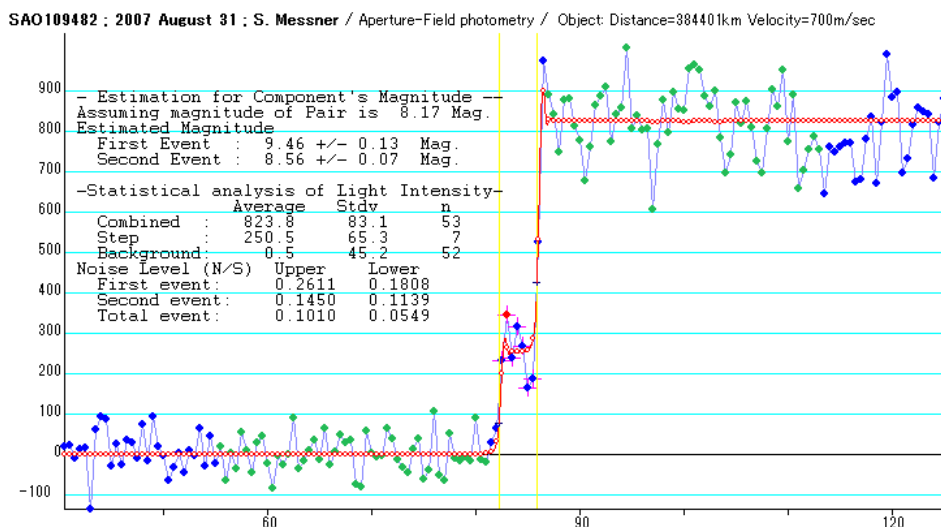


Figure 1. Occultation reappearance of TYC0604-01110-1 (SAO109482). The fainter star appeared first, 0.12 second before the brighter star.

Lunar Occultation Observations of Double Stars – Report #7

SA092918 ; 2012 January 31 ; R. Sandy / Aperture-Field photometry / Object: Distance=384401km Velocity=700m/sec

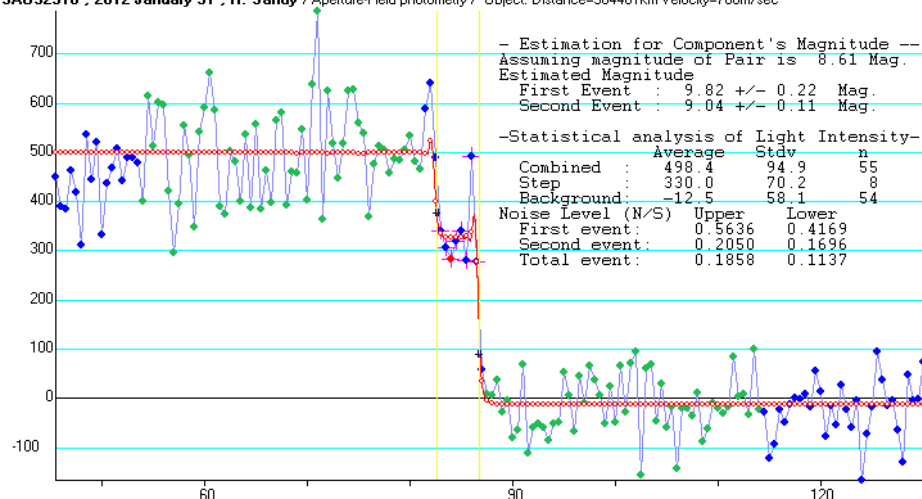


Figure 2: Occultation disappearance of TYC1215-00520-1 (SAO 92918). The fainter star disappeared first, 0.14 second before the brighter.

S93702 = XZ5187 ; 2019 February 13 ; Dave Herald / Aperture-Field photometry / Object: Distance=384401km Velocity=700m/sec

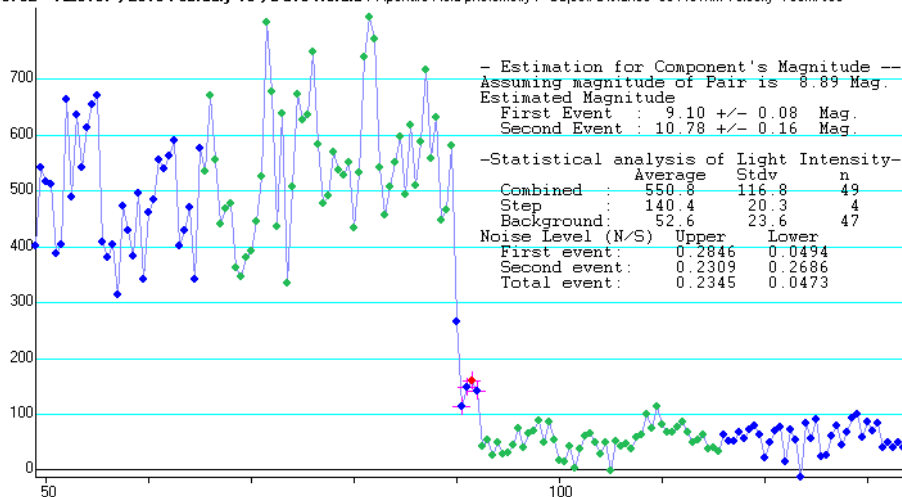


Figure 3: Occultation disappearance of TYC1253-00461-1 (SAO 93702). The brighter star was first to disappear with the step lasting for 0.08 second.

/ Aperture-Frame photometry / Object: Distance=384401km Velocity=700m/sec

X 79423, new dbl; 2017 March 6; D. Gault

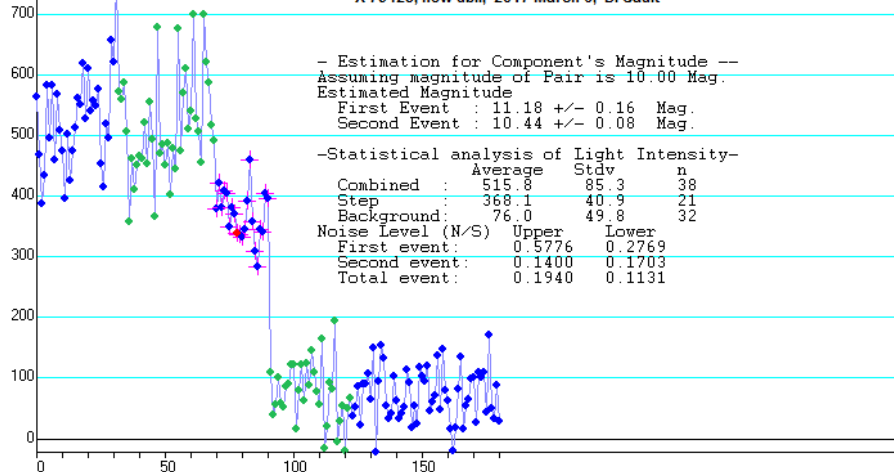


Figure 4. Occultation disappearance of TYC 1320-01983-1 (XZ 79423). The fainter star disappeared 0.84 second before the brighter.

Lunar Occultation Observations of Double Stars – Report #7

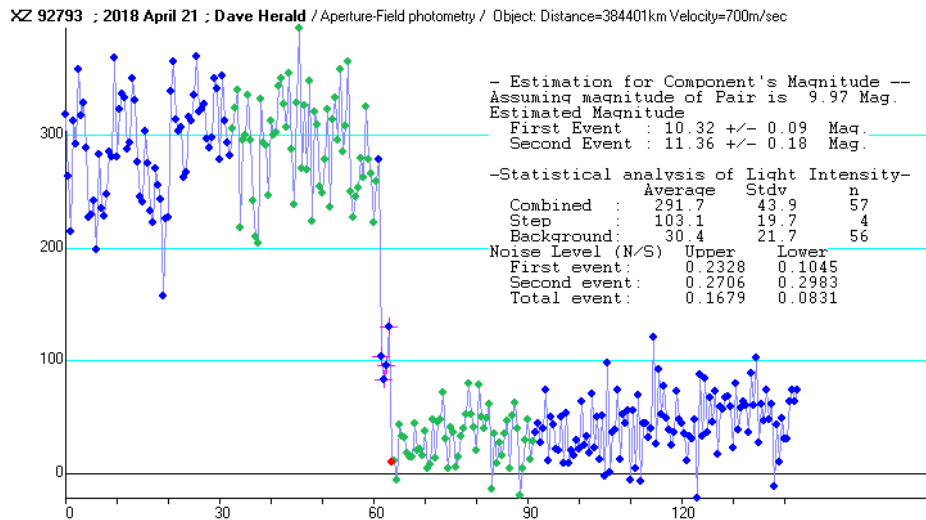


Figure 5. Occultation disappearance of TYC 1342-01830-1 (XZ 92793) with a 0.08 second step. The fainter star was the second to disappear.

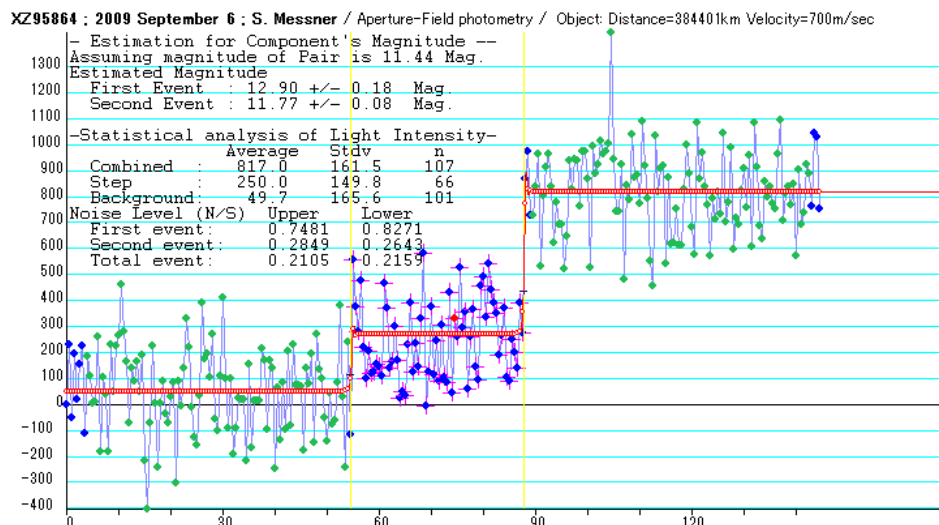


Figure 6. Occultation reappearance of TYC 1902-00526-1 (XZ 95864). The step lasts for 1.11 second with the fainter star being occulted first.

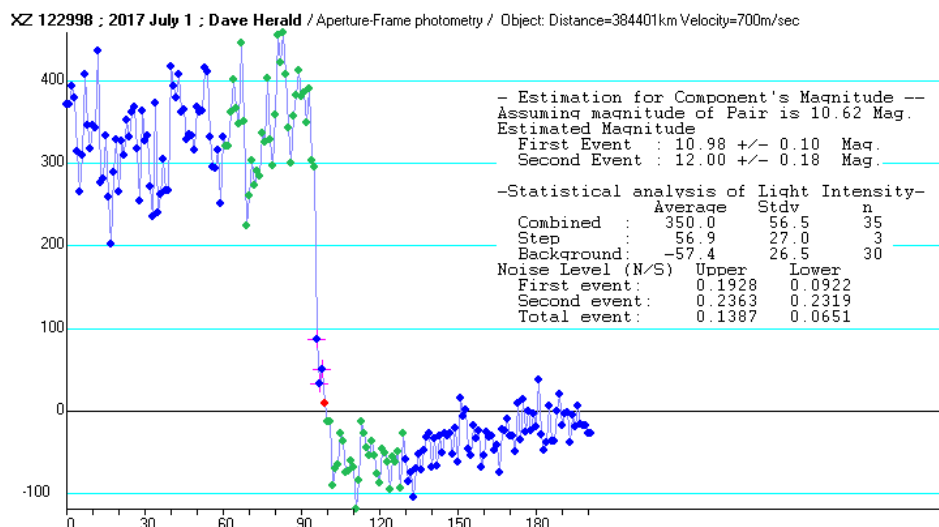


Figure 7. Occultation disappearance of TYC 0283-00658-1 (XZ122998) shows a step lasting for 0.12 second, measured at PAL frame rate. The brighter star was the first to disappear.

Lunar Occultation Observations of Double Stars – Report #7

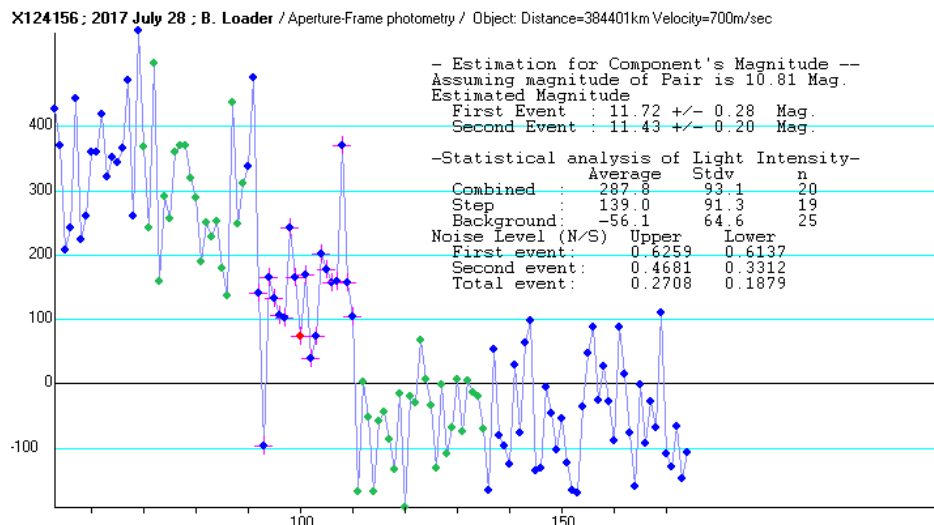


Figure 8. A noisy light curve of the occultation of TYC 0290-00520-1 (XZ124156). The step lasts for 0.76 second with the fainter star occulted first.

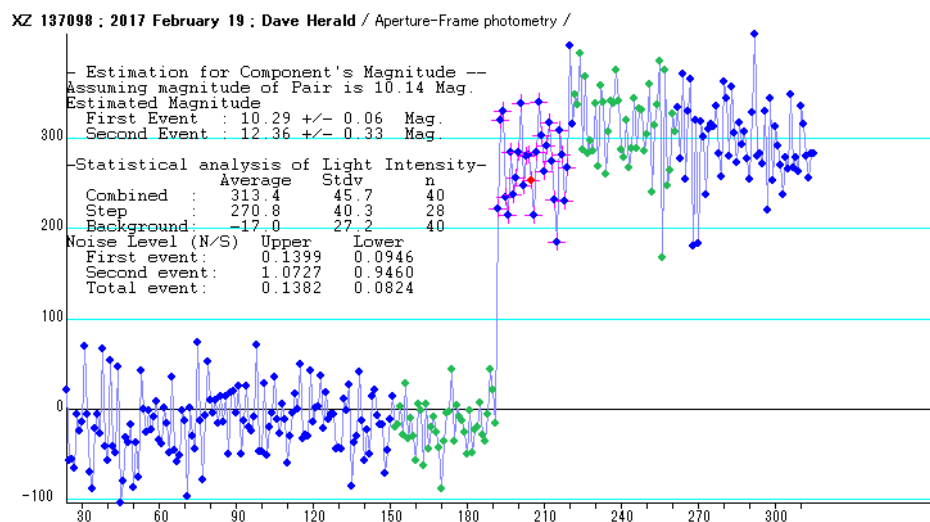


Figure 9. Light curve for the occultation reappearance of TYC 6217-00770-1 (XZ137098). The step lasts for 1.12 second, with the brighter star appearing first.

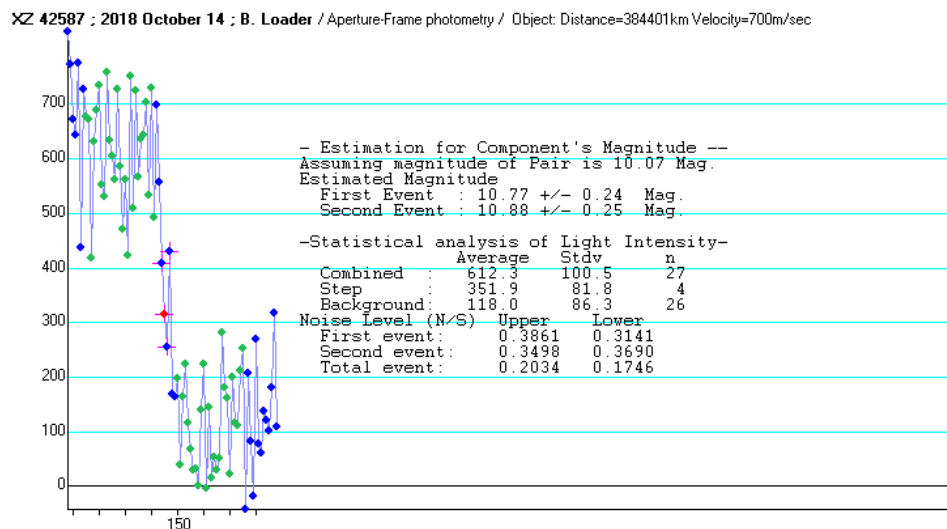


Figure 10. The light curve for the occultation disappearance TYC 6256-01444-1 (XZ42587) shows a likely brief step lasting 0.08 second. The slightly fainter star was the second to disappear.

Lunar Occultation Observations of Double Stars – Report #7

XZ155991 = TOB288 A ; 2017 February 21 ; Dave Herald / Aperture-Field photometry / Object: Distance=384401km Velocity=700m/sec

— Estimation for Component's Magnitude —
Assuming magnitude of Pair is 11.21 Mag.

Estimated Magnitude

First Event : 12.04 +/- 0.13 Mag.
Second Event : 11.89 +/- 0.14 Mag.

—Statistical analysis of Light Intensity—

	Average	Stdv	n
Combined :	216.9	42.0	40
Step :	95.8	28.9	11
Background :	-9.0	26.9	48

Noise Level (N/S) Upper Lower
First event: 0.2763 0.2565
Second event: 0.3465 0.2390
Total event: 0.1858 0.1190

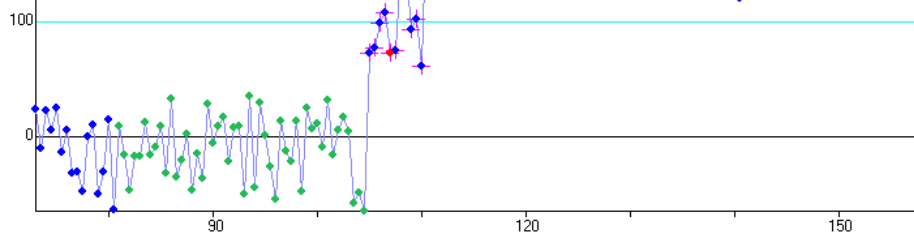


Figure 11. Light curve for the reappearance of TYC 6269-03059-1 (XZ155991) shows a step lasting for 0.22 second. The fainter star probably appeared first but the magnitude difference is small. The observations indicates TOB 288 A is itself double.

/ Aperture-Frame photometry / Object: Distance=384401km Velocity=700m/sec

X 79423, new dbl.; 2017 March 6; D. Gault

— Estimation for Component's Magnitude —
Assuming magnitude of Pair is 10.00 Mag.

Estimated Magnitude

First Event : 11.18 +/- 0.16 Mag.
Second Event : 10.44 +/- 0.08 Mag.

—Statistical analysis of Light Intensity—

	Average	Stdv	n
Combined :	515.8	85.3	38
Step :	368.1	40.9	21
Background :	76.0	49.8	32

Noise Level (N/S) Upper Lower
First event: 0.5776 0.2769
Second event: 0.1400 0.1703
Total event: 0.1940 0.1131

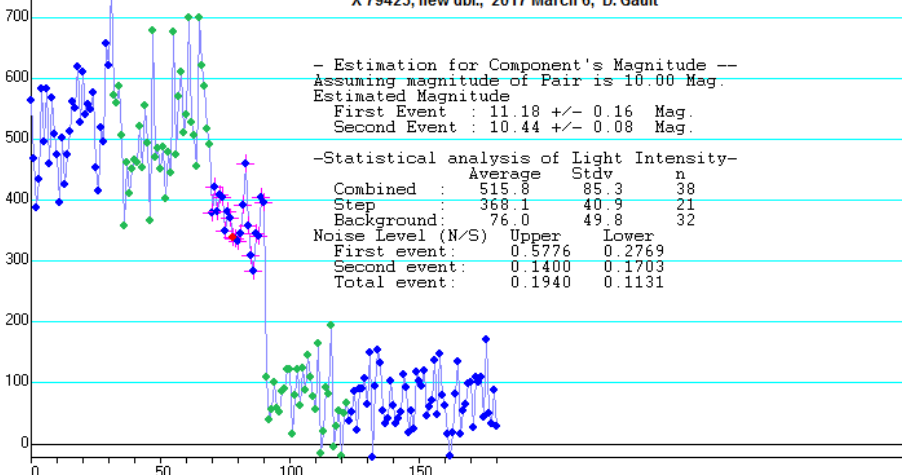


Figure 12. The light curve for the disappearance of TYC 1320-01983-1 (XZ 79423) shows a step lasting for 0.84 second. The fainter star disappeared first.

Analyzed file name [20161008 e.avi] Photometry in each Frame / Object: Distance=384401km Velocity=700m/sec

X44022 ; 2016 October 8 ; S. Kerr

— Estimation for Component's Magnitude —
Assuming magnitude of Pair is 10.80 Mag.

Estimated Magnitude

First Event : 11.05 +/- 0.08 Mag.
Second Event : 12.51 +/- 0.18 Mag.

—Statistical analysis of Light Intensity—

	Average	Stdv	n
Combined :	413.5	66.5	30
Step :	92.1	33.6	21
Background :	8.4	35.2	26

Noise Level (N/S) Upper Lower
First event: 0.2070 0.1045
Second event: 0.4013 0.4207
Total event: 0.1642 0.0869

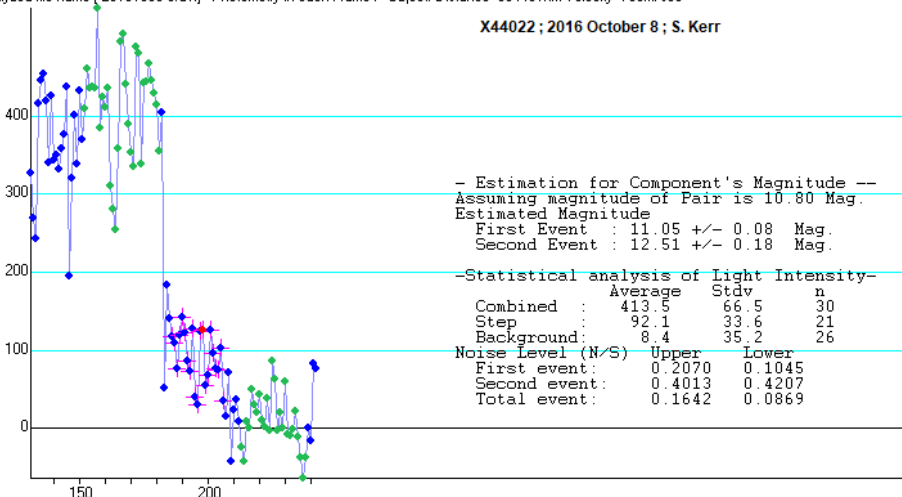


Figure 13. The light curve for the disappearance of TYC 6270-00109-1 (XZ 44022) shows a step lasting for 1.04 second. The brighter star was occulted first

Lunar Occultation Observations of Double Stars – Report #7

X157882 : 2017 September 28 ; B. Loader / PSF-Field photometry / Object: Distance=384401km Velocity=700m/sec

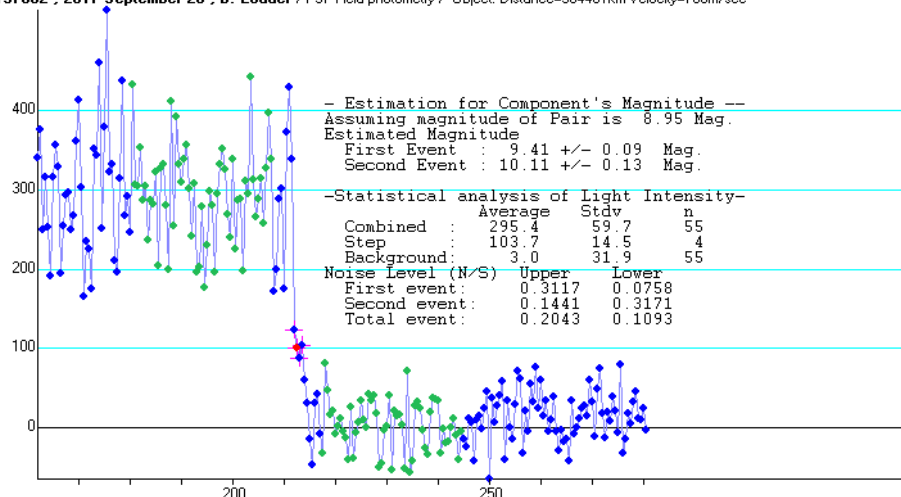


Figure 14. The light curve for the occultation of TYC 6274-01331-1 (XZ157882) shows a brief 4 field step lasting 0.08 seconds. The brighter star disappeared first.

XZ44271 : 2017 September 28 ; Dave Herald / Aperture-Frame photometry / Object: Distance=384401km Velocity=700m/sec

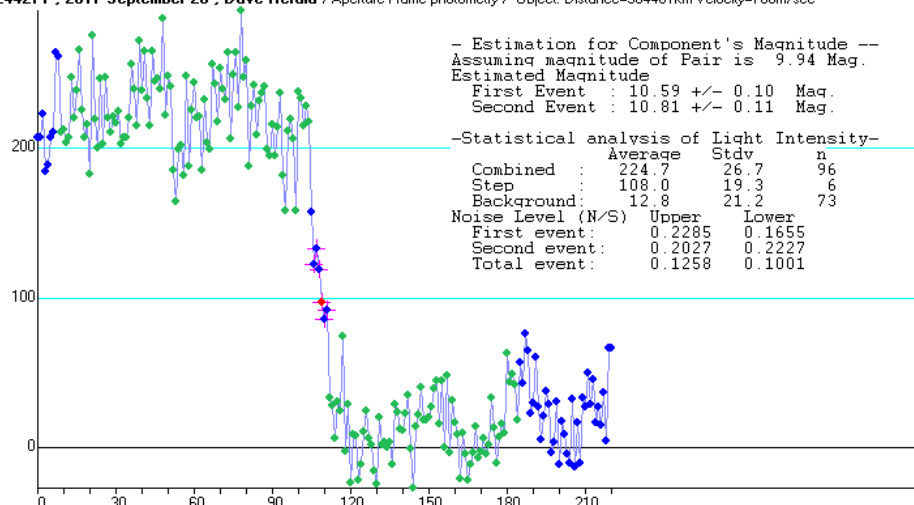


Figure 15. The light curve for occultation of TYC 6275-00749-1 (XZ 44271) shows a 6 frame, 0.24 second step. The fainter star was occulted first.

XZ 161543 : 2017 November 22 ; Dave Herald / Aperture-Frame photometry / Object: Distance=384401km Velocity=700m/sec

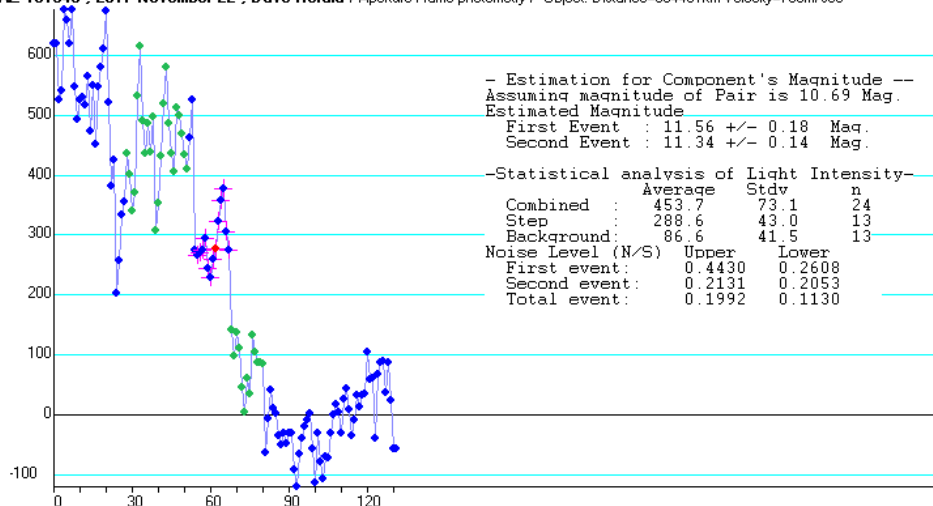


Figure 16. The light curve for the occultation of TYC 6289-01280-1 (XZ161543) shows a 0.56 second step. The fainter star disappeared first.

Lunar Occultation Observations of Double Stars – Report #7

X45164 ; 2019 March 28 ; B. Loader / Aperture-Field photometry / Object: Distance=384401km Velocity=700m/sec

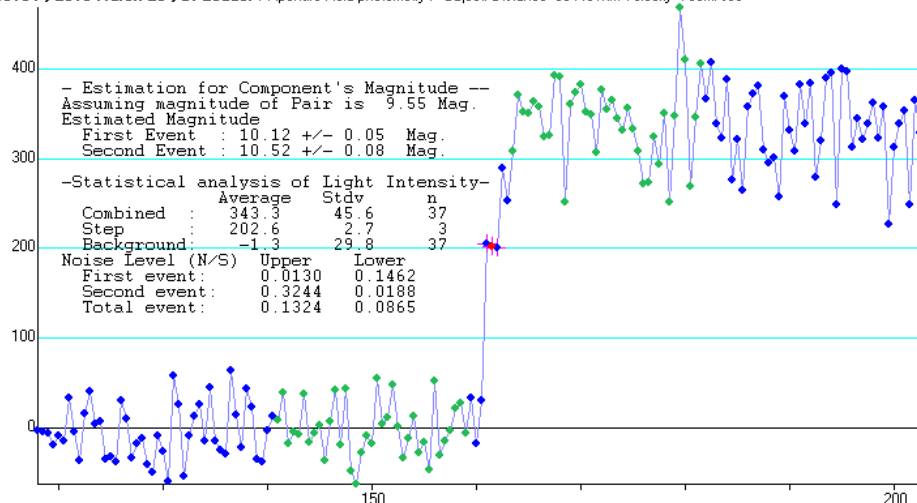


Figure 17. The light curve for the reappearance of TYC 6294-00379-1 (XZ 45164) shows a brief 3 field step lasting 0.06 second. The brighter star appeared first.

Analyzed file name [] Photometry in each Field / Object: Distance=384401km Velocity=693m/sec

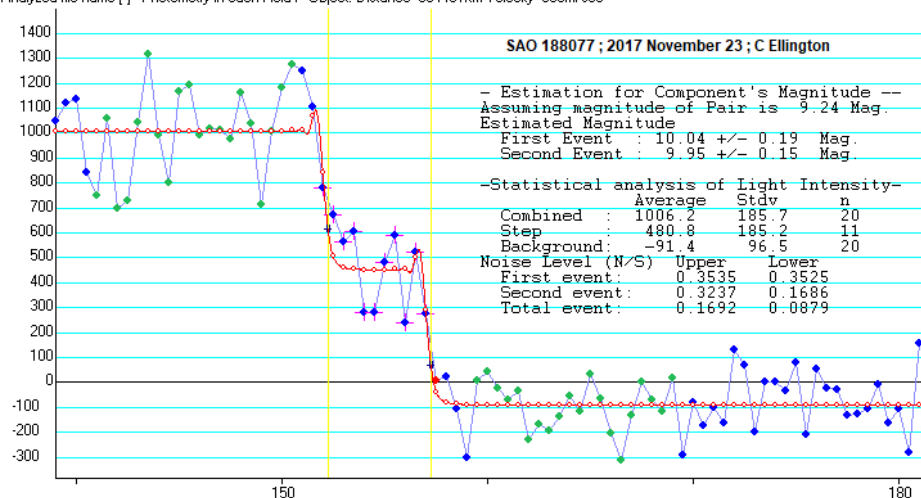


Figure 18. The light curve of the occultation of TYC 6305-01605-1 (SAO188077) shows a step lasting for 0.17 second. The fainter star was apparently occulted first but the apparent magnitude difference of the components is only 0.09.

/ Aperture-Frame photometry / Object: Distance=384401km Velocity=700m/sec

X47100; 2018 November 13; D.Gault

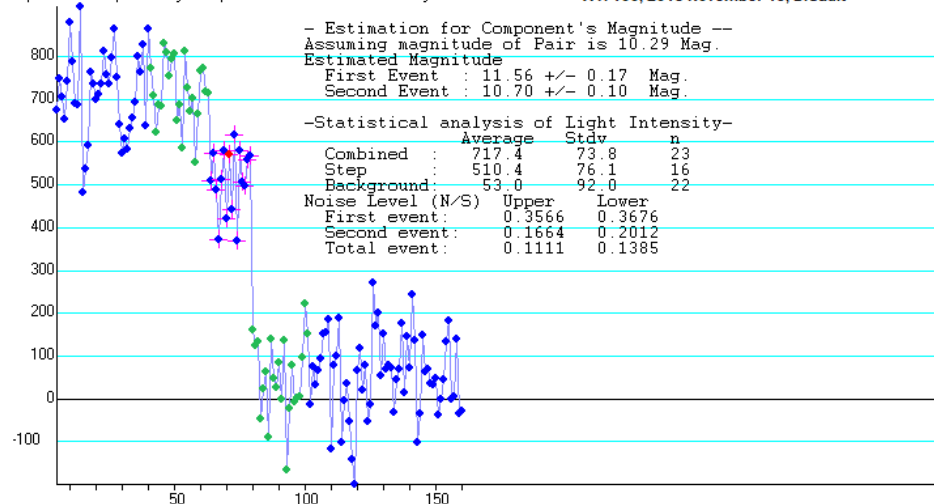
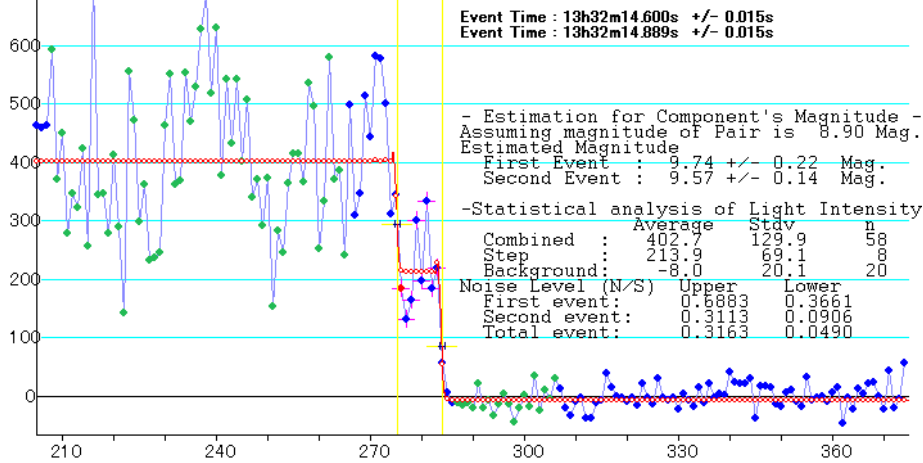


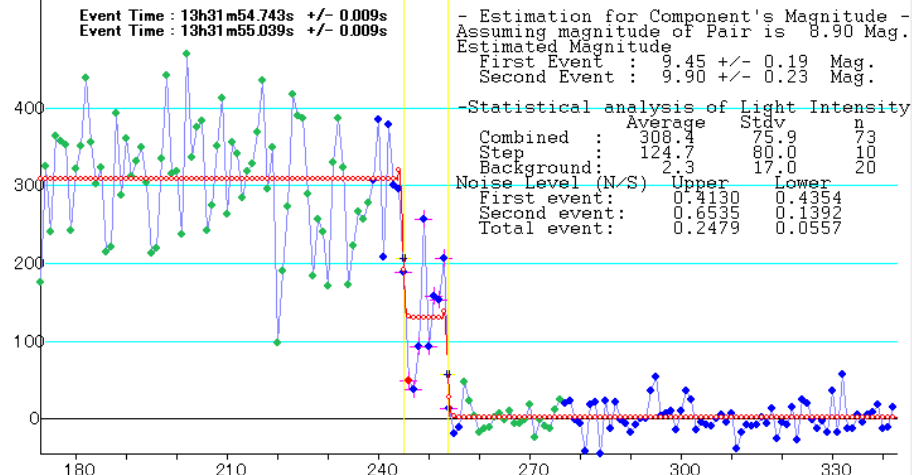
Figure 19. The light curve for the occultation of TYC 6321-01088-1 (XZ 47100) shows a 0.64 second step. The fainter star was clearly occulted first.

Lunar Occultation Observations of Double Stars – Report #7

SAO 163520 ; 2017 September 30 ; H. Yamamura / PSF-Frame photometry / Object: Distance=395100km

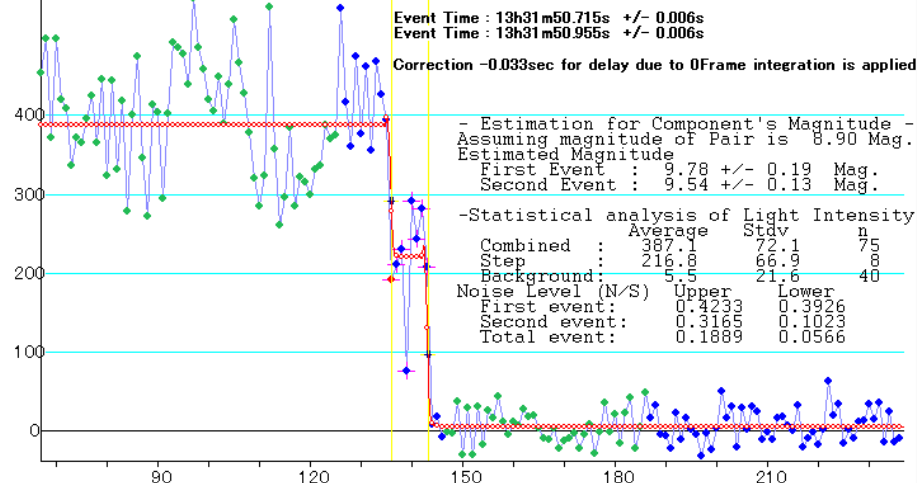


SAO 163520 ; 2017 September 30 ; M. Ishida / PSF-Frame photometry / Object: Distance=395100km Velo



Figures 20, 21, and 22. The occultation of TYC 6332-01468-1 (SAO 163520) was observed by three Japanese observers, H. Yamamura, M. Ishida and Y. Asada, on the same night. The three occultations were too close to each other on the moon's limb to obtain a solution of the double. The observed lengths of the step were all close to 0.25 second. The magnitude observed differences are more variable with M Ishida's curve showing the brighter star as occulted first.

SAO 163520 ; 2017 September 30 ; Y. Asada / PSF-Frame photometry / Object: Distance=395100km Velo



Lunar Occultation Observations of Double Stars – Report #7

XZ 49915 ; 2017 April 20 ; B. Loader / Aperture-Frame photometry / Object: Distance=384401km Velocity=700m/sec

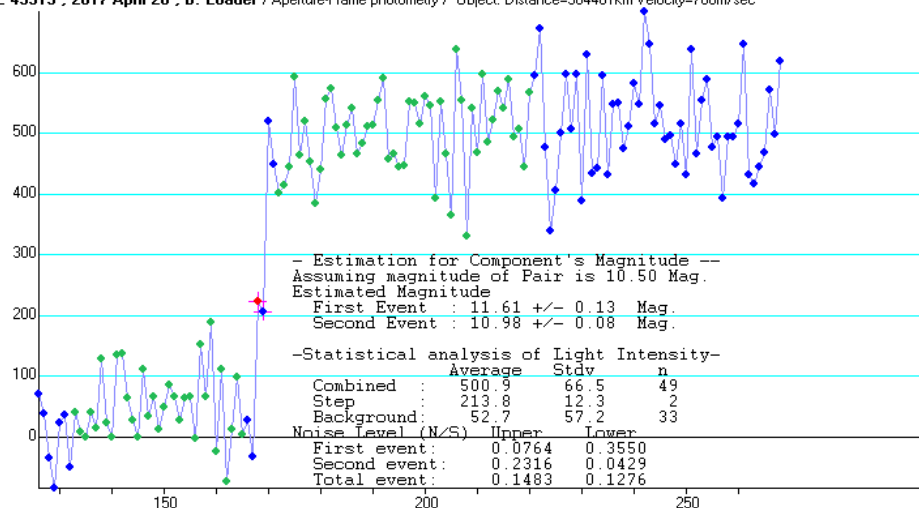
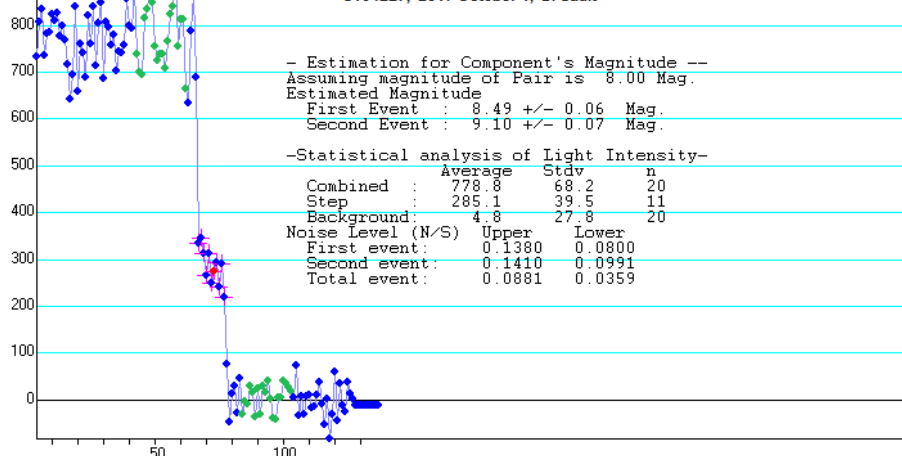


Figure 23. The light curve for the occultation reappearance of TYC 5784-00577-1 (XZ 49915) lasts only 0.08 second. The fainter star was the first to appear from behind the moon.

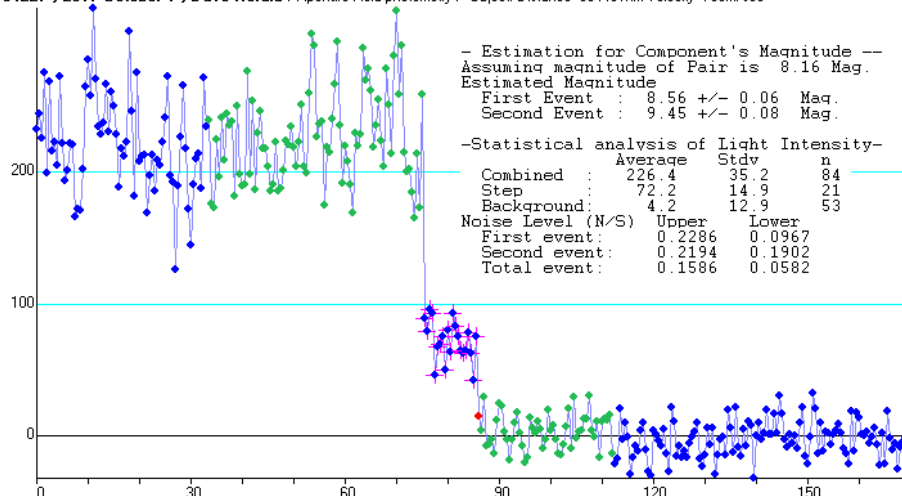
/ Aperture-Frame photometry / Object: Distance=384401km Velocity=700m/sec

S164227, 2017 October 1, D. Gault



Figures 24 & 25. Both D. Gault and D. Herald observed this occultation of TYC 5784-00642-1 (SAO164277). The positions on the moon's limb of their two events differed by only 2.1°, too small to obtain a solution of the double. The lengths of the observed steps were similar, 0.42 second for Herald and 0.44 for Gault. The brighter star was occulted first.

S164227 ; 2017 October 1 ; Dave Herald / Aperture-Field photometry / Object: Distance=384401km Velocity=700m/sec



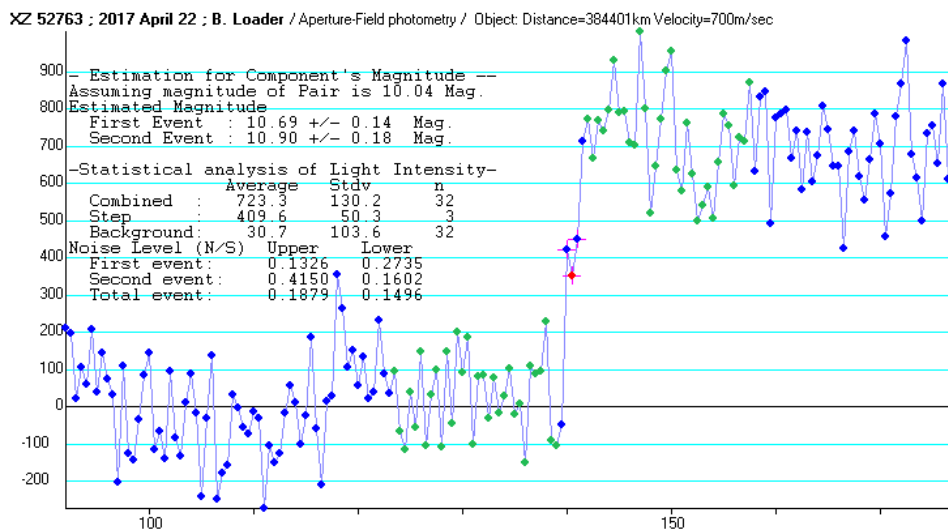
Lunar Occultation Observations of Double Stars – Report #7

Figure 26. The light curve for the occultation reappearance of TYC 5241-00846-1 (XZ 52763) shows a very brief ca 0.06 second step with the brighter star being the first to appear.

Astrometric Measurements and Analysis of WDS 00425+1044 HJ 5

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Abstract: Astrometric measurements of the double star system WDS 00425+1044 were conducted to provide further insight on the classification of the system as either optical or physical. Although data proves to be continuous and consistent from historical trends, consideration of the distance between the primary and secondary, as well as differences in proper motion suggest that the system is optical. The results of this measurement were $\theta = 295.72^\circ$ and $\rho = 23.9''$.

Introduction

This research project was part of an Astronomy Research Seminar offered by San Diego Mesa College and supported by Boyce Research Initiatives and Education Foundation (BRIEF). BRIEF enables students to learn the tenets of scientific research as well as the fundamental aspects of binary star systems.

A double star system is one in which two or more stars appear to be companions due to a chance alignment from the perspective of an observer on Earth. Physical double star systems, commonly known as binary stars, are gravitationally bound. Binary systems have scientific value in that, by determining the mutual gravitational orbit of the stars in the system, one can apply one of the few ways to derive stellar masses. Mass, being the most important stellar property, determines the life and death of the star. By performing these astrometric measurements and classifying systems as binary, we can further our collective knowledge of stellar science.

With the use of the Stelle Doppie website and the Washington Double Star Catalog (WDS), candidate star systems were found based on the following criteria: (a) visible between 00 and 08 hours of right ascension for optimal observing during Fall, (b) an angular separation greater than five arc seconds, (c) maximum magnitude difference of three, with the primary star being between seven and 12, and the secondary between seven and 13. In addition to specific astrometric criteria, a star system

with multiple observations was chosen in order to obtain an adequate amount of previous data to reference.

WDS 00425+1044 HJ 5 fulfilled these criteria. See Figure 1. Observations of HJ 5 were first recorded by John Herschel in 1825; initial reports indicated separation of $25''$ and position angle of 290° . Stelle Doppie labels HJ 5 as an uncertain double, with Richard Harshaw, a leader in the field of double star astronomy who maintains a database of nearly all observed double stars, labeling it as having a 0.6264 binary probability, or a 62% chance of being physically bound.

Materials and Methods

Research on HJ 5 began with a data request from the Washing Double Star catalog. Historical data was gathered from a data request on WDS 00425+1044 HJ 5 from the Washington Double Star Catalog. HJ 5 was initially viewed through AladinLite and Aladin 10 before requesting our own images for measurements.

CCD images were taken using a 0.4-meter SBIG STL-6303 camera using a telescope of the Las Cumbres Observatory Network. The 0.4-meter telescope yields a resolution of 2048×3072 pixels, each $0.57''$ square, for a total field of view (FoV) of 19×29 arcminutes and a default of 1×1 binning mode. After various test images, 2 filter types were determined to yield the best images. The filters used for HJ 5 were rp (red) with 7 second increments of exposure for 15 images, and gp (green) filter with 6 second increments of exposure for 15 images. Thirty images were collected on 2018.835.

Astrometric Measurements and Analysis of WDS 00425+1044 HJ 5

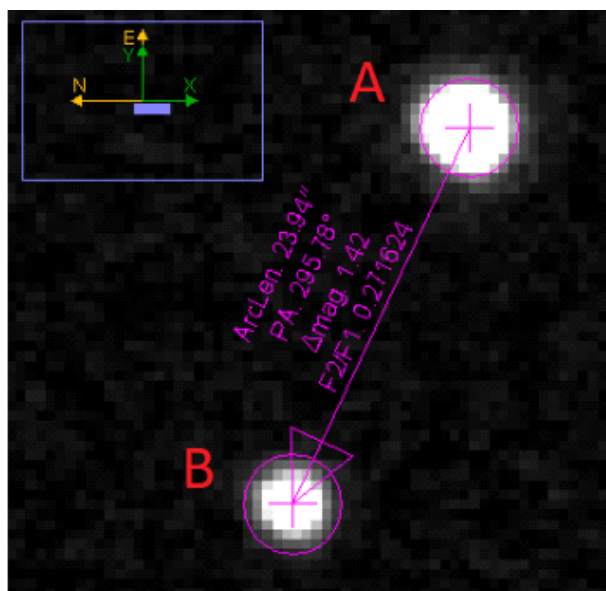


Figure 1. Image taken with a 0.4m SBIG STL-6303 telescope with gp filter; measured using AstroImageJ.

Table 1 displays the theta and rho of each recorded observation, from the initial discovery in 1825 to the measurement in this paper. Present data was averaged after performing repeated measurements on our science images using the AstroImageJ image processing software. The software located the centroids of the A and B stars to accurately measure Theta (position angle) and Rho (angular separation) between the stars. Measurements were recorded in a Microsoft Excel spreadsheet allowing statistical analysis of the data to determine the mean, standard deviation, and standard error of the mean.

Results

A visual representation of the data listed in Table 1 is plotted in Figure 2 by converting theta and rho into x and y coordinates. The primary star is located at the origin. Table 2 lists the parallax measurements (PX) and distances in parsecs (PC) to the primary and secondary stars from our position on Earth.

Table 2. Comparison of the parallax (px) and distance in parsecs (pc) of Star A and Star B. Information gathered from Richard Harshaw's extensive collection of WDS and Gaia data on double stars.

	PX	PC
Star A	2.10 ± 0.0417	$466.92 - 485.84$
Star B	1.71 ± 0.0478	$568.89 - 601.61$

Epoch	θ	ρ
1825	290°	$25''$
1898.65	292.3°	$25.5''$
1912.98	291.4°	$25.118''$
1920.99	292.2°	$25.387''$
1921.59	291.8°	$25.1''$
1990.784	294°	$24.4''$
2000.68	295°	$24.205''$
2010.5	295.4°	$24.07''$
2015	295.607°	$24.008''$
2018.835	295.72°	$23.94''$

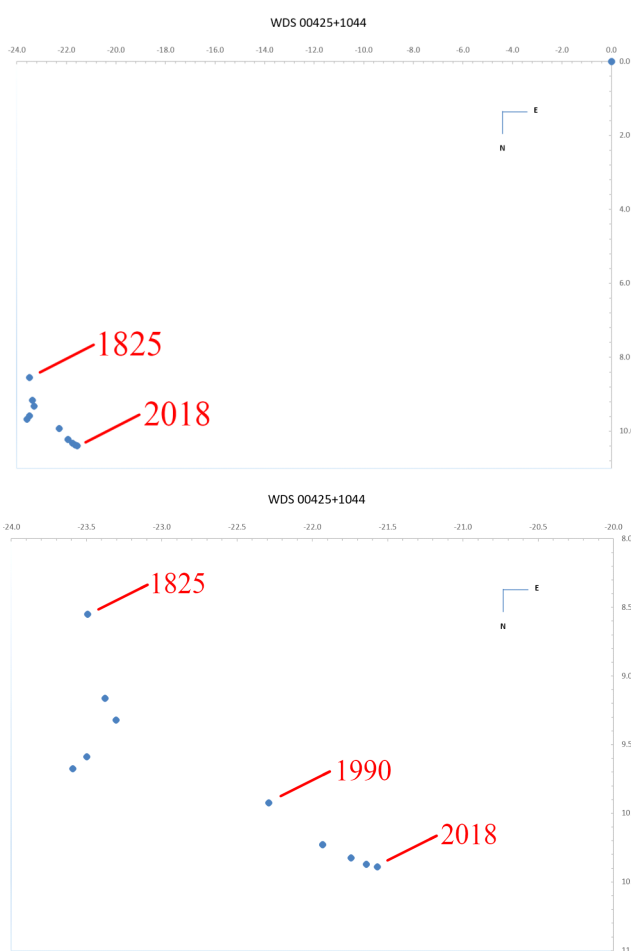


Figure 2. Plot of current and historical data ranging from 1825 to 2018. Historical data gathered from the Washington Double Star Catalog.

Astrometric Measurements and Analysis of WDS 00425+1044 HJ 5

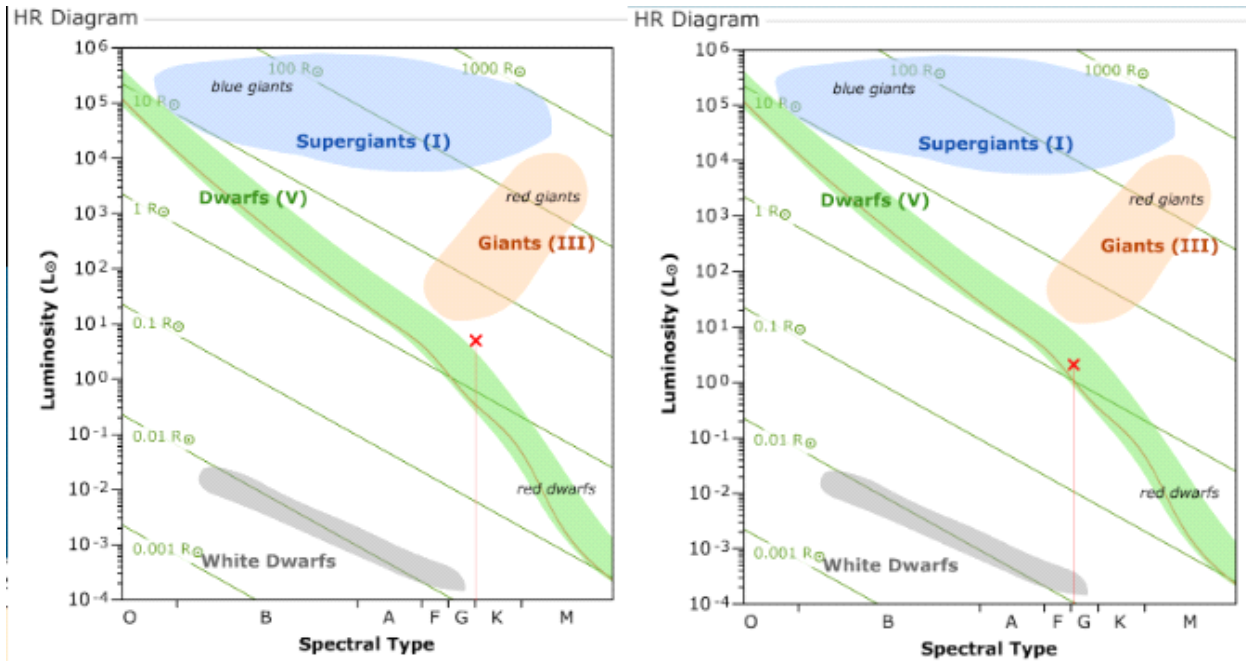


Figure 3. Placement of the primary (left) and secondary (right) stars on the Hertzsprung-Russell diagram based on information about their temperature and luminosity.

Discussion

Over the span of 193 years, with a total of 10 observations, position angle (theta) has changed by $+5.723^\circ$ degrees and angular separation (rho) has decreased by $1.057''$ arcseconds. Data trends prove to be consistent, with the exception of observations between 1912 and 1921, where theta briefly decreased, and rho increased. These slight deviations are not significant and are most probably caused by small measurement errors given the methods used during that time.

In addition to the previously mentioned data, we were able to narrow down the spectral classes for both the primary and secondary stars using information on the star's temperatures and luminosity from Gaia data. Figure 3 depicts the predicted spectral class of both the primary and secondary star based on Gaia data using reported temperature and luminosity. The primary star has a luminosity of $4.97 L_{\text{sun}}$ and a temperature of 5,070 Kelvin (K). The secondary star has a luminosity of $2.08 L_{\text{sun}}$ and a temperature 5,856 K. The Hertzsprung-Russell Diagram Explorer by the University of Nebraska-Lincoln was used to place the stars accordingly. The primary of HJ 5 (G9-K0) is most likely a star entering the Red Giant stage of its life, whereas the secondary star (G1-G2) remains on the main sequence. The spectral classes determined are inferences derived from Gaia's extrapolation of data, and are inferences,

rather than precise measurements of photometry. Our reasons for wanting to find the spectral class of this star system was to get a better understanding the sizes and potential masses, as well as to further contribute to the historical data of HJ 5.

The nearest wide binary to Earth is Alpha Centauri, which, like the secondary star of HJ 5, is very similar to the Sun. Alpha Centauri is a close binary with a small distant companion, Proxima Centauri about a quarter of a light-year away, or 0.077 parsecs (Wide Binary Stars, 2018). In comparison to Alpha Centauri, it is more than highly unlikely for HJ 5 to be classified as physically bound, due to the vast distance between the stars. Given that the maximum distance of Star A is 485.84 parsecs and the minimum distance for star B is 568.89 parsecs it is clear that the max distance for star A is far less than the minimum distance for star B. Therefore the probability of the two stars being physically bound is unlikely. Parallax of star A is $2.10 \pm 0.0417''$, whereas parallax of star B is $1.71 \pm 0.0478''$.

One other consideration for HJ 5 is as a common proper motion pair, or, a visual binary in which the stars have a similar proper motion. Star A has a proper motion of $[-21 -20]$. Star B has a proper motion of $[-1 -9]$, as illustrated in Figure 4. Using the methods provided in Harshaw's paper on tools for evaluating binary stars, we found the difference between the proper mo-

Astrometric Measurements and Analysis of WDS 00425+1044 HJ 5

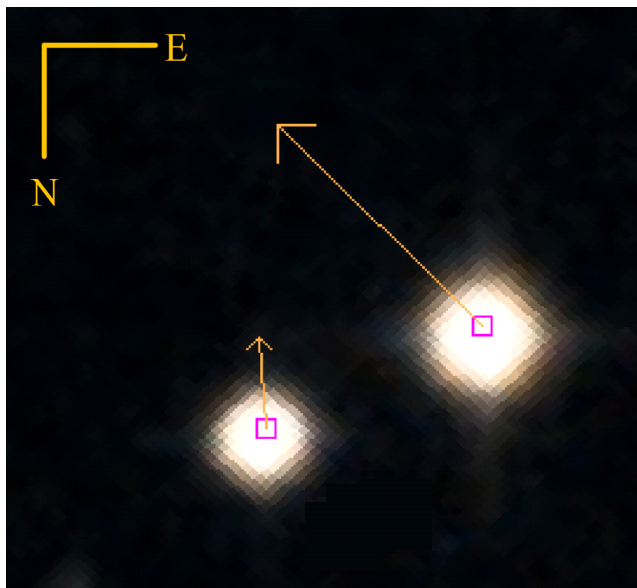


Figure 4: GAIA DR2 proper motion data on HJ 5 taken from ALADIN

tion vectors to be about $[-21 \ -20] + [+1 \ +9] = [-20, -11]$. This method produces a statistic by dividing the vector difference by the vector sum, resulting in 0.599. This final result (0.6) is called the “rating” and its value will range from 0.00 for orbital pairs up to 0.99 for optical ones (Harshaw, 2014). Using GAIA’s proper motion data in Harshaw’s method shows that this system does not satisfy the criteria for a common proper motion pair.

Conclusion

Initial records of WDS 00425+1044 HJ 5 piqued our interest for further research into determining if the double star candidate was optical or physical. The level of uncertainty surrounding HJ 5 is what made this system a worthy contender.

Astrometric data shows the separation between the component stars is decreasing by $1.057''$ over the span of about 200 years. The vast physical distance between the stars of HJ 5 should be conclusive evidence as to why this system is most probably not gravitationally bound. In addition, GAIA data disproves the idea of a

common proper motion pair.

Due to these two factors of physical distance and proper motion, the data suggests that HJ 5 is simply an optical double. Further observations are required in order to determine if an orbital pattern exists.

Acknowledgements

The authors would like to thank Pat and Grady Boyce of the Boyce Research Initiatives and Educational Foundation (BRIEF) for their support and the opportunity to conduct this research. Our sincere thanks is extended to Alexander Beltzer-Sweeney and Dr. Irena Stojimirovic for their guidance and expertise. In addition, we would like to thank the Las Cumbres Observatory for the use of their telescopes and the United States Naval Observatory for the data and information provided.

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Astrometric Measurements and Historical Data Summary of WDS 05599-3703 (B 1044AD)

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Kelcey Davis

San Diego State University, San Diego, CA

Abstract: Position angle and angular separation for the double star system WDS 05599-3703 B 1044AD were measured from images acquired through the iTelescope network and processed through Maxim DL and MiraPro x64. A position angle of 189.9° and a separation of $27.3''$ were measured.

Introduction

The selection criteria for determining a double star system to study included a right ascension between 00 and 06 hours, a separation of at least 6 arcseconds, and a maximum differential magnitude of 6. The Washington Double Star catalog (WDS) (Mason and Hartkopf 2015), managed by the United States Naval Observatory (USNO), was used to find a candidate star system. WDS 05599-3703 B 1044AD fit this criteria, with a right ascension of 05h 59m 55.79s, a separation angle (ρ) of $21.3''$, and a differential magnitude of 4.58.

Historical data, provided by the USNO, shows two complete sets of previous measurements. There are other measurements that did not provide position angle (θ) or angular separation (ρ), but instead provided data such as magnitude for a given epoch. The earliest measurement was made in 1999 indicating a θ of 215° and a ρ of $16.2''$. The other measurement, also taken in 1999, shows a θ of 216° and a ρ of $15.8''$.

Double Star WDS 05599-3703 B 1044AD was selected with the objective of taking new astrometric measurements in an effort to assist in determination of the system's gravitational nature, while also evaluating the possibility of a chance alignment of the A star over the D star.

Materials and Methods

Images were taken through the iTelescope network where each observatory has multiple telescopes that could be used for scientific research. The first telescope



Figure 1. iTelescope T27



Figure 2. iTelescope T30.

used was the T27, Figure 1, located in Siding Spring, Australia at an elevation of 1122 meters. T27 has a resolution of 0.53 arc-secs/pixel, a pixel size of $12\ \mu\text{m}$ square, and a position angle of 0° . The second telescope was the T30, Figure 2, also located at 1122 meters in Siding Spring, Australia. This telescope has a resolution of 0.81 arc-secs/pixel, a pixel size of $9\ \mu\text{m}$ square, and a position angle of 086° .

We requested images, with select filters, exposure length, and time windows for the images. The equip-

Astrometric Measurements and Historical Data Summary of WDS 05599-3703 (B 1044AD)

Table 1. Number of images with filter and exposure time.

Filter	Images	Exposure (Seconds)
Luminance	1	60
Hydrogen Alpha	4	120
Blue	2	120
TOTAL	7	

ment used to measure our stars included 2 images of Luminance with 30 seconds exposure, one Luminance with 60 seconds of exposure, a Hydrogen-alpha with 120 seconds of exposure, and Blue with 120 seconds of exposure for T27 and T30, Table 1.

The luminance filter is a clear filter that was used to get a general image of the system. Hydrogen-alpha filters were used to acquire a narrow bandpass of light between the A and D stars. Because of the high magnitude of both the A and D stars, which are G type stars, we wanted to look at them in a color other than their peak wavelength to see less light, and consequently used a blue filter. These different filters were used to discern whether or not there were differences in measurement that could be attributed to the varying wavelengths corresponding to each filter.

Each image was processed through Maxim DL, software for astronomical imaging which processes data acquired through imaging array detectors such as CCDs (charge-coupled device). Mira Pro was used to clean, label, and calibrate images, along with measuring our position angle and separation. To ensure accurate measurements in Mira Pro, the vertical transfer function was set to 99.5% or 99.9%, based on trial and error to see which provided the clearest image. Each image was then measured using the Distance and Angle tool in Mira Pro. This statistically located the center of each star. Figure 3 is a CCD image after being processed in Maxim DL and MiraPro x64. Theta and rho of the AD pair was recorded and organized in an Excel spreadsheet. Then, we determined the mean, standard deviation, and the deviation of error for all measurements.

Data and Results

Table 2 shows the mean, standard error of the mean, and standard deviation for WDS 05599-3703 B 1044AD Theta and Rho. Table 3 shows the raw data from CCD image measurements made in this study. Parallax and distances were evaluated in Tables 4 and 5.

Discussion

The historical measurements of this system, Table

6,
in-

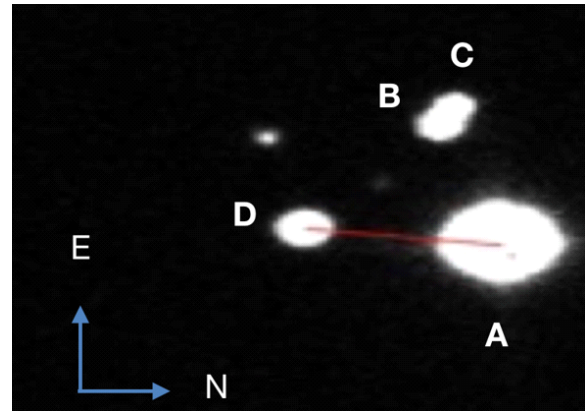


Figure 3. Processed CCD image of WDS 05599-3703B 1044B under a luminance filter with an exposure of 60 seconds.

Table 2. The mean, standard error of the mean, and standard deviation for astrometric measurements of WDS 05599-3703 (B 1044AD)

Statistics	Theta (°)	Rho (")
Mean	189.9°	27.3"
Standard Deviation	1.04°	0.29"
Standard error of mean	0.39°	0.11"

Table 3. Summary of raw data from CCD image measurements made in this study.

Image	Exposure (Seconds)	Theta (°)	Rho (")
1	60	189.1	27.2
2	120	190.1	27.6
3	120	191.7	27.7
4	120	190.5	26.9
5	120	188.7	27.2
6	120	190.2	27.0
7	120	189.1	27.2

Table 4. Parallax and error measurements for both stars

Inputs	Parallax	Error
Star A	18.8	0.0378
Star D	2.28	0.0307

Astrometric Measurements and Historical Data Summary of WDS 05599-3703 (B 1044AD)

Table 5. Min, Mid, and Max distances from both stars to earth in Parsecs and Light Years

Results	Min Distance (Parsecs)	Mid Point (Parsecs)	Max Distance (Parsecs)	Min Distance (Light Years)	Mid Point (Light Years)	Max Distance (Light Years)
Star A	53.08	53.19	53.3	173.06	173.4	173.75
Star D	432.77	438.6	444.58	1410.83	1429.82	1449.34

indicate some shift in Theta and Rho, Figure 4, from the first measurement in 1999. To determine these distances, parallax angles were used to determine the distance of each star from Earth in both parsecs and light years, Table 5. From the parallax data, it appears that the A and D stars are most probably not gravitationally bound, which complies with the nature of most G class stars. The line of sight distance between the two for the most optimal configuration (A at its furthest distance, and D at its closest to us) is 379.47 parsecs, or 1,237.08 light years. Therefore, the inference is that the system of stars is not gravitationally linked; their connection appears to be that of an optical alignment. Therefore, given the large distance between these stars, there is no gravitational connection.

Conclusion

The measurements from this study indicate that there has been a decrease in position angle and an increase in separation for WDS 05599-3703 B 1044AD since its first recorded measurement in 1999. When viewed from the perspective of the positional measurements in this study, and consideration given to the distances between the stars, it is proposed that these are optical double stars and not gravitationally bound.

Acknowledgements

We would like to thank the Boyce Research Initiatives and Education Foundation (B.R.I.E.F.) for facilitating my research through lectures the research technology they provided. Lastly, we would like to thank the United States Naval Observatory for providing all the information on my double star system along with the iTelescope network for granting the use of their telescopes to us.

References

Mason, B. and Hartkopf, W. 2015, The Washington Double Star Catalog. Astrometry Department, U.S. Naval Observatory.

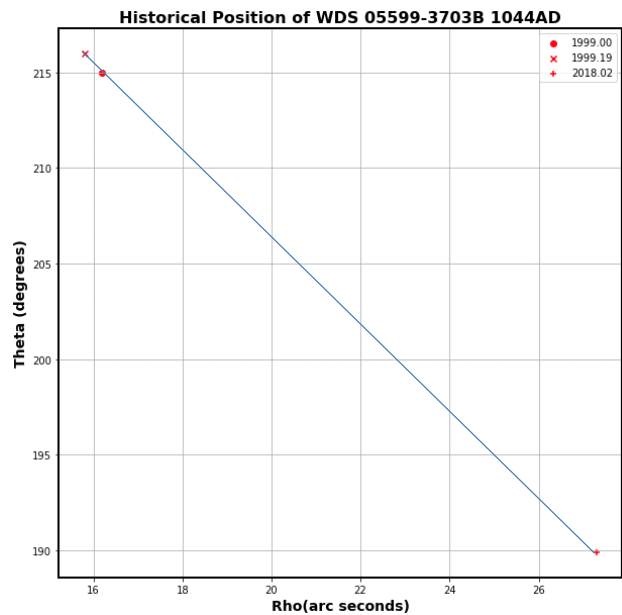


Figure 4. Historical Position of WDS 05599-3703B 1044AD

Table 6. Current measurements and data available on WDS 05599-3703B 1044AD courtesy of the Washington Double Star Catalog.

Epoch (Decimal Year)	Epoch (Julian Date)	Theta	Rho
1999.00	2451179.5	215°	16.2"
1999.19	2451248.5	216°	15.8"
2018.02	2458126.5	189.9°	27.3"

A New Double Star from Lunar Occultation: XZ 103822

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Abstract: A lunar occultation observation by the author in April 2019 detected a new double star: XZ 103822.

XZ 103822

On 2019 April 12, a lunar occultation disappearance of XZ 103822 was video-recorded at 50 fields/second using a 28cm telescope and a Watec 910HX camera at amateur observatory MPC Z92. The waxing Moon was 51% illuminated. The star is 10th magnitude so the recording was analysed at 25 frames/second (using Limovie software), giving a better signal to noise ratio and a less noisy light curve than at 50 fields/second (Figure 1).

The intermediate step was measured to have a dura-

tion of 0.423s, with the fainter star being the first to disappear behind the Moon. The position angle of the event at the Moon's limb was 110.9° and the radial velocity of the Moon at the location of the occultation was $0.465''/\text{second}$ (Occult4 software). The consequent separation of the components of this star is at least $0.2''$. The magnitude of XZ 103822 is $M_v 10.29$. From the heights of the three portions of the light curve, the V magnitudes of the components are derived as 10.7 and 11.5.

There are no previous observations of this star in

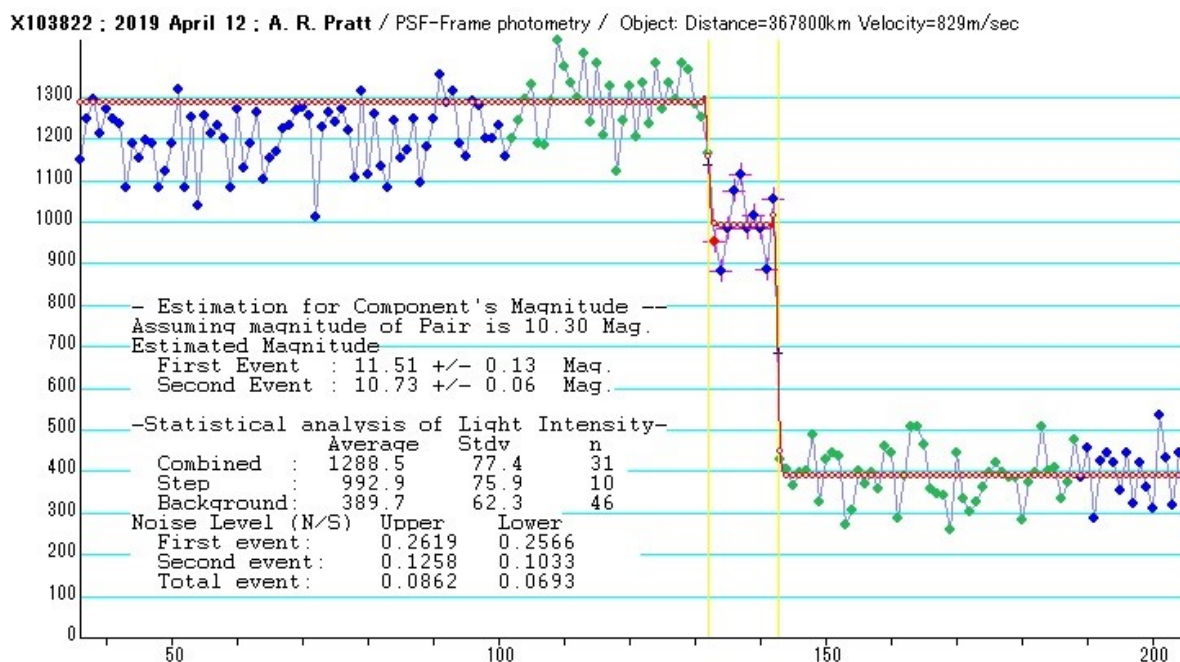


Figure 1.

A New Double Star from Lunar Occultation: XZ 103822

the Archive of Lunar Occultation Observations.

Star XZ 103822 = TYC 1373-37-1
 = GSC 01373-00037
 = 2MASS J07403872+2052502
 = Gaia DR2 673152977377071616

Coord. (J2000) 7h 40m 38.72s, 20° 52' 50.11"

Spectral type ?

Derived double data:

Mag A 10.7 ± 0.1 (V)

Mag B 11.5 ± 0.1 (V)

Epoch 2019.28

Separation $> 0.2''$

PA at epoch between 21 and 201 deg

References

Miyashita, K. : Limovie - http://astro-limovie.info/limovie/limovie_en.html

Herald, D. : Occult4 - <http://www.lunar-occultations.com/iota/occult4.htm>

Lunar Occultation Archive: VizieR Catalogue number
VI/132A



Counter-Check of WDS Farihi Objects with GAIA DR2

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Abstract: The topic of this report is the recovery of 68 WDS FAR objects in GAIA DR2 with the intention to counter-check proposed potential gravitational relationship and assumed minimum distances between the components of these pairs.

1. Introduction

The Farihi et al. 2006 and 2010 papers on White Dwarf–Red Dwarf systems caught my attention with the approach to estimate the smallest possible distance between components of double stars with Monte Carlo simulation using photometry based distance estimations. I decided to cross-match the WDS FAR objects with GAIA DR2 and to counter-check for potential gravitational relationship (PGR) using GAIA DR2 RA, Dec and parallax data for a Monte Carlo simulation of the distance between the components of the double stars.

2. Cross-Match of WDS FAR Objects with GAIA DR2

The number of FAR objects, 68, is rather small so I decided to do the cross-match with GAIA DR2 manually by entering the RA/Dec coordinates into Aladin bringing up the DSS image for this position, loading the GAIA DR2 catalog on top and identifying the corresponding DR2 objects. In case of a positive cross-match for both components the data was copied into a spreadsheet executing a Monte Carlo simulation with sample size 120,000 using the RA, Dec and Plx values as mean values for a normal distribution with the given error range as standard deviation. The resulting Plx and Sep values were then used to calculate the distance between the components of the double star with the law of cosines to estimate the likelihood of a distance smaller than 200,000 AU (~1 parsec) considered as threshold for potential gravitational relationship (Knapp 2019) as well as the minimum, median and maximum distance covering the GAIA DR2 error range values.

Out of the 68 FAR objects, 23 are listed with a sep-

aration smaller than 0.4 arcseconds (the declared GAIA DR2 resolution limit) and for this reason not suited for cross-matching.

Out of the remaining 45 FAR objects 9 objects lack resolution in GAIA DR2 for at least one component and 36 could be matched successfully with GAIA DR2 objects but with 6 of them lacking parallax data necessary for PGR assessment. From the remaining 30 objects only 7 have a likelihood > 50% for a potential gravitational relationship and an additional 3 have a likelihood > 40%. 10 objects seem far outside the distance range allowing for PGR and can be considered as most likely optical pairs and another 10 pairs have a PGR likelihood between 3 and 18%, mostly due to rather large Plx errors, resulting in a huge spread in the likely distances and for this reason also most likely opticals.

Table 1 lists the following 2015.5 GAIA DR2 based data for the successfully cross-matched 30 FAR objects:

- | | | |
|---|---------|--|
| • | WDS_ID | WDS ID |
| • | FAR | FAR object number |
| • | C | Component (AB if blank) |
| • | PA | Position angle in degrees |
| • | e_PA | Error position angle |
| • | Sep | Separation in arcseconds |
| • | e_Sep | Error separation |
| • | Vest1 | Estimated Vmag1 calculated from GAIA DR2 G/B/R-mags |
| • | e_Vest1 | Error Vmag1 estimation (Vmag1 estimated only from Gmag if blank) |
| • | Vest2 | Estimated Vmag2 calculated from GAIA DR2 G/B/R-mags |

Counter-Check of WDS Farihi Objects with GAIA DR2

- e_Vest2 Error Vmag2 estimation (Vmag2 estimated only from Gmag if blank)
- pmRA1 Proper motion RA1 in mas/yr
- pmDE1 Proper motion DE1 in mas/yr
- pmRA2 Proper motion RA2 in mas/yr
- pmDE2 Proper motion DE2 in mas/yr
- CPMR Common proper motion rating
- CPMS Common proper motion score
- Notes Notes

14 out of these 30 objects are with a CPM score >50% positively assessed for likely common proper motion.

The estimation of the visual magnitudes is based on GAIA DR2 G/B/R-mags using the formula

$$\begin{aligned} \text{Vest} &= 3.9379083526304 + \\ &0.269235360436179 * \text{Gmag}^{1.36701081887491} - \\ &0.123879978164097 * [\text{Gmag} - \text{Rmag}] - \\ &0.943379695375539 * [\text{Gmag} - \text{Bmag}] \end{aligned}$$

with a regression coefficient of 0.999 and a standard deviation of 0.064 derived by statistical analysis using nonlinear regression with the UBVRI catalogs of Landolt&Clem (VizieR II/183A, J/AJ/146/88 and J/AJ/152/91) after eliminating a few outliers due to questionable cross-match results with GAIA DR2. This estimation formula shares the photometry caveats of GAIA DR2 for very bright (<10Gmag) and very faint (>18Gmag) objects according to Evans et al. 2018 and Riello et al. 2018. In case of missing GAIA DR2 Bmag and Rmag data the visual magnitude was estimated with an average delta of +0.318 to Gmag.

Table 2 lists the following 2015.5 GAIA DR2 based data for the successfully cross-matched 30 FAR objects using Monte Carlo simulation with a sample size of 120,000 allowing for an assessment for potential gravitational relationship (PGR):

- WDS_ID WDS ID
- FAR FAR object number
- C Component (AB if blank)
- Plx1 Parallax1 in mas
- e_Plx1 Error parallax1
- Plx2 Parallax2 in mas
- e_Plx2 Error parallax2
- Min_Dist_AU Minimum distance between the components in AU from GAIA DR2 data
- Far_MD_AU Minimum distance between the components in AU according to Farihi et al. 2010
- Median_AU Median distance between the

- components in AU from GAIA DR2 data
- Max_Dist_AU Maximum distance between the components in AU from GAIA DR2 data
- PGRS Potential gravitational relationship score
- P_min Minimum orbit period using the minimum distance as semi-major axis with zero inclination and 2 Sun masses
- P_med Median orbit period using the median distance as semi-major axis with zero inclination and 2 Sun masses
- e_Plx1R Parallax1 error rating ("OK" if <0,5% and "X" if larger indicating a reliability issue)
- e_Plx2R Parallax2 error rating ("OK" if <0,5% and "X" if larger indicating a reliability issue)

7 out of these 30 objects are with a PGR score >50% (means percentage of simulation results with a distance between the components smaller than 200,000 AU) positively assessed for being likely bound by gravitation but only 2 of them have a parallax error relation e_Plx/Plx <0.5% for both components making the positive PGR assessment for the other 5 objects somewhat questionable.

The Farihi et al. 2010 report gives for 10 out of the listed 30 FAR objects estimations for a minimum distance between the components and for 7 of these the GAIA DR2 data based estimations come very close to the Farihi et al. 2010 values even if in most cases for objects considered likely rather not physical due to large parallax error values causing a huge spread regarding distances. This also means that the given minimum distances have to be taken with the caveat that the likelihood for these distances is extremely small.

Summary

Only about 50% out of the 68 FAR objects could be recovered in GAIA DR2. Separations <0.4 arcseconds means below the self-declared resolution limit of GAIA DR2 (Arenou et al. 2018) are the main reason for a lack of resolution and most of these objects are so far still WDS listed with only 1 observation. Eight of the in total 36 objects listed with so far only 1 observation were positively cross-matched with GAIA DR2 raising the percentage of confirmed FAR objects from 47 to 59%.

The percentage of likely physical pairs is even with allowance for unfavourable parallax error relation with 7 out of 30 objects in the average of WDS CPM

(Text continues on page 534)

Counter-Check of WDS Farihi Objects with GAIA DR2

Table 1: 30 FAR objects with CPM assessment and estimated *Imags*

WDS_ID	FAR	C	PA	e_PA	Sep	e_Sep	Vest1	e_Vest1	Vest2	e_Vest2	pmFA1	pmDE1	pmRA2	pmDE2	CPMR	CPMS	Notes
01083+3535	2		174.818	0.000	111.06771	0.00006	14.39173	0.00599	15.70410	0.00298	38.296	-51.810	-38.254	-52.359	AAAC	95	
01186+2255	24		10.495	0.016	1.09295	0.00031	15.87625	0.01901	17.99490		34.990	-78.381	31.323	-82.705	DCAA	0	
01481+2533	26		334.006	0.002	2.32277	0.00006	16.04866	0.03364	14.35283	0.03157	133.908	-59.481	132.596	-56.811	ABAA	80	
02081+1336	27		10.196	0.009	1.25242	0.00019	14.46451	0.07342	15.08326	0.03683	44.764	-6.944	43.665	-6.811	ACAA	40	
02107+1507	28		38.344	0.003	2.62369	0.00012	16.00829	0.01528	15.51693	0.01587	33.755	60.475	34.987	56.633	CDAA	1	
03502+1335	32		263.044	0.031	1.06009	0.00056	15.71560		15.20378	0.05706	173.772	65.855	174.233	61.555	BAAA	80	
03591+2312	3		350.560	0.008	1.18173	0.00017	15.43053	0.01604	17.52806	0.10529	1.498	18.713	1.273	17.604	ADAA	5	
04202+3336	4		134.379	0.000	70.18403	0.00021	15.00384	0.00658	17.79442	0.02048	83.671	-175.117	83.717	-174.562	AAAB	97	
06291+4131	5		250.536	0.000	102.68132	0.00013	14.76988	0.00836	17.59708	0.01016	-10.587	-114.047	-10.587	-72.911	DDAC	0	
08271+2844	6	AB	120.528	0.003	3.34283	0.00015	14.01596	0.00791	16.61598	0.01176	-17.811	-13.164	-20.363	-13.677	CDAB	1	
09040+1349	7		174.780	0.002	3.76571	0.00011	15.99784	0.00542	16.54942	0.00691	-115.579	-22.206	-115.208	-26.764	CAAA	20	
09357+0222	56		167.209	0.010	1.22713	0.00022	16.21239	0.11185	16.65560		-5.101	-68.614	-6.733	-68.581	BAAA	80	
09384+7242	9		81.927	0.000	81.47100	0.00006	15.49111	0.00577	15.23911	0.00356	-55.128	-52.879	-56.645	-66.621	DDAB	0	
09524+4454	34	AB	121.444	0.002	2.88979	0.00012	15.77952	0.01576	16.40319	0.00877	-10.014	47.958	-14.335	45.177	DDAA	0	
10180+0721	11	AC	49.750	0.000	38.13383	0.00017	16.96490		17.15805	0.00889	-32.602	-26.032	-25.923	-30.340	DDAB	0	
10199+1217	12		337.779	0.000	50.23598	0.00019	15.54241	0.00836	16.76349	0.01407	-26.974	-20.274	-26.540	-20.045	ABAC	76	
12068+4450	13	BC	279.543	0.000	84.33665	0.00009	14.83166	0.00712	18.06783	0.01783	-41.500	-8.229	-64.994	-23.140	DDAC	0	WDS M2 in error?
12130+4610	63		83.266	0.013	1.06905	0.00024	14.77219	0.02032	16.52360		24.736	-57.249	27.242	-53.313	DDAA	0	WDS PA in error?
13006+5904	15		236.972	0.001	16.06750	0.00016	15.19067	0.00429	18.06895	0.01964	39.105	71.447	37.432	71.897	BAAB	78	
13104+1427	64		165.234	0.006	2.13540	0.00022	16.43476	0.10013	17.67277	0.16128	-51.756	-2.620	-51.159	-2.489	ABAA	80	
13360+4829	38		73.295	0.001	3.00494	0.00007	13.83375	0.00596	16.14048	0.01206	-134.097	-42.980	-127.551	-47.549	CDAA	1	
14150+0511	39		255.441	0.003	3.51168	0.00017	16.50544	0.01552	16.58284	0.00932	-5.051	-0.327	-5.423	-0.775	DDAB	0	
14376+3652	41		318.364	0.008	1.26588	0.00017	17.13000		16.45300	0.06010	-88.535	-104.037	-91.044	-105.056	ABAA	80	
14460+3329	42		285.532	0.014	0.67790	0.00017	15.94485	0.00876	16.02996	0.07784	29.430	-23.977	29.449	-24.190	AAAA	100	
15409+5253	17		69.046	0.002	2.85461	0.00009	16.21295	0.02449	16.02600	0.00557	18.057	9.444	16.640	8.120	BDAB	4	
16204+5223	45	AC	281.338	0.002	3.20549	0.00009	15.39742	0.00503	16.66030	0.01264	53.459	-17.421	-1.374	-11.831	DDAA	0	
16221+1214	18		311.205	0.000	62.48143	0.00005	8.81819	0.00181	14.45046	0.00479	64.784	-68.144	63.604	-66.828	ABAB	78	
17011+3016	19		330.254	0.000	149.10761	0.00005	14.81652	0.00588	14.66394	0.00993	19.874	-71.172	21.883	-70.069	BAAC	76	
18272+0404	20		126.138	0.000	60.28963	0.00034	13.76584	0.00379	19.13152	0.10610	-248.997	-284.164	-251.366	-286.433	AAAB	97	
21004+3426	1		104.419	0.001	46.44519	0.00057	15.48317	0.00502	19.44530		128.383	109.245	127.185	109.319	AAAB	97	

Counter-Check of WDS Farihi Objects with GAIA DR2

Table 2: 30 FAR objects with PGR assessment and estimated minimum distances between the components

WDS_ID	FAR	C	Plx1	e_Plx1	Plx2	e_Plx2	Min_Dist_AU	Far_MD_AU	Median_AU	Max_Dist_AU	PGRS	P_min	P_med	e_Plx1R	e_Plx2R
01083-3535	2		10.7057	0.0595	10.6278	0.0361	10351		145795	686777	68	748767	39581917	X	OK
01186-2255	24		7.2530	0.2038	5.4608	0.1751	2754941		9338012	16207877	0	3251261359	20289211205	X	X
01481-2533	26		12.5663	0.0530	12.7320	0.0395	184	184	213041	603735	44	1772	69916094	OK	OK
02081+1336	27		4.9783	0.1038	5.6562	0.0653	1387745	238	4966706	9061911	0	1162380240	7870206942	X	X
02107-1507	28		10.5992	0.0663	10.1552	0.0818	3224	294	852339	1820221	0	130176	559502627	X	X
03502-1335	32		14.7511	0.0884	13.6212	0.4774	88	62	1163143	3977230	3	587	891934477	X	X
03591-2312	3		3.0243	0.0726	2.8607	0.1454	389	365	4067618	23672370	3	5453	5833023812	X	X
04202+3336	4		13.8287	0.0653	15.2195	0.1811	573875		1363621	2096296	0	309107218	1132202514	OK	X
06291+4131	5		17.1892	0.0631	6.8860	0.0908	16332922		17955283	19738695	0	46933109142	54096838651	OK	X
08271+2844	6	AB	6.5589	0.1550	6.6245	0.0713	497	604	582290	4656651	18	7888	315931017	X	X
09040+1349	7		17.7470	0.0661	17.8166	0.0771	211		56056	328508	99	2174	9436509	OK	OK
09357+0222	56		7.9095	0.1664	7.5771	0.1203	161	137	1144310	4024451	6	1451	870360135	X	X
09384+7242	9		12.3262	0.0490	7.4810	0.0236	10341538		10838150	11400426	0	23646191793	25369753042	OK	OK
09524+4454	34	AB	16.0519	0.0915	16.1291	0.1193	178	188	92050	536696	86	1689	19857268	X	X
10180+0721	11	AC	5.0748	0.1231	3.8713	0.0969	3515865		12629020	19990522	0	4687397244	31910820179	X	X
10199+1217	12		9.4445	0.0745	9.4716	0.1042	5175		204035	1574695	49	264683	65529994	X	X
12068+4450	13	BC	8.3051	0.0442	5.1134	0.0949	12487301		15503522	19082640	0	31375190996	43403928757	X	X
12130+4610	63		7.8174	0.1483	7.6169	0.1284	134	145	726846	3820816	14	1102	440602755	X	X
13006+5904	15		15.4197	0.0530	15.5909	0.1477	1035		151873	686450	65	23668	42082945	OK	X
13104-1427	64		5.4565	0.1262	5.7514	0.1334	378	288	1946105	7338016	4	5226	1930336375	X	X
13360+4829	38		27.0914	0.0367	27.0585	0.0610	111	100	14997	98255	100	828	1305799	OK	OK
14150-0511	39		3.0784	0.1412	2.9173	0.0809	1151	1360	3912304	20898722	3	27776	5502149031	X	X
14376+3652	41		7.4300	0.1153	7.6277	0.1139	167	201	732083	3319939	13	1539	445372900	X	X
14460+3329	42		4.4038	0.1280	4.4267	0.1383	158	192	1350700	8938710	8	1414	1116148299	X	X
15409+5253	17		5.4955	0.0582	5.5861	0.0275	513		609694	2569226	14	8265	338494621	X	OK
16204+5223	45	AC	11.1969	0.0500	11.5316	0.0445	100584844	503	116246909	135816266	0	717269424766	891159873312	OK	X
16221+1214	18		17.9599	0.0399	17.9485	0.0443	3465		26356	165634	100	145006	3042310	OK	OK
17011+3016	19		20.7275	0.0363	7.2880	0.0259	17916663		18351010	18810481	0	53922395056	55895064142	OK	OK
18272+0404	20		22.4153	0.0864	22.9758	0.2584	2669		224452	678579	41	98024	75607930	OK	X
21004+3426	1		19.0453	0.0446	19.0156	0.3701	2427		143953	1013216	65	84990	38834251	OK	X

Counter-Check of WDS Farihi Objects with GAIA DR2

(Continued from page 531)

pairs thus not especially impressive. The concept of using the distances of the components with their angular separation for a Monte Carlo simulation to get an indication for the likely space distance between the components and in consequence for the minimal orbit period seems a valid one with the caveat that the likelihood for such minimum distances is often extremely small.

Acknowledgements

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

- 2MASS, DSS2 and PS1 images
- Aladin Sky Atlas v10.0
- GAIA DR2 catalog
- CDS VizieR
- Washington Double Star Catalog

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Appendix A

Description of the CPM rating procedure (according Knapp and Nanson 2017 and Knapp 2018):

- Four rating factors are used: Proper motion vector direction, proper motion vector length, size of position error in relation to proper motion vector length and relation separation to proper motion speed
- Proper motion vector direction ratings: "A" for within the error range of identical direction, "B" for similar direction within the double error range, "C" for direction within the triple error range and "D" for outside
- Proper motion vector length ratings: "A" for identical length within the error range, "B" for similar length within the double error range, "C" for length within the triple error range and "D" for outside
- Error size ratings: "A" for error size of less than 5% of the proper motion vector length, "B" for less than 10%, "C" for less than 15% and "D" for a larger error size
- Relation separation to proper motion speed: "A" for less than 100 years, "B" for less than 1000 years, "C" or less than 10000 years and "D" for above

To compensate for the extremely small proper motion GAIA DR2 errors resulting in a worse than "A" rating despite only very small deviations an absolute lower limit is applied regardless of calculated error size:

- Proper motion vector direction: Max. 1   difference for an "A"
- Proper motion vector length: Max. 1% difference for an "A"

The letter based scoring is then transformed into an estimated likelihood for being CPM

Counter-Check of WDS Farihi Objects with GAIA DR2***Description of the PGR assessment procedure:***

- GAIA DR2 data for RA/Dec and Plx are used for a Monte Carlo simulation assuming a normal distribution for these parameters with the given error range as standard deviation. The distance between the components is calculated from the inverted simulated parallax data and the simulated angular separation using the law of cosines

$$c = \sqrt{a^2 - 2ab \cos \gamma + b^2}$$

with a and b = distance vectors for the stars A and B in light years calculated as $(1000/\text{Plx}) \times 3.261631$ and γ = angular separation in degrees calculated as

$$\gamma = \arccos \left[\sin(DE1) \sin(DE2) + \cos(DE1) \cos(DE2) \cos(\text{abs}(RA1 - RA2)) \right]$$

- The potential gravitational relationship score (PGRS) is the percentage of simulation results $< 200,000$ AU (~ 1 parsec) out of the simulation sample with a size of 120,000 corresponding with the likelihood that the real distance is smaller than 200,000 AU
- The smallest, median and largest distance is the smallest, median and largest result of the simulation sample



Double Star Measurements Using a CMOS Camera, Annual Report of 2018

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Abstract: This report shows the results on 213 double star measurements from 2018; minimum separation is 0.43 as (STF1909), maximum separation is 167 as (SMR 40AO). The mean value of all measurements is about 14 as.

213 double stars were measured in 2018. Observations were done with a 12-inch Newtonian telescope in combination with a CMOS QHY5L II Color camera. Reproduction scale is about 0.52" per pixel. In cases of separation < 3" focal length was magnified with different Barlow lenses. As in the previous years, especially double stars with large magnitude differences were of interest (Schlimmer 2017, Schlimmer 2018). Figure 1 shows the 213 measurements sorted by separation. In 162 cases (76%) the separation is smaller or equal than 7.5". Figure 2 shows the differences in magnitudes of the measured double star components. In 100 cases (47%) the difference is more or equal than 2 magnitudes.

Notes to WDS20281+3820 and WDS20282+3821 (TDT2304)

Next to ES 206 are 3 stars in line, TYC3152-00864 -1, TDT2304 and TYC3152-00892-1. Figure 3a shows the stars from Digitized Sky Survey (SIMBAD database), Figure 3b shows the same field from author's observation.

The first of them on left hand side is not of interest. The second star, TDT2304 is also marked as double star in SIMBAD database and in the planetary software Redshift 7, which is used for telescope control. TDT2304 was only observed one time in 1991. Although the star was clearly identified, but relative brightness of companion (12.49 mag), position angle (139 degree) and distance (2.4 as) are different to my observation (199 degree, 5.4 as). The proper motion for primary and secondary star is equal, so the difference of both measurements from 1991 and 2018 can't be clarified.

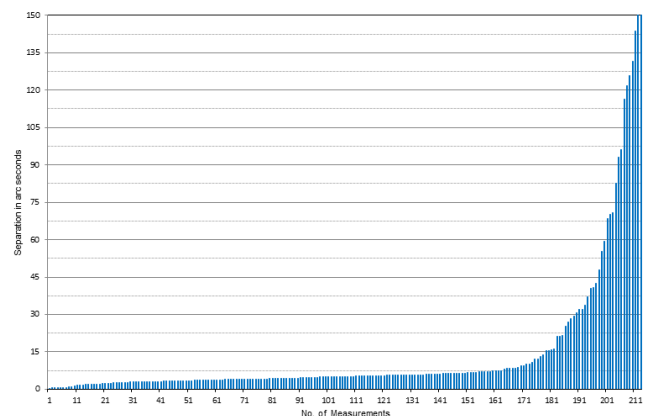


Figure 1. The 213 measurements sorted by separation

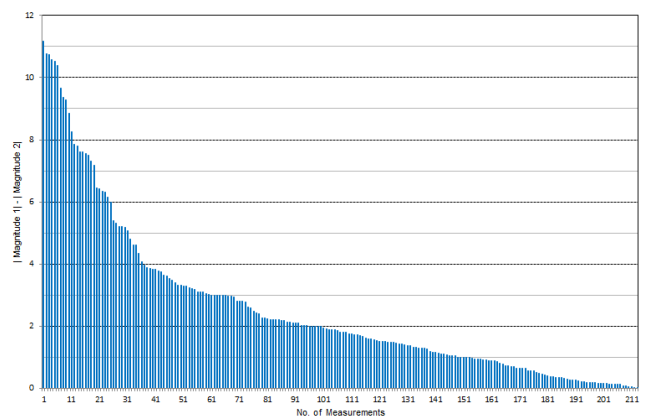


Figure 2. Differences in magnitudes of the measured double star components.

Double Star Measurements Using a CMOS Camera, Annual Report of 2018

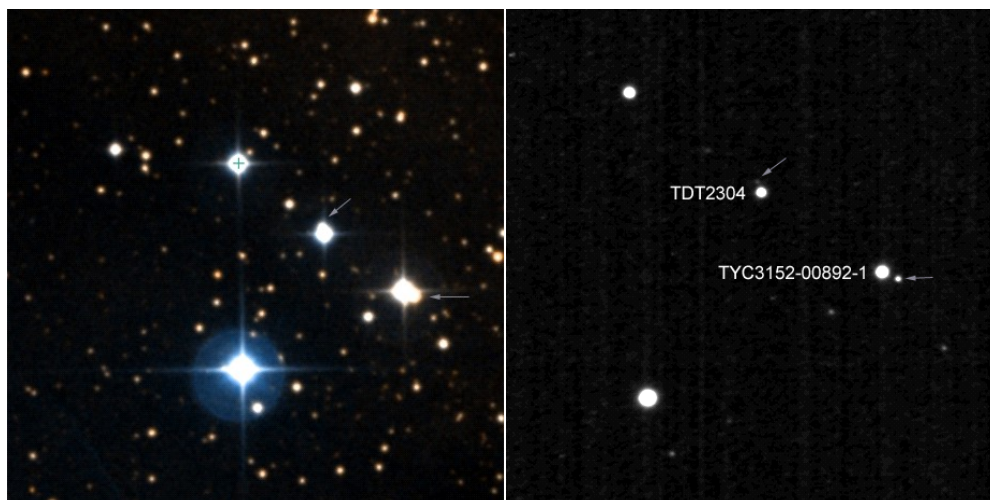


Figure 3a (left). WDS20281+3820 and WDS20282+3821 from Digitized Sky Survey (SIMBAD database, 2018) Figure 3b. WDS20281+3820 and WDS20282+3821 from author

The last star TYC3152-00892-1 on the right hand side looks like an optical double star but isn't yet listed in the WDS catalog or marked as double star in SIMBAD database or in Redshift 7 software. A distance of 8.43" and a position angle of 64.6° were found.

Table 1 shows the measurements of separation and position angle of 213 components from 2018. Brightness and coordinates are taken from Washington Dou-

ble Star catalog (Mason, 2017). Date is given in Besselian years.

Acknowledgements

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

(Text continues on page 543)

Table 1. Measurements of 213 Components from 2018.

RA+DEC	Name	Mags	PA	Sep	Date	N
00286+3905	ES 1939	8.44, 12.4	280.6	6.40	2018.039	1
00530+1806	A 2207	9.19, 12.30	168.3	3.65	2018.039	1
00550+5530	ES 939	10.60, 12.5	343.3	6.44	2018.039	1
01097+5438	ES 156	8.55, 11.8	218.5	5.91	2018.039	1
01180+5355	ES 119AB	8.22, 11.02	115.7	4.97	2018.039	1
01204+5652	ES 1809	9.48, 10.8	119.1	6.03	2018.039	1
01226+1245	BU 1360	9.62, 11.76	23.7	5.65	2018.039	1
01354+4123	ES 1494	10.64, 10.9	7.0	5.64	2018.039	1
01379+2554	A 2007	8.78, 10.45	220.8	4.57	2018.039	1
02473+3835	ES 2083AB	9.79, 11.9	334.8	6.48	2018.039	1
02494+5159	ES 873	9.74, 12.0	99.2	4.82	2018.039	1
02497+5356	ES 120	8.99, 12.60	72.4	4.27	2018.039	1
02497+3721	ES 2553	10.6, 13.9	177.8	6.24	2018.039	1
02511+4807	ES 557	9.58, 12.9	324.2	5.84	2018.039	1
02515+5314	ES 766	9.08, 11.3	302.0	4.46	2018.039	1
03007+5700	KR 15	9.43, 11.54	111.8	4.23	2018.039	1
03082+4057	BU 526AB	2.11, 12.7	155.8	59.36	2018.039	1
03082+4057	BU 526AC	2.11, 12.5	146.7	68.60	2018.039	1
03082+4057	BU 526AD	2.11, 11.47	193.1	82.61	2018.039	1
03082+4057	BU 526BC	12.7, 12.5	103.6	13.66	2018.039	1

Table 1 continues on the next page.

Double Star Measurements Using a CMOS Camera, Annual Report of 2018*Table 1 (continued). Measurements of 213 Components from 2018.*

RA+DEC	Name	Mags	PA	Sep	Date	N
03082+4057	BU 526DE	10.5, 12.5	121.0	10.91	2018.039	1
03212+3019	COU 684	10.29, 12.4	126.5	4.37	2018.039	1
03362+2959	BU 1040	7.66, 11.5	338.1	3.21	2018.039	1
03372+4905	ES 54	9.77, 12.2	250.7	4.59	2018.039	1
03388+5055	ES 953	10.49, 13.6	245.7	4.42	2018.039	1
03416+3942	ES 166	8.95, 12.48	3.1	4.69	2018.039	1
03458+2309	STF 444AB	6.91, 10.09	337.5	3.42	2018.039	1
06106+3132	ES 416	10.00, 12.6	207.0	6.69	2018.266	1
06116+4843	STF 845	6.16, 6.86	357.1	7.55	2018.266	1
06144+5110	STF 865	8.12, 10.26	69.1	5.21	2018.263	1
06295+3414	HDS 885AB	9.32, 12.53	256.1	4.15	2018.263	1
06408+4815	STF 944AB	8.45, 10.17	57.8	6.39	2018.266	1
06431+5004	ES 1076	8.98, 12.76	263.0	5.70	2018.263	1
06469+4825	ES 1237	9.32, 11.5	0.5	5.00	2018.266	1
07007+5456	A 1574	9.72, 12.2	166.9	3.60	2018.263	1
07026+5039	ES 1079AB	8.21, 11.7	323.4	6.16	2018.263	1
07081+5915	A 1325	9.08, 11.3	311.1	2.93	2018.263	1
07324+1822	A 2871	7.98, 11.83	114.8	4.39	2018.266	1
07372+4802	ES 1143	9.03, 12.0	290.0	3.50	2018.263	1
07490+2834	STF1144AB	7.94, 10.33	358.4	8.39	2018.266	1
07523+2842	ES 421	10.00, 13.0	217.9	6.47	2018.279	2
08054+0812	STF1181	8.28, 9.26	140.4	5.20	2018.291	1
08056+2732	STF1177	6.69, 7.41	349.3	3.53	2018.291	1
08058+3435	ES 423	9.3, 11.2	303.9	3.02	2018.291	1
08088+2729	STF1186	7.06, 10.08	211.7	3.28	2018.263	1
08109+4439	A 1744	9.59, 11.5	302.0	3.66	2018.291	1
08131+4133	ES 592	9.23, 10.98	330.9	2.99	2018.291	1
08160+4946	STF1200	9.16, 9.33	181.0	8.39	2018.291	1
08165+0911	BU 1065AB	3.52, 14.3	294.3	29.38	2018.291	1
08165+0911	DAL 42AC	3.68, 14.2	38.5	70.20	2018.291	1
08181+3050	STF1212	8.63, 10.1	241.3	5.40	2018.291	1
08190+4927	HU 1124AB	8.55, 12.3	34.2	6.24	2018.263	1
08201+3219	HU 626	8.72, 12.00	154.1	3.23	2018.263	1
08235+2311	STF1218	9.76, 11.3	268.0	4.06	2018.291	1
08268+2656	STF1223	6.16, 6.21	219.6	5.21	2018.291	1
08298+5112	STF1225	9.60, 9.75	193.3	3.65	2018.291	1
08404+1940	SMR 30AE	6.52, 12.5	155.6	15.87	2018.266	1
08415+0649	A 2963	9.34, 10.86	264.3	3.22	2018.332	1
08447+1809	HJ 457AB	3.94, 12.2	71.1	40.91	2018.266	1
08467+2846	STF1268	4.13, 5.99	306.8	30.84	2018.279	1

Table 1 continues on the next page.

Double Star Measurements Using a CMOS Camera, Annual Report of 2018

Table 1 (continued). Measurements of 213 Components from 2018.

RA+DEC	Name	Mags	PA	Sep	Date	N
08515+1208	STF1287AB	8.28, 10.17	92.8	2.07	2018.291	1
08554+1208	BAR 35	10.21, 13.2	326.0	2.55	2018.291	1
08585+1151	HJ 110	4.25, 11.8	320.8	10.26	2018.279	1
09013+1516	STF1300AB	9.47, 9.73	179.8	4.94	2018.265	2
09051+3931	AG 160	9.97, 9.83	58.8	3.86	2018.332	1
09071+3037	AG 162	9.78, 10.09	106.8	4.09	2018.332	1
09088+1625	HDS1328AB	9.54, 11.78	143.0	4.11	2018.263	1
09268+0105	AG 166	9.1, 11.1	73.5	3.56	2018.332	1
09425+4058	STT 205	7.99, 12.6	202.2	12.02	2018.332	1
09427+4018	ES 301	9.8, 11.8	243.2	5.02	2018.298	2
09564+1040	STF1396AB	8.79, 10.42	131.1	3.94	2018.332	1
10019+4248	A 2141	9.1, 10.5	175.2	5.06	2018.332	1
10170+1007	STF1419	8.87, 9.86	225.8	4.47	2018.332	1
10241+4034	ES 1394	9.00, 10.1	143.6	6.75	2018.340	1
10256+0847	STF1431	7.76, 9.07	76.8	3.22	2018.332	1
10334+0705	A 2767	8.63, 12.28	53.3	5.37	2018.332	1
10339+4158	ES 1396AB	9.91, 13.0	190.2	5.58	2018.340	1
10406+4209	STF1460	8.72, 8.90	161.1	3.80	2018.340	1
10425+0640	LDS2877	9.75, 11.55	273.7	5.58	2018.340	1
10433+0445	STF1466AB	6.23, 7.13	240.5	6.93	2018.340	1
10453+4458	STF1467	8.58, 10.76	288.4	3.94	2018.266	1
10596+2527	AG 342	8.57, 9.22	116.3	5.30	2018.345	1
11004+5237	ES 722	9.95, 11.4	102.9	8.41	2018.345	1
11007+0606	BU 598	4.99, 12.6	219.1	40.32	2018.266	1
11050+0720	KUI 54AB	4.66, 11.0	267.9	4.92	2018.266	1
11080+5249	STF1510	7.65, 9.03	328.1	5.63	2018.345	1
11174+3430	ES 305	10.0, 11.3	31.7	3.90	2018.345	1
11182+3132	STF1523AB	4.33, 4.80	159.5	1.96	2018.347	3
11185+3306	STF1524AB	3.64, 10.1	149.3	7.45	2018.340	1
11256+1627	HJ 4433AB	5.62, 10.84	6.2	55.37	2018.348	1
11268+0301	STF1540AB	6.55, 7.50	150.0	28.37	2018.381	1
11285+0750	WLF 1AB	10.34, 10.51	336.4	116.35	2018.381	1
11291+3920	STF1543AB	5.35, 10.67	354.0	5.07	2018.348	1
11317+1422	STF1547AB	6.33, 9.14	331.5	15.5	2018.381	1 Wolf 401
11329+5525	A 1593	8.95, 10.53	255.4	4.06	2018.348	1
11347+1648	STF1552AB	6.26, 7.31	208.9	3.05	2018.348	1
11385+4405	ES 1153	9.78, 12.74	261.2	5.76	2018.266	1
11396+2657	STF1564	8.81, 9.33	87.4	5.04	2018.348	1
11443+3900	STF1569	8.83, 10.59	322.0	3.61	2018.348	1
11468+5951	KR 40	9.92, 10.64	273.0	3.01	2018.348	1

Table 1 continues on the next page.

Double Star Measurements Using a CMOS Camera, Annual Report of 2018

Table 1 (continued). Measurements of 213 Components from 2018.

RA+DEC	Name	Mags	PA	Sep	Date	N
11527+5647	ES 1826	8.95, 12.8	214.6	5.58	2018.348	1
11578+4518	A 1778	9.6, 11.8	225.1	2.91	2018.266	1
12089+2147	LDS 930AB	9.45, 14.63	39.3	15.54	2018.419	1
12244+2535	STF1639AB	6.74, 7.83	322.8	1.79	2018.419	1
12269+2816	SMR 58	4.4, 12.	206.7	16.12	2018.343	2
12272+2701	STF1643AB	9.03, 9.45	3.7	2.68	2018.419	1
12291+3123	STT 251	8.35, 9.27	54.8	0.67	2018.419	1
12324+1211	LDS 937	11.02, 12.45	122.1	42.33	2018.381	1 Wolf 418
12417-0127	STF1670AB	3.48, 3.53	359.8	2.73	2018.384	2
12481+0327	BU 459	8.06, 11.05	294.3	4.35	2018.381	1
13119+2753	STT 578	4.30, 12.1	179.9	131.51	2018.422	1
14220+5107	A 148	8.32, 8.96	194.1	0.53	2018.419	1
14380+5135	STF1863	7.71, 7.80	63.2	0.62	2018.419	1
14515+4456	STT 287	8.40, 8.62	5.7	0.54	2018.419	1
15038+4739	STF1909	5.20, 6.10	90.7	0.43	2018.503	2
15151+3318	SMR 32AB	12.76, 11.21	335.7	26.86	2018.545	1
15151+3318	SMR 32AC	12.76, 12.90	72.0	36.94	2018.545	1
15151+3318	SMR 32BC	11.21, 12.90	105.8	47.99	2018.545	1
15155+3319	SMR 31AC	3.56, 14.30	4.8	93.19	2018.545	1
15209+1057	HDS2158	9.73, 13.55	201.4	4.48	2018.545	1
15264+4400	STT 296AB	7.83, 9.09	274.1	2.01	2018.586	1
15348+1032	STF1954AB	4.17, 5.16	172.9	3.97	2018.545	1
15348+1032	STF1954CD	13.9, 14.6	341.1	4.03	2018.545	1
15405+1840	A 2076	8.28, 8.44	187.3	0.75	2018.589	1
15498+4431	BU 621	7.94, 9.37	26.5	0.60	2018.589	1
15514+2921	COU 617	9.53, 12.53	98.3	4.72	2018.545	1
15554+2932	HO 399	7.68, 10.49	114.9	3.43	2018.545	1
15568+1229	STF1988	7.59, 7.84	249.2	1.72	2018.534	1
16009+1316	STT 303AB	7.69, 8.06	174.6	1.38	2018.589	1
16030+1359	STF2000	8.42, 9.22	227.8	2.41	2018.540	1
16089+4521	STF2015AB	8.24, 9.52	160.0	3.00	2018.540	1
16124+2626	HO 551	8.01, 12.8	80.2	7.07	2018.545	1
16231+1350	STF2040	8.11, 10.14	313.1	7.08	2018.545	1
16232+2341	J 399	10.1, 12.3	50.7	5.10	2018.545	1
16246+3632	HO 405AB	9.5, 12.5	346.9	4.18	2018.575	1
16246+3632	HO 405AC	9.5, 12.5	339.1	13.02	2018.575	1
16254+1402	BU 625AC	4.58, 11.76	87.3	25.42	2018.575	1
16315+3331	BU 816	7.12, 12.2	220.6	4.87	2018.545	1
16231+1350	STF2040	8.11, 10.14	313.2	7.01	2018.575	1
16254+1718	STF2043	8.03, 11.44	85.2	10.02	2018.594	1

Table 1 continues on the next page.

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Table 1 (continued). Measurements of 213 Components from 2018.

RA+DEC	Name	Mags	PA	Sep	Date	N
16289+1825	STF2052AB	7.69, 7.91	118.3	2.45	2018.594	1
16316+1917	STF2057AB	10.49, 10.63	268.0	5.03	2018.594	1
16317+1919	STF2058AB	10.37, 10.55	352.3	1.80	2018.594	1
16321+4014	ES 1646	10.69, 13.3	120.5	4.63	2018.545	1
16326+4007	STT 313	7.97, 8.31	128.2	0.88	2018.567	2
16442+2331	STF2094AB	7.48, 7.87	76.1	1.01	2018.540	1
16496+1316	STF2103AB	5.93, 10.0	43.1	4.87	2018.575	1
16538+2110	STF2109	7.52, 10.30	312.4	5.88	2018.575	1
16579+4523	ES 1254	10.85, 13.9	133.6	4.41	2018.575	1
16582+2520	STT 320	8.47, 11.79	251.6	5.76	2018.575	1
17010+1636	A 2085AB	7.29, 13.7	353.1	6.26	2018.575	1
17053+5428	STF2130AB	5.66, 5.69	359.6	2.54	2018.540	1
17255+5130	HU 672	9.16, 10.97	58.1	3.96	2018.594	1
17290+5052	STF2180	7.79, 8.06	259.9	2.95	2018.594	1
17386+5546	STF2199	8.03, 8.60	54.7	1.88	2018.540	1
17386+5546	STF2199	8.03, 8.60	53.9	1.95	2018.594	1
17414+2111	STF2195	11.68, 11.75	286.0	21.56	2018.589	1
17416+2111	STF2196	10.2, 12.2	257.3	3.26	2018.589	1
17420+2127	STF2197	10.64, 10.99	356.1	8.05	2018.589	1
18171+4015	STF2304	8.75, 9.75	100.0	5.55	2018.742	1
17541+3928	HLM 9	9.05, 10.85	284.7	5.27	2018.742	1
17566+5129	BU 633AB	2.23, 13.4	152.3	21.08	2018.540	1
17566+5129	BU 633AE	2.23, 11.9	234.8	96.01	2018.540	1
17566+5129	BU 633AF	2.38, 11.67	114.4	125.99	2018.540	1
17566+5129	BU 633AG	2.38, 11.23	27.5	143.60	2018.540	1
18055+0230	STF2272AB	4.22, 6.17	123.7	6.65	2018.534	1
18171+4015	STF2304	8.75, 9.75	69.3	5.18	2018.742	1
18201+2532	STF2309	9.31, 9.95	351.7	3.38	2018.742	1
18210+3630	ES 2110	9.3, 10.8	96.2	6.43	2018.742	1
18438+5654	BU 465	9.2, 11.2	289.1	2.69	2018.742	1
18443+3940	STF2382AB	5.15, 6.10	345.6	2.16	2018.594	1
18443+3940	STF2383CD	5.25, 5.38	75.0	2.40	2018.594	1
19365+2500	STF2548	8.47, 9.85	99.5	9.38	2018.742	1
19435+3450	AG 236AB	9.78, 10.16	148.6	4.21	2018.742	1
19452+2055	STF2577AB	8.43, 9.56	261.8	5.94	2018.742	1
19486+2458	STF2586AB	7.56, 9.28	227.3	3.33	2018.781	1
19503+2240	BU 361AB	9.37, 9.93	348.4	3.57	2018.781	1
19524+2551	STT 388AB	8.32, 8.45	138.3	3.72	2018.781	1
19524+2551	STT 388AC	8.32, 9.49	129.3	31.89	2018.781	1
19552+2230	STF2600	8.75, 9.93	55.0	2.87	2018.781	1

Table 1 concludes on the next page.

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Table 1 (conclusion). Measurements of 213 Components from 2018.

RA+DEC	Name	Mags	PA	Sep	Date	N
19581+5355	ARG 35	9.00, 9.92	227.0	7.42	2018.781	1
20000+1736	SMR 7	10.1, 11.4	264.6	3.60	2018.789	1
20026+2859	ES 496	9.9, 11.0	280.9	2.79	2018.740	1
20030+1528	D 21	8.68, 10.95	210.5	21.30	2018.740	1
20034+1528	STF2618	9.41, 9.77	115.9	5.55	2018.740	1
20104+2532	AG 400	9.72, 11.24	12.3	5.54	2018.789	1
20104+4949	STF2648	8.11, 9.59	117.2	6.71	2018.789	1
20105+4923	ES 1099	10.0, 11.0	185.0	4.61	2018.789	1
20111+4946	ES 2691	9.01, 12.9	313.7	9.53	2018.789	1
20114+2910	A 1200	7.39, 13.7	197.0	5.36	2018.789	1
20117+4943	ES 500	9.97, 10.91	345.3	5.37	2018.789	1
20124+2923	AG 401	9.41, 10.20	305.6	4.02	2018.789	1
20246+3212	AG 254AB	9.13, 10.17	343.0	5.43	2018.805	1
20251+3159	ES 2433	9.13, 10.6	266.8	8.63	2018.805	1
20281+3820	new	10.06, 12	64.6	8.43	2018.805	¹ TYC3152-00892-1
20282+3821	TDT2304	10.47, 12.49	198.5	5.43	2018.805	1 see text
20288+3810	ES 206	9.85, 10.49	124.5	3.95	2018.805	1
20293+3731	WEI 35AB	8.35, 8.81	213.9	4.01	2018.805	1
20293+3731	WEI 35CD	9.40, 10.55	201.5	12.14	2018.805	1
20302+4343	AG 407	9.94, 10.13	230.8	7.02	2018.805	1
20314+4403	ES 1443	9.8, 11.4	303.7	2.49	2018.805	1
20329+3515	ES 2306	9.76, 14.1	328.4	7.39	2018.805	1
20336+4719	ES 665	9.91, 10.80	129.0	5.72	2018.805	1
20356+3510	STF2702	8.70, 8.99	208.4	3.14	2018.805	1
20377+3322	STF2705AB	7.48, 8.54	266.5	3.09	2018.805	1
20456+3043	STF2726	4.33, 9.53	72.4	5.90	2018.781	1
21069+3845	STF2758AB	5.20, 6.05	153.1	31.96	2018.773	2
21069+3845	STF2758AH	5.35, 9.97	266.5	121.80	2018.740	1
21069+3845	SMR 1AI	5.35, 10.74	237.2	33.71	2018.740	1
21069+3845	SMR 40AO	5.35, 12.65	278.8	166.91	2018.740	1
21069+3845	SMR 40AP	5.35, 12.84	287.7	158.72	2018.740	1
21069+3845	SMR 40AQ	5.35, 13.19	306.7	70.98	2018.740	1
21110+0933	STF2765AB	8.47, 8.50	81.7	2.85	2018.789	1

Double Star Measurements Using a CMOS Camera, Annual Report of 2018

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

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Jonckheere Double Star Photometry – Part XIV

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Abstract: If any double star discoverer is in urgent need of photometry then it is Jonckheere. There are over 3000 Jonckheere objects listed in the WDS catalog and a good part of them with magnitudes obviously far too bright. This report covers the Jonckheere objects in the constellations Pup, Pyx and partly Mon. One image per object was taken with V-filter to allow for visual magnitude measurement by differential photometry. All objects were additionally checked for potential gravitational relationship.

Preamble: This report in no way intends to belittle the work of Jonckheere – on the contrary: He was obviously a very dedicated and able double star observer fighting with a lot of obstacles up to equipment destroyed in war. It seems that the basic double star parameters, RA/Dec coordinates and separation as well as position angle were his main concern and the estimation of magnitudes was rather a side aspect to him. The often crass over estimation of magnitudes may also be a side effect of his obviously extraordinary eyesight.

1. Introduction

As follow up to the reports on J-objects photometry beginning with Knapp/Nanson 2016 this report covers the J-objects in the constellations Pup, Pyx and to some degree in Mon. The plan to cover the rest of J-objects in Mon after the Mon I report in JDSO 14/4 failed due to repeated weather conditions unsuitable for imaging. Imaging sessions were rescheduled several times and images from seemingly successful sessions had to be dismissed due to poor quality. Usually even low quality images provide still useful differential photometry results but in this case I got the impression that the existing material provides mostly Vmag measurements of little value – so only a fraction of the existing Mon image material was used for this report restricted to objects with current WDS Vmag values obviously in very great need of improvement.

The prospect to wait for another year to get a chance to complete the necessary imaging sessions in Mon led to the decision to quit the plan of covering all J-objects by constellations. For this reason this is my last report on Jonckheere objects photometry covering so far in total about 30% of all J-objects - but I intend to

continue with photometry reports for WDS objects in need of precise Vmag photometry regardless of discoverer.

2. Results of Photometry and Catalog Checking

For all selected J-objects one single image was taken with iTelescope iT24 or iT27 with V-filter and 3s exposure time. Astrometry results based on one single image have to be taken with caution beyond the given error range but this aspect seems less significant for the V-filter measured magnitudes as a magnitude error of ~0.1 or even a bit larger seems negligible in comparison with those of many Jonckheere objects, which often have given magnitude errors in the range of up to 2 or more magnitudes.

The images were plate solved with Astrometrica using the URAT1 or UCAC4 catalog with reference stars in the Vmag range of 8.5 to 14.5 giving not only RA/Dec coordinates but also photometry results for all reference stars used including an average dVmag error. The J-objects were then located in the center of the image and astrometry/photometry was then done by the rather comfortable Astrometrica procedure with point

Jonckheere Double Star Photometry – Part XIV

and click at the components delivering RA/Dec coordinates and Vmag measurements based on all reference stars used for plate solving.

The photometry measurement results are given in Table 1 below with the following structure:

- J#: number of J-object
- C: components
- RA/Dec: positions for primary and secondary in HH MM SS.SSS/DD MM SS.SS format
- dRA/dDec: plate solving errors for RA and Dec in arcseconds
- Sep: calculated separation in arcseconds using the given positions
- e_Sep: separation error
- PA: calculated position angle in degrees using the given positions
- e_PA: position angle error
- Mag: Vmags for both components measured by differential photometry
- e_Mag: magnitude error
- SNR: signal to noise ratio of the image used for plate solving
- dVmag: plate solving error in Vmag
- Date: Julian observation epoch
- Notes: telescope used with exposure time or reference to additional comments listed below Table 1

All listed objects were additionally checked for being potential physical by cross-matching with GAIA DR2 using proper motion and parallax data if available. The results are listed in table 2 below with the following structure:

- J#: number of J-object
- C: components (AB if blank)
- PA: calculated epoch 2015.5 position angle in degrees
- e_PA: position angle error
- Sep: calculated epoch 2015.5 separation in arcseconds
- e_Sep: separation error
- Vest1/2: estimated Vmags from GAIA G/R/B-mags (see Appendix)
- e_Vest1/2: estimated Vmag error
- pmRA/DE/1/2: GAIA DR2 proper motion values
- CPMS: Common proper motion score (estimated likelihood for common proper motion)
- Plx1/2: GAIA DR2 parallax values
- e_Plx1/2: GAIA DR2 parallax error values
- PGRS: potential gravitational relationship score (estimated likelihood for potential gravitational

relationship (see Appendix)

Summary

Most of the listed J-objects in Pup, Mon and Pyx show the expected magnitude difference larger than 0.5 compared with the WDS catalog data. Only 4 of these objects qualify as solid or at least good CPM candidates based on a rating scheme using GAIA DR2 proper motion data if available for both components with the caveat of rather small proper motion values for most of them. Finally only J 2638BC has parallax and angular separation values allowing for a 100% likelihood for a distance between the components of less than 200,000 AU suggesting potential gravitational relationship between the components which means WDS notes code “T”. While several of the other listed objects have very similar parallax values for both components these parallax values are far too small to allow for a noticeable likelihood for being physical as the possible distances between the components increases in such cases exponentially even within a small parallax error range (Knapp 2019). So all of the listed objects with exception of J 2638BC are most likely optical pairs.

A comparison of estimated Vmags calculated from GAIA DR2 G/R/B-mags with the results from differential photometry shows a mean difference of -0.090 and a standard deviation of 0.236 – this indicates a small bias for Vmag estimations slightly fainter compared to differential photometry measurement results with a standard deviation mostly caused by the average plate solving dVmag errors. The correlation coefficient between measured and estimated Vmags with 0.986 allows for the conclusion that the estimated Vmags are a useful substitute in cases of lacking Vmag measurements.

Acknowledgements:

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- Washington Double Star Catalog
- CDS VizieR
- GAIA DR2 catalog
- DSS and 2MASS images
- Aladin Sky Atlas v10.0
- iTelescope
- iT24: 610mm CDK with 3962mm focal length. CCD: FLI PL09000. Resolution 0.62 arcsec/pixel. V-filter. Located in Auberry, California. Elevation 1405m
- iT27: 700mm CDK with 4531mm focal length. CCD: FLI PL09000. Resolution 0.53 arcsec/

(Text continues on page 552)

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Table 1: Photometry results for measured J objects

J#	C	RA	Dec	dRA	dDec	Sep	e_Sep	PA	e_PA	Mag	e_Mag	SNR	dVmag	Date	Notes
1493	A	07 32 05.119	-12 16 24.94	0.06	0.06	6.72113	0.08485	75.525	0.723	10.884	0.080	144.68	0.08	2016.10968	iT27 1x3s
	B	07 32 05.563	-12 16 23.26									127.00			
1497	A	07 33 53.509	-11 23 21.95	0.07	0.07	8.27451	0.09899	58.933	0.685	11.029	0.081	97.31	0.08	2016.10968	iT27 1x3s
	B	07 33 53.991	-11 23 17.68									63.84			
1505	A	07 56 39.184	-23 30 09.83	0.06	0.07	6.33445	0.09220	258.342	0.834	9.763	0.080	241.59	0.08	2016.10972	iT27 1x3s
	B	07 56 38.733	-23 30 11.11									91.11			
1506	A	07 58 54.559	-24 38 57.27	0.07	0.07	7.17486	0.09899	86.004	0.790	10.732	0.080	177.66	0.08	2016.10972	iT27 1x3s
	B	07 58 55.084	-24 38 56.77									115.69			
1507	A	08 02 32.861	-24 47 07.28	0.07	0.07	7.10971	0.09899	323.026	0.798	9.654	0.080	198.26	0.08	2016.10971	iT27 1x3s
	B	08 02 32.547	-24 47 01.60									130.56			
1509	A	08 11 07.464	-21 07 09.93	0.07	0.08	6.01542	0.10630	266.283	1.012	11.210	0.081	96.89	0.08	2016.10968	iT27 1x3s
	B	08 11 07.035	-21 07 10.32									47.05			
1509	A	08 11 07.464	-21 07 09.93	0.07	0.08	16.40414	0.10630	337.269	0.371	11.210	0.081	96.89	0.08	2016.10968	iT27 1x3s
	C	08 11 07.011	-21 06 54.80									58.96			
1510	A	08 13 12.062	-12 27 06.67	0.06	0.07	3.54930	0.09220	262.065	1.488	10.465	0.071	92.60	0.07	2016.10964	iT27 1x3s
	B	08 13 11.822	-12 27 07.16									52.21			
1519	A	08 24 40.788	-18 31 20.28	0.07	0.08	5.79216	0.10630	321.771	1.051	10.883	0.081	102.47	0.08	2016.10965	iT27 1x3s
	B	08 24 40.536	-18 31 15.73									87.89			
2041	A	07 35 45.384	-11 43 12.59	0.08	0.08	6.27458	0.11314	336.405	1.033	11.383	0.081	96.40	0.08	2016.10968	iT27 1x3s
	B	07 35 45.213	-11 43 06.84									73.70			
2041	A	07 35 45.384	-11 43 12.59	0.08	0.08	17.66848	0.11314	306.099	0.367	11.383	0.081	96.40	0.08	2016.10968	iT27 1x3s
	C	07 35 44.412	-11 43 02.18									59.03			
2048	A	07 51 46.554	-16 44 15.95	0.07	0.07	5.38181	0.09899	350.630	1.054	11.212	0.071	127.57	0.07	2016.10969	iT27 1x3s
	B	07 51 46.493	-16 44 10.64									83.91			
2049	A	07 57 46.742	-16 00 19.79	0.07	0.08	5.38238	0.10630	194.109	1.131	12.873	0.082	60.67	0.08	2016.10967	iT27 1x3s
	B	07 57 46.651	-16 00 25.01									30.33			
2049	A	07 57 46.742	-16 00 19.79	0.07	0.08	9.45945	0.10630	270.787	0.644	12.873	0.082	60.67	0.08	2016.10967	iT27 1x3s
	C	07 57 46.086	-16 00 19.66									30.45			
2050	A	07 58 20.815	-11 57 56.96	0.08	0.08	6.95458	0.11314	333.428	0.932	10.966	0.071	121.22	0.07	2016.10966	iT27 1x3s
	B	07 58 20.603	-11 57 50.74									54.07			
2052	A	08 05 26.049	-12 34 35.86	0.06	0.07	4.18656	0.09220	183.207	1.262	11.169	0.071	105.87	0.07	2016.10965	iT27 1x3s
	B	08 05 26.033	-12 34 40.04									48.78			
2052	A	08 05 26.049	-12 34 35.86	0.06	0.07	20.52456	0.09220	228.500	0.257	11.169	0.071	105.87	0.07	2016.10965	iT27 1x3s
	C	08 05 24.999	-12 34 49.46									38.57			

Table 1 continues on the next page.

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Table 1 (continued): Photometry results for measured J objects

J#	C	RA	Dec	dRA	dDec	Sep	e_Sep	PA	e_PA	Mag	e_Mag	SNR	dVmag	Date	Notes
2053	A	08 05 23.270	-16 53 20.29	0.08	0.08	4.80075	0.11314	31.347	1.350	12.307	0.082	59.94	0.08	2016.10967	iT27 1x3s
	B	08 05 23.444	-16 53 16.19							13.188	0.084	44.17			
2056	A	08 17 43.301	-12 14 30.20	0.07	0.07	3.52435	0.09899	22.757	1.609	13.113	0.074	42.67	0.07	2016.10964	iT27 1x3s
	B	08 17 43.394	-12 14 26.95							12.883	0.074	47.08			
2058	A	08 24 36.981	-17 30 38.60	0.06	0.08	6.76697	0.10000	328.666	0.847	13.146	0.087	31.86	0.08	2016.10965	iT27 1x3s
	B	08 24 36.735	-17 30 32.82							13.402	0.088	29.73			
2479	A	07 31 03.427	-12 25 33.69	0.07	0.07	5.93364	0.09899	274.156	0.956	13.037	0.072	59.51	0.07	2016.10969	iT27 1x3s
	B	07 31 03.023	-12 25 33.26							13.326	0.073	48.04			
2480	A	07 31 08.805	-12 27 04.55	0.06	0.07	7.65420	0.09220	237.966	0.690	10.594	0.070	134.48	0.07	2016.10970	iT27 1x3s
	B	07 31 08.362	-12 27 08.61							13.024	0.073	52.89			
2480	A	07 31 08.805	-12 27 04.55	0.06	0.07	5.65756	0.09220	315.859	0.934	10.594	0.070	134.48	0.07	2016.10970	iT27 1x3s
	B	07 31 08.536	-12 27 00.49							13.396	0.078	30.37			
2481	A	07 32 51.789	-12 33 02.38	0.07	0.07	5.36726	0.09899	256.203	1.057	12.313	0.071	76.23	0.07	2016.10969	iT27 1x3s
	B	07 32 51.433	-12 33 03.66							13.621	0.075	38.07			
2481	A	07 32 51.789	-12 33 02.38	0.07	0.07	10.70234	0.09899	72.209	0.530	12.313	0.071	76.23	0.07	2016.10969	iT27 1x3s
	B	07 32 52.485	-12 32 59.11							13.744	0.080	27.75			
2489	A	07 53 08.249	-12 47 58.25	0.07	0.08	3.84023	0.10630	21.214	1.586	10.366	0.081	74.06	0.08	2016.10966	iT27 1x3s
	B	07 53 08.344	-12 47 54.67							11.398	0.084	40.83			
2490	A	07 56 47.471	-18 40 23.37	0.07	0.07	5.88230	0.09899	189.595	0.964	11.219	0.070	130.86	0.07	2016.10970	iT27 1x3s
	B	07 56 47.402	-18 40 29.17							11.979	0.071	88.37			
2633	A	07 30 40.661	-14 03 48.25	0.07	0.07	5.59821	0.09899	293.810	1.013	11.380	0.071	128.75	0.07	2016.10970	iT27 1x3s
	B	07 30 40.309	-14 03 45.99							11.699	0.071	102.43			
2635	A	07 51 45.238	-18 09 28.26	0.06	0.07	9.03741	0.09220	287.716	0.584	10.380	0.080	168.74	0.08	2016.10970	iT27 1x3s
	B	07 51 44.634	-18 09 25.51							12.476	0.081	70.85			
2638	A	08 10 21.327	-18 11 30.71	0.07	0.07	79.64168	0.09899	98.179	0.071	8.366	0.070	235.37	0.07	2016.10966	iT27 1x3s
	B	08 10 26.859	-18 11 42.04							12.856	0.017	64.72			
2638	B	08 10 26.859	-18 11 42.04	0.07	0.07	4.99265	0.09899	6.556	1.136	12.856	0.072	64.72	0.07	2016.10966	iT27 1x3s
	C	08 10 26.899	-18 11 37.08							13.634	0.074	44.67			
2639	A	08 10 25.117	-18 46 03.68	0.07	0.08	49.74785	0.10630	268.802	0.122	10.410	0.080	132.45	0.08	2016.10967	iT27 1x3s
	B	08 10 21.615	-18 46 04.72							13.147	0.083	45.71			
2639	B	08 10 21.615	-18 46 04.72	0.07	0.08	5.90116	0.10630	65.470	1.032	13.147	0.023	45.71	0.08	2016.10967	iT27 1x3s
	C	08 10 21.993	-18 46 02.27							13.357	0.083	46.02			
2838	A	07 35 09.517	-16 37 56.77	0.07	0.07	6.89338	0.09899	57.832	0.823	10.710	0.070	151.90	0.07	2016.10971	iT27 1x3s
	B	07 35 09.923	-16 37 53.10							12.320	0.071	81.35			

Table 1 continues on the next page.

Jonckheere Double Star Photometry – Part XIV

Table 1 (continued): Photometry results for measured J objects

J#	C	RA	Dec	dRA	dDec	Sep	e_Sep	PA	e_PA	Mag	e_Mag	SNR	dVmag	Date	Notes
2875	A	08 15 20.453	-11 26 44.54	0.07	0.08	5.82608	0.10630	207.666	1.045	11.174	0.070	129.66	0.07	2016.10963	iT27 1x3s
	B	08 15 20.269	-11 26 49.70							12.581	0.072	57.59			
2876	A	08 21 12.707	-13 33 48.14	0.07	0.08	5.23582	0.10630	153.360	1.163	11.098	0.070	133.68	0.07	2016.12070	iT27 1x3s
	B	08 21 12.868	-13 33 52.82							11.758	0.071	95.20			
2876	A	08 21 12.707	-13 33 48.14	0.07	0.08	13.37432	0.10630	37.080	0.455	11.098	0.070	133.68	0.07	2016.12070	iT27 1x3s
	C	08 21 13.260	-13 33 37.47							11.388	0.070	129.04			
261	A	06 27 20.546	07 47 50.55	0.10	0.10	3.31243	0.14142	102.023	2.445	10.674	0.151	55.02	0.15	2019.00576	iT24 1x3s. SNR B <20
	B	06 27 20.764	07 47 49.86							12.145	0.179	10.54			
277	A	06 57 11.929	06 55 49.97	0.11	0.10	7.53963	0.14866	6.578	1.130	9.861	0.131	81.31	0.13	2019.00580	iT24 1x3s. SNR B <20
	B	06 57 11.987	06 55 57.46							13.501	0.155	12.44			
356	A	07 00 03.959	-03 18 25.52	0.08	0.11	6.50076	0.13601	219.308	1.199	9.671	0.161	54.94	0.16	2018.94546	iT24 1x3s
	B	07 00 03.684	-03 18 30.55							11.705	0.169	19.71			
664	A	06 34 36.771	05 35 41.56	0.11	0.11	3.61360	0.15556	202.851	2.465	12.659	0.129	15.68	0.11	2018.94552	iT24 1x3s. SNR A and B <20
	B	06 34 36.677	05 35 38.23							13.240	0.151	10.05			
1486		07 07 22.652	-08 46 45.07	0.10	0.08	9.45001	0.12806	179.910	0.776	11.720	0.144	32.01	0.14	2018.95094	iT24 1x3s
		07 07 22.653	-08 46 54.52							11.902	0.145	27.32			
1974	A	06 48 44.430	08 44 27.04	0.08	0.10	3.88570	0.12806	40.152	1.888	13.075	0.210	8.32	0.17	2018.95101	iT24 1x3s. SNR A <10 and B <5
	B	06 48 44.599	08 44 30.01							14.470	0.310	3.70			
1981	A	06 57 06.795	06 32 08.80	0.09	0.11	7.62369	0.14213	112.683	1.068	12.607	0.157	23.46	0.15	2018.95102	iT24 1x3s. SNR B <20
	B	06 57 07.267	06 32 05.86							12.752	0.162	17.02			
1982	A			0.09	0.10		0.13454						0.15	2018.95103	1)
	B														
2460	A	07 16 51.154	-05 10 40.70	0.11	0.12	6.01024	0.16279	333.741	1.551	12.147	0.092	23.55	0.08	2019.07389	iT24 1x3s
	B	07 16 50.976	-05 10 35.31							12.306	0.090	25.55			
2485	A	07 41 36.573	-10 43 28.06	0.11	0.11	6.61999	0.15556	131.772	1.346	12.788	0.079	29.95	0.07	2019.07392	iT24 1x3s. SNR B <20
	B	07 41 36.908	-10 43 32.47							13.879	0.109	12.54			
2618	A	06 57 55.178	05 44 53.11	0.10	0.10	6.33283	0.14142	292.858	1.279	10.603	0.081	82.55	0.08	2019.07396	iT24 1x3s
	B	06 57 54.787	05 44 55.57							11.914	0.086	34.04			
2632	A	07 27 09.724	-05 34 40.78	0.10	0.09	34.07951	0.13454	71.754	0.226	9.307	0.071	80.18	0.07	2019.07397	iT24 1x3s
	B	07 27 11.892	-05 34 30.11							12.639	0.085	21.92			
2751	A	06 44 43.895	02 23 10.55	0.10	0.10	5.65217	0.14142	136.207	1.433	12.581	0.086	34.00	0.08	2019.07400	iT24 1x3s. SNR B <20
	B	06 44 44.156	02 23 06.47							13.884	0.116	12.47			

Table 1 concludes on the next page.

Table 1 (conclusion): Photometry results for measured J objects

J#	C	RA	Dec	dRA	dDec	Sep	e_Sep	PA	e_PA	Mag	e_Mag	SNR	dVmag	Date	Notes
2778	A	07 05 30.154	05 22 25.41	0.12	0.08	5.82443	0.14422	308.553	1.418	10.720	0.121	68.71	0.12	2019.14769	2)
	B	07 05 29.849	05 22 29.04							11.494	0.124	35.87			
2811	A	07 20 51.278	-01 31 22.54	0.10	0.10	7.45939	0.14142	156.295	1.086	11.371	0.151	55.23	0.15	2019.14773	iT24 1x3s
	B	07 20 51.478	-01 31 29.37							13.371	0.159	20.18			
2824	A	07 28 00.425	-04 45 01.25	0.11	0.09	5.38758	0.14213	99.940	1.511	11.196	0.153	34.36	0.15	2019.14776	iT24 1x3s. SNR B <10
	B	07 28 00.780	-04 45 02.18							13.427	0.261	4.59			
1522	A	08 28 34.969	-19 08 45.47	0.07	0.09	8.79439	0.11402	10.397	0.743	10.917	0.061	120.67	0.06	2016.12343	iT27 1x3s
	B	08 28 35.081	-19 08 36.82							11.903	0.061	90.88			
1524	A	08 31 12.586	-19 36 42.58	0.05	0.08	6.07998	0.09434	318.165	0.889	11.596	0.082	64.10	0.08	2016.12341	iT27 1x3s
	B	08 31 12.299	-19 36 38.05							11.652	0.082	62.91			
1524	A	08 31 12.586	-19 36 42.58	0.05	0.08	13.05790	0.09434	218.636	0.414	11.596	0.082	64.10	0.08	2016.12341	iT27 1x3s
	C	08 31 12.009	-19 36 52.78							13.489	0.087	30.16			
1526	A	08 35 08.573	-29 21 27.31	0.08	0.08	7.36512	0.11314	357.864	0.880	11.586	0.071	95.09	0.07	2016.12344	iT27 1x3s
	B	08 35 08.552	-29 21 19.95							12.153	0.072	71.51			
1527	A	08 35 57.718	-20 04 50.85	0.07	0.08	6.63478	0.10630	334.331	0.918	8.818	0.071	126.44	0.07	2016.12341	iT27 1x3s
	B	08 35 57.514	-20 04 44.87							10.821	0.072	72.55			
1529	A	08 39 30.343	-28 52 18.54	0.09	0.08	8.28491	0.12042	130.585	0.833	11.672	0.071	74.82	0.07	2016.12343	iT27 1x3s
	B	08 39 30.822	-28 52 23.93							12.113	0.072	63.00			
1531	A	08 45 39.380	-21 23 22.13	0.07	0.08	7.82122	0.10630	14.267	0.779	10.567	0.070	152.43	0.07	2016.12343	iT27 1x3s
	B	08 45 39.518	-21 23 14.55							10.883	0.070	139.55			
1532	A	08 49 33.845	-20 55 39.53	0.07	0.08	10.18146	0.10630	197.126	0.598	11.757	0.071	92.98	0.07	2016.12342	iT27 1x3s
	B	08 49 33.631	-20 55 49.26							12.322	0.071	77.99			
1541	A	09 09 42.714	-20 41 43.12	0.07	0.07	7.17334	0.09899	289.462	0.791	10.899	0.071	124.47	0.07	2016.12340	iT27 1x3s
	B	09 09 42.232	-20 41 40.73							12.235	0.071	75.21			
2061	A	08 39 57.204	-18 03 21.09	0.07	0.08	5.54347	0.10630	29.600	1.099	12.369	0.072	58.29	0.07	2016.12341	iT27 1x3s
	B	08 39 57.396	-18 03 16.27							13.603	0.081	26.60			
2645	A	08 41 45.359	-20 18 43.88	0.08	0.08	6.98177	0.11314	306.880	0.928	11.343	0.071	114.52	0.07	2016.12342	iT27 1x3s
	B	08 41 44.962	-20 18 39.69							11.810	0.071	98.03			

- Notes:
1. J 1982: iT24 1x3s. No resolution of neither A nor B - faintest resolved star in this image is 13.9mag, thus both components have to be fainter than 14mag corresponding also with estimated Vmags from GAIA G/B/R values (see Table 2)

2. J 2778: iT24 1x3s. WDS position wrong. J 2778 is ident with AHD 36

Jonckheere Double Star Photometry – Part XIV

Table 2: Gaia DR2 Cross-Match Results for Listed J Objects

J#	C	PA	e_PA	Sep	e_Sep	Vest1	e_Vest1	Vest2	e_Vest2	pmRA1	pmDE1	pmRA2	pmDE2	CPMS	Plx1	e_Plx1	Plx2	e_Plx2	PGRS
1493		75.439	0.001	6.73305	0.00007	11.031	0.001	11.221	0.001	10.500	-27.317	11.159	-27.787	39	3.7112	0.0552	3.6657	0.0408	12
1497		58.790	0.001	8.18258	0.00009	11.038	0.003	12.381	0.002	-3.917	0.530	-3.218	-1.515	0	0.4533	0.0498	1.3275	0.0709	0
1505		258.140	0.000	6.34048	0.00004	10.088	0.001	11.981	0.007	17.164	-18.819	16.820	-21.315	0	5.2322	0.0323	5.3051	0.0336	14
1506		85.909	0.000	7.17996	0.00005	11.025	0.001	11.930	0.002	-4.902	7.626	-4.980	7.648	97	0.5349	0.0307	0.5498	0.0328	1
1507		323.099	0.000	7.10507	0.00005	10.054	0.002	11.135	0.002	-1.317	-0.477	-5.959	3.092	0	1.1838	0.0372	0.9852	0.0402	0
1509		265.280	0.001	5.99852	0.00007	11.243	0.002	12.377	0.004	-8.644	0.001	-8.395	-0.009	39	1.3906	0.0619	1.3398	0.0349	2
1509	AC	337.555	0.000	16.34125	0.00006	11.243	0.002	12.681	0.001	-8.644	0.001	-1.293	-0.498	0	1.3906	0.0619	0.6224	0.0323	0
1510		261.969	0.002	3.64123	0.00011	10.677	0.002	11.248	0.031	-2.378	0.785	-2.157	1.085	0	0.9369	0.0378	0.9995	0.0652	1
1519		321.691	0.000	5.87758	0.00005	11.040	0.001	11.284	0.001	7.817	-24.734	6.404	-25.987	0	3.6020	0.0316	3.5998	0.0270	24
2041		336.423	0.001	6.26336	0.00008	11.406	0.002	11.988	0.002	-7.360	3.873	-11.490	11.035	0	1.6066	0.0451	1.0423	0.0626	0
2041	AC	306.165	0.000	17.77356	0.00007	11.406	0.002	12.483	0.002	-7.360	3.873	-2.224	0.967	0	1.6066	0.0451	0.3213	0.0496	0
2048		350.367	0.001	5.37883	0.00005	11.418	0.001	11.860	0.002	2.243	1.434	-0.718	3.271	0	0.4947	0.0343	0.3272	0.0392	0
2049		194.268	0.000	5.36746	0.00003	12.837	0.001	13.801	0.002	-20.016	1.805	-4.545	2.961	0	2.7672	0.0329	0.7571	0.0217	0
2049	AC	270.560	0.000	9.50887	0.00003	12.837	0.001	14.180	0.002	-20.016	1.805	3.492	0.036	0	2.7672	0.0329	1.3860	0.0238	0
2050		333.661	0.001	6.99831	0.00007	11.102	0.002	12.935	0.003	-14.353	2.505	-13.194	2.982	1	3.7928	0.0354	3.8837	0.0620	7
2052		182.979	0.001	4.19698	0.00004	11.221	0.001	12.730	0.002	-19.444	7.481	-19.378	7.180	97	3.2664	0.0396	3.3253	0.0438	9
2052	AC	228.325	0.000	20.49247	0.00004	11.221	0.001	13.846	0.003	-19.444	7.481	-1.532	0.779	0	3.2664	0.0396	0.2852	0.0303	0
2053		33.078	0.000	4.91482	0.00003	12.214	0.001	13.054	0.001	3.548	-4.882	-2.069	-4.535	0	1.2152	0.0297	1.0855	0.0264	0
2056		24.053	0.001	3.56004	0.00005	12.945	0.002	12.749	0.002	-2.735	2.386	-3.046	2.517	4	1.5391	0.0351	1.5487	0.0359	4
2058		329.361	0.000	6.85339	0.00005	13.034	0.002	13.213	0.001	0.015	-0.754	0.236	-0.629	0	0.5069	0.0351	0.5664	0.0251	0
2479		274.046	0.000	5.94477	0.00005	13.033	0.001	13.191	0.002	-3.384	-6.614	-2.938	-0.285	0	1.6214	0.0374	0.3881	0.0276	0
2480		238.017	0.001	7.71328	0.00011	10.668	0.002	12.928	0.003	-5.692	0.203	-6.331	0.610	0	1.2923	0.0442	1.2901	0.0926	1
2480	AC	315.767	0.001	5.75591	0.00006	10.668	0.002	13.255	0.004	-5.692	0.203	1.269	-10.957	0	1.2923	0.0442	3.0337	0.0359	0
2481		255.864	0.000	5.36742	0.00005	12.305	0.002	13.599	0.002	-0.876	2.089	-1.328	1.253	0	0.5954	0.0385	0.5686	0.0246	0
2481	AC	72.125	0.000	10.74123	0.00005	12.305	0.002	13.633	0.001	-0.876	2.089	-3.271	1.580	0	0.5954	0.0385	0.2807	0.0242	0
2489		23.617	0.001	3.74778	0.00007	10.393	0.001	11.281	0.006	-4.785	0.167	-4.922	2.132	0	0.7582	0.0533	0.8806	0.0555	0
2490		189.588	0.001	5.88094	0.00005	11.422	0.010	12.051	0.002	-3.343	1.825	-0.065	2.106	0	0.3285	0.0505	0.7422	0.0380	0
2633		293.620	0.001	5.62429	0.00007	11.569	0.002	11.856	0.002	-4.844	2.752	6.498	-8.238	0	0.8925	0.0421	0.7566	0.0486	0
2635		289.828	0.000	8.82956	0.00006	10.495	0.001	12.387	0.002	-4.218	-0.470	-4.055	-0.461	5	1.1381	0.0524	1.1261	0.0417	1
2638		98.176	0.000	79.65792	0.00005	9.043	0.002	12.853	0.002	-6.138	-0.169	20.864	-12.585	0	1.5812	0.0462	25.8263	0.0337	0

Table 2 concludes on the next page.

Jonckheere Double Star Photometry – Part XIV

Table 2 (conclusion): Gaia DR2 Cross-Match Results for Listed J Objects

J#	C	PA	e_PA	Sep	e_Sep	Vest1	e_Vest1	Vest2	e_Vest2	pmRA1	pmDE1	pmRA2	pmDE2	CPMS	Plx1	e_Plx1	Plx2	e_Plx2	PGRS
2639		268.845	0.000	49.70631	0.00004	10.683	0.001	13.094	0.003	-6.742	2.270	-6.178	3.335	1	1.0811	0.0348	2.4756	0.0308	0
2639	BC	65.596	0.000	5.83782	0.00003	13.094	0.003	13.302	0.003	-6.178	3.335	-5.845	2.639	0	2.4756	0.0308	2.6000	0.0201	0
2638		58.011	0.001	6.91249	0.00007	10.766	0.002	12.368	0.002	-0.662	-0.832	-2.847	0.570	0	0.7051	0.0593	0.6333	0.0420	0
2875		208.384	0.001	5.71969	0.00005	11.273	0.001	12.581	0.001	-3.980	-0.057	-16.947	-2.689	0	1.4208	0.0391	3.2662	0.0338	0
2876		153.196	0.001	5.24668	0.00008	11.205	0.001	11.899	0.003	-21.613	-1.566	-4.243	2.974	0	3.4896	0.0424	0.3979	0.0452	0
2876	AC	37.270	0.000	13.37154	0.00006	11.205	0.001	11.550	0.002	-21.613	-1.566	-20.818	-19.869	0	3.4896	0.0424	6.2456	0.0338	0
261		102.101	0.001	3.90096	0.00009	11.481	0.003	12.589	0.004	1.993	4.084	-0.845	-6.519	0	2.9185	0.0569	1.3040	0.0609	0
277		6.854	0.001	7.70996	0.00010	10.911	0.003	13.535	0.002	-2.933	-2.438	-4.341	-3.922	1	0.8999	0.0590	0.5614	0.0575	0
356		217.500	0.001	6.57617	0.00011	10.792	0.003	12.338	0.007	2.030	-3.308	-0.091	-0.108	0	0.8565	0.0819	0.4766	0.0812	0
664		194.880	0.001	3.40434	0.00006	12.686	0.002	13.254	0.004	6.456	-5.526	1.122	-4.969	0	1.8879	0.0449	1.3399	0.0330	0
1486		180.241	0.001	9.21598	0.00008	11.970	0.002	12.252	0.002	-2.284	-0.688	-17.916	-51.279	0	0.7393	0.0537	2.8149	0.0492	0
1974		53.657	0.001	3.92146	0.00005	13.150	0.002	14.205	0.003	-0.357	0.048	-0.574	0.391	0	0.8213	0.0244	0.7185	0.0296	0
1981		115.050	0.001	7.76494	0.00007	12.966	0.002	12.871	0.002	-1.151	-3.418	-1.347	-0.401	0	0.4325	0.0397	0.2790	0.0391	0
1982		238.915	0.001	4.90824	0.00005	14.120	0.005	14.189	0.002	-0.354	-1.833	-0.384	-1.499	0	0.3031	0.0254	0.2508	0.0269	0
2460		336.122	0.001	5.91347	0.00008	12.269	0.001	12.275	0.002	-1.644	4.394	-1.075	1.062	0	2.3518	0.0484	1.2476	0.0461	0
2485		127.485	0.000	6.55021	0.00004	12.717	0.002	13.630	0.002	-1.740	1.375	3.604	-10.424	0	0.1545	0.0361	1.3976	0.0229	0
2618		292.240	0.002	6.38459	0.00028	10.883	0.002	11.878	0.004	-4.303	-1.956	-3.700	-1.562	5	1.0333	0.2420	0.9108	0.0574	0
2632		72.116	0.000	33.81145	0.00006	9.641	0.002	12.627	0.002	-4.879	3.228	-1.007	-0.227	0	1.7447	0.0486	0.8064	0.0371	0
2751		126.517	0.001	5.70216	0.00006	12.528	0.002	13.664	0.003	3.675	-6.044	3.764	-6.168	39	1.0571	0.0414	1.0956	0.0261	1
2778		308.916	0.001	5.83739	0.00008	11.431	0.003	12.046	0.003	-10.264	27.785	-9.859	28.077	97	2.6479	0.0405	2.6627	0.0413	9
2811		163.302	0.000	7.48701	0.00005	11.864	0.002	13.564	0.002	-1.506	3.043	-0.747	-1.367	0	0.9646	0.0496	1.1279	0.0310	0
2824		95.458	0.001	5.26691	0.00006	11.761	0.002	12.979	0.002	3.913	-1.435	-1.300	-2.232	0	1.1100	0.0379	0.4102	0.0366	0
1522		10.240	0.001	8.88254	0.00009	10.979	0.003	11.887	0.002	-5.260	0.837	-5.093	0.619	4	0.9687	0.0720	0.9056	0.0534	1
1524		317.702	0.001	6.22694	0.00006	11.711	0.001	11.779	0.002	-3.337	1.890	-3.657	5.264	0	0.6377	0.0334	0.2823	0.0382	0
1524	AC	219.752	0.000	13.23908	0.00005	11.711	0.001	13.335	0.001	-3.337	1.890	-5.161	1.626	0	0.6377	0.0334	0.6151	0.0228	1
1526		355.768	0.000	7.43479	0.00004	11.779	0.001	12.208	0.001	-0.365	1.147	1.473	-11.099	0	0.7302	0.0305	1.3633	0.0303	0
1527		334.307	0.002	6.43792	0.00026	9.184	0.002	10.918	0.001	-5.483	26.665	-3.059	27.131	1	1.5718	0.0669	2.6627	0.2083	0
1529		131.510	0.001	8.43129	0.00008	11.685	0.001	12.106	0.001	-8.726	4.635	-8.435	5.193	1	1.4067	0.0862	1.2547	0.0283	0
1531		14.671	0.001	7.97205	0.00008	10.713	0.001	11.001	0.001	-9.476	4.842	-9.618	4.831	78	1.8788	0.0438	1.8672	0.0511	4
1532		196.795	0.000	10.12412	0.00007	11.873	0.002	12.454	0.001	-5.342	-2.956	-5.872	5.614	0	2.2060	0.0377	0.5450	0.0452	0
1541		290.444	0.000	7.06738	0.00006	10.998	0.001	12.175	0.002	-11.002	3.604	-12.106	2.974	0	1.6073	0.0464	1.6029	0.0407	3
2061		29.156	0.001	5.70365	0.00005	12.353	0.002	13.410	0.002	-7.643	7.778	-6.638	8.175	0	1.0595	0.0456	1.0370	0.0251	1
2645		306.128	0.000	7.01379	0.00006	11.446	0.002	11.853	0.002	-4.924	-0.045	-5.613	0.232	1	1.3754	0.0400	1.3676	0.0314	3

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(Continued from page 545)

pixel. V-filter. Located in Siding Spring, Australia. Elevation 1122m

- Astrometrica v4.10.0.427
- URAT1 and UCAC4 catalog
- MaxIm DL6 v6.08

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Appendix

Description of the CPM rating procedure (according Knapp and Nanson 2017 and Knapp 2018)

- Four rating factors are used: Proper motion vector direction, proper motion vector length, size of position error in relation to proper motion vector length and relation separation to proper motion speed
- Proper motion vector direction ratings: “A” for within the error range of identical direction, “B” for similar direction within the double error range, “C” for direction within the triple error range and “D” for outside
- Proper motion vector length ratings: “A” for identical length within the error range, “B” for similar length within the double error range, “C” for length within the triple error range and “D” for outside
- Error size ratings: “A” for error size of less than 5% of the proper motion vector length, “B” for less than 10%, “C” for less than 15% and “D” for a larger error size
- Relation separation to proper motion speed: “A” for less than 100 years, “B” for less than 1000 years, “C” or less than 10000 years and “D” for above

To compensate for the extremely small proper motion GAIA DR2 errors resulting in a worse than “A” rating despite only very small deviations an absolute lower limit is applied regardless of calculated error size:

- Proper motion vector direction: Max. 1° difference for an “A”
- Proper motion vector length: Max. 1% difference for an “A”

The letter based scoring is then transformed into an estimated probability and a verbal assessment for being CPM

Description of the PGR assessment procedure (according to Knapp 2019)

- - GAIA DR2 data for RA/Dec and Plx are used for a Monte Carlo simulation assuming a normal distribution for these parameters with the given error range as standard deviation. The distance between the components is calculated from the inverted simulated parallax data and the simulated angular separation using the law of cosine

$$\sqrt{a^2 + b^2 - 2ab \cos \gamma}$$

with a and b = distance vectors for the stars A and B in lightyears calculated as $(1000/\text{Plx}) \cdot 3.261631$ and γ = angular separation in degrees calculated as

$$\gamma = \arccos \left[\sin(DE1) \sin(DE2) + \cos(DE1) \cos(DE2) \cos(\text{abs}(RA1 - RA2)) \right]$$

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- The potential gravitational relationship score (PGRS) is the percentage of simulation results <200,000 AU (~1 parsec) out of the simulation sample with a size of 120,000 corresponding with the likelihood that the real distance is smaller than 200,000 AU
- The smallest, median and largest distance is the smallest, median and largest result of the simulation sample
- The smallest/median/largest distance is also used as estimation for the minimum value for the semi-major axis of a potential orbit allowing for the calculation of a smallest/median/largest possible orbit period assuming zero inclination and in total double Sun mass

Estimation of visual magnitudes (according Knapp and Nanson 2018):

The estimation of the visual magnitudes is based on GAIA DR2 G/B/R-mags using the formula

$$V_{est} = 3.9379083526304 + 0.269235360436179 * Gmag^{1.36701081887491} - 0.123879978164097 * [Gmag - Rmag] - 0.943379695375539 * [Gmag - Bmag]$$

with a regression coefficient of 0.999 and a standard deviation of 0.064 derived by statistical analysis using nonlinear regression with the UBVRI catalogs of Landolt&Clem (VizieR II/183A, J/AJ/146/88 and J/AJ/152/91) after eliminating a few outliers due to questionable cross-match results with GAIA DR2. This estimation formula shares the photometry caveats of GAIA DR2 for very bright (<10Gmag) and very faint (>18Gmag) objects according to Evans et al. 2018 and Riello et al. 2018. In case of missing GAIA DR2 Bmag and Rmag data, the visual magnitude was estimated with an average delta of +0.318 to Gmag.



TYC 0152-00753-1 Duplicity Discovery from Occultation by the Asteroid (392) Wilhelmina

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Abstract: During the occultation of TYC 0152-00753-1 by the asteroid (392) Wilhelmina observed on 2018 January 29 in Argentina, evidence of a double star was found – a close component with separation of 3 ± 2 mas, position angle 3 ± 10 deg and magnitude difference of 0.7 ± 0.3 .

Introduction

On 2018 January 29 the main belt asteroid (392) Wilhelmina occulted the star TYC 152-00753-1 (UCAC4 461-023559). This event was predicted by Steve Preston on behalf of the International Occultation Timing Association during routine prediction of asteroid occultations of bright stars (Preston, 2018). (392) Wilhelmina has mean diameter $D = 60 \pm 6$ km (Ali-Lagoa *et al.*, 2018). According to the JPL Horizon System, at the moment of the occultation its apparent angular diameter was $\delta = 0.043''$ and its magnitude was $M_{\text{ast}} = 14.17$. The maximum predicted duration was 7.0 s (see Figure 1 for the predicted trajectory of the shadow and the circumstances of the event).

The star TYC 152-00753-1 (HD 49203) is listed in the Tycho-2 catalog as an 8.46 VT-mag star. The Gaia DR2 catalog (Gaia Collaboration *et al.*, 2016, 2018) records this star under the identifier 3126362567994357376, with $G\text{-Mag} = 8.4265 \pm 0.0012$. This star is not listed in the Washington Double Star (WDS) catalog, and it was not observed during an occultation before the event reported in the present work (Herald *et al.*, 2018).

Observation

The occultation was observed in Argentina in two different sites, in the cities of Alta Italia and General Pico, province of La Pampa. The position of each observing station, the names of the observers and the details of the equipment used are displayed in the Table 1.

In General Pico the observation was carried out with a QHY5L-II-M camera which was set to take a sequence of images with a cycle of 0.1 s and negligible read-out time. The initial time of each exposure was recorded in the header of the FITS images and was calibrated by the software *Dimension4*, which uses a Network Time Protocol. Inspection of the acquired data shows, nonetheless, that there were periods (which could last for up to 2 s) during which no image was recorded; this was possibly caused by a computer memory conflict. Moreover, the times listed in the FITS headers suggest that the cycle was not constant during observation, as the time interval between images could vary by about 20% of the exposure time. In our opinion this apparent irregularity in the cycle does not mean an oscillation in the exposure time itself, as the fluxes of the stars in the field did not vary abnormally during the ob-

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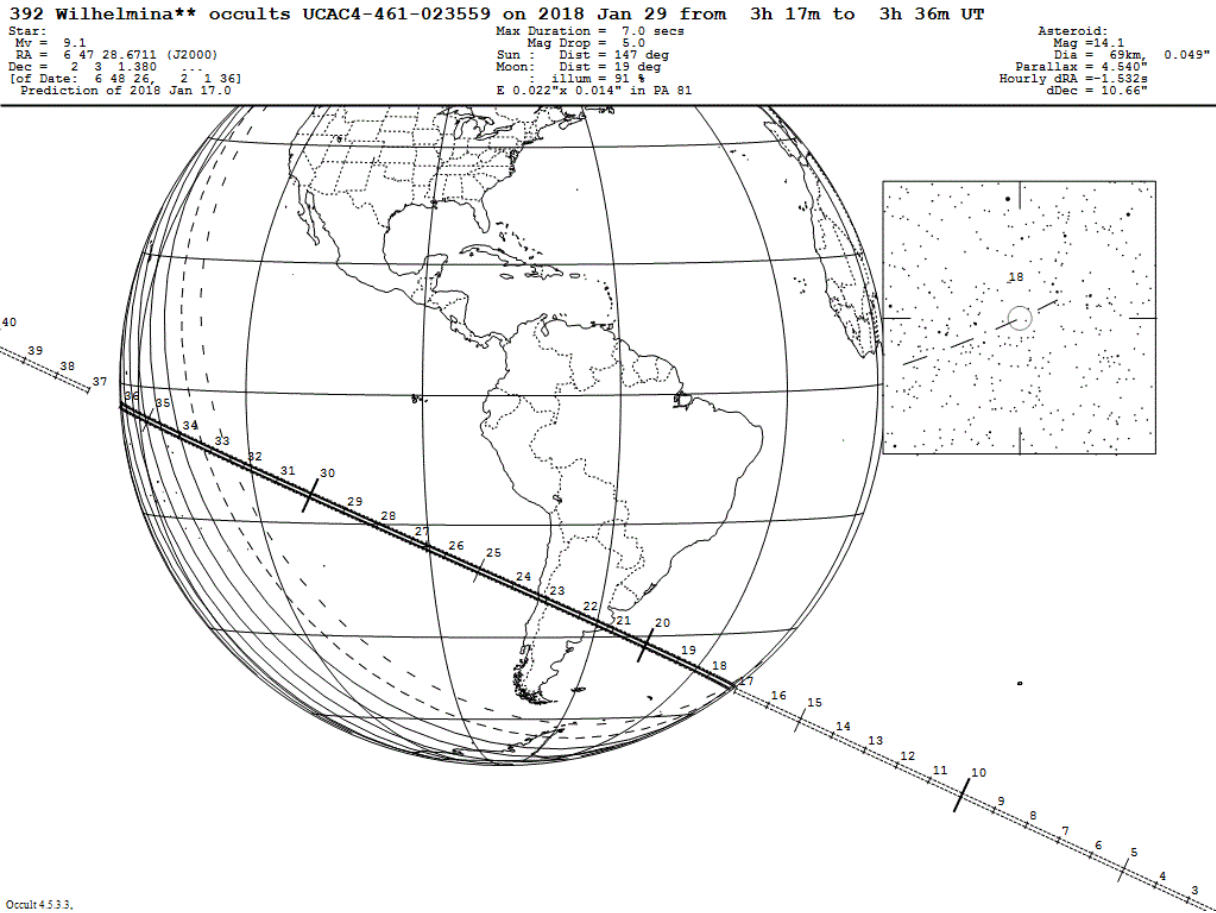


Figure 1: Predicted path and occultation details (Preston, 2018).

servation. Indeed, before the occultation the flux oscillation spans an interval of about 6% of the average flux. Hence, in our analysis we consider that the aforementioned variation in the cycle is due to the synchronization between *Dimension4* and the capture software. Accordingly, we assume an *a priori* uncertainty of 0.02 s on the times reported in the FITS header.

The sequence of images obtained by Wilberger at General Pico was analyzed using the Tangra software (Pavlov, 2018) to produce a light curve (Figure 2). The

main feature of the resultant light curve is the presence of two flux drops during the disappearance of the star. The short step event lasted for 0.29 ± 0.02 s and it is evidence of the duplicity of the star. Unfortunately, it was not possible to verify the occurrence of the secondary event during the reappearance, inasmuch as it happened during a gap of 2.17 s when no image was taken (see Figure 2), a result of the aforementioned memory conflict. It is also important to point out that the remaining flux when both stars were occulted is compatible to a

Table 1: Observation sites, observers and equipment

Site	Longitude Latitude Elevation	Telescope: aperture, type, f-ratio Camera Observing method	Observer
General Pico	63°44'34.2" W 35°40'01.2" S 141 m	20 cm, Newtonian, f/5 QHY5L-II-M Sequential images	A. J. Wilberger
Alta Italia	64°06'53.0" W 35°19'57.0" S 167 m	20 cm, Newtonian, f/5 Meade DSI I CCD drift-scan	J. Spagnotto

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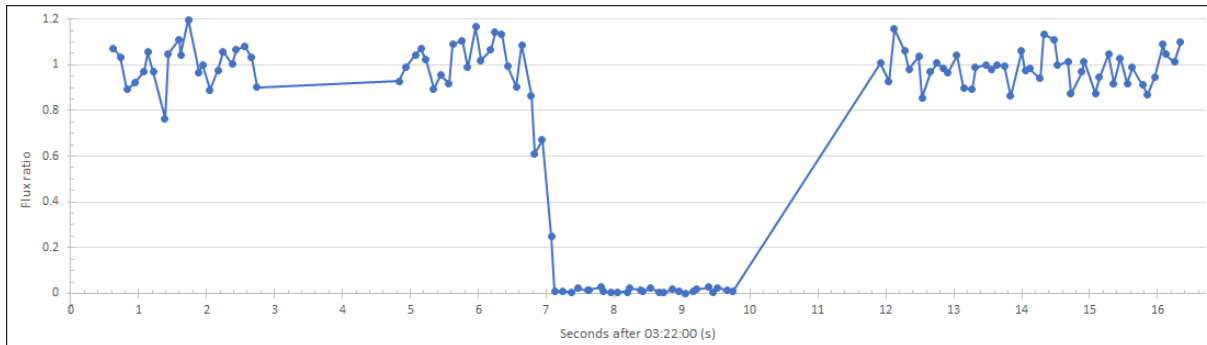


Figure 2. Combined star plus asteroid light curve after 03:22:00, in General Pico. The light curve was normalized to the average flux corresponding to the period in which both stars were visible.

magnitude variation of 5 ± 2 with respect to the initial (combined) magnitude, in agreement to the predicted variation.

Observation at Alta Italia was carried out by the drift-scan technique. A single exposure of 40 s was taken, during which the target drifted through the field since the clock-driven mechanism had been turned off. The light curve resultant from the drift-scan image obtained by Spagnotto is depicted in Figure 3. It is, actually, an intensity profile, from which the background average before and after the occultation has been subtracted. From the flux during the occultation it follows that the presence of a non-occulted companion at most 3 magnitudes fainter is ruled out. In addition, the profile shows no clear evidence of a secondary event. However, the variation of flux for each event was gradual, spanning about 7 pixels and yielding a smooth profile. This feature is typical in this technique and it is consequence of the smearing of the star light among more than one pixel. The effect of this moving distribution of flux, when suddenly switched off due to the occultation, is a smooth pattern, like the one in Figure 3. A secondary occultation event would be easily detectable in the “light curve” if it happened with a large separation with respect to the time scale associated to this

smooth flux drop. On the other hand, if the step event is very short, then its signature may be hidden in this gradual variation. In particular, for the event under discussion the velocity of the star in the field was 9.78 pixel/s, which means that a secondary event of 0.3 s – like the one observed in General Pico – would increase the gradual dimming of the star by about 3 pixels, which may have been in the limit of detectability. During the disappearance one can note that there are two consecutive pixels with a somewhat similar flux, which may indicate a very short step event. The reappearance occurred more smoothly, which could be justified by an even shorter step.

The times of the contacts in both light curves were determined with the R-OTE software (Anderson, 2013) and the results are displayed in Table 2. Since the first star occulted is fainter than the second one, we identify them by the labels B and A, respectively.

Double star analysis

From the two flux drops h_1 and h_2 in the light curve obtained in General Pico it is possible to determine the difference of magnitude between the stars, which is given by

$$\Delta\text{mag} = 2.5 \log_{10} (h_1/h_2).$$

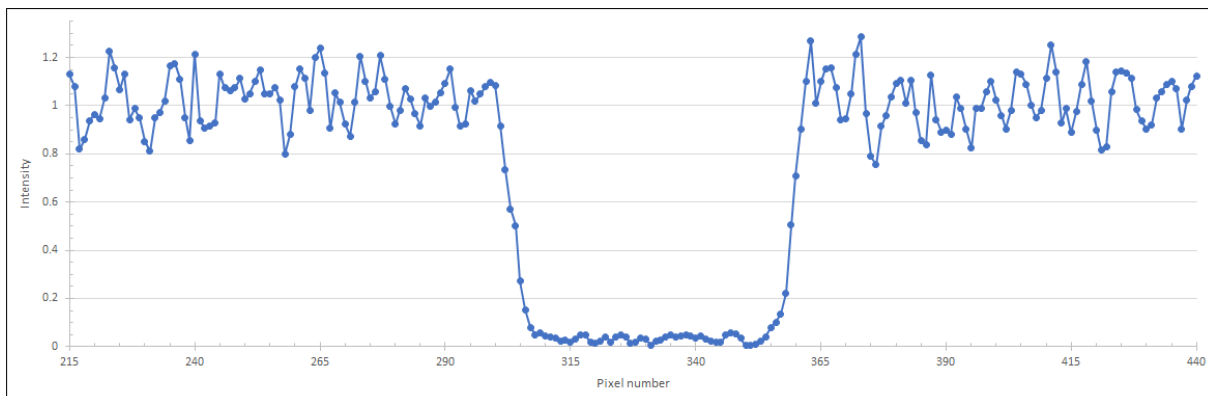


Figure 3: Normalized intensity profile from the drift-scan image in Alta Italia.

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Table 2. Times of the Observed Events.

Event	Time (UT)	
	General Pico	Alta Italia
Start of observation	03 ^h 18 ^m 00 ^s .28	03 ^h 21 ^m 51 ^s .0 ± 0.5 s
Star B disappears	03 ^h 22 ^m 06 ^s .82 ± 0.02 s	03 ^h 22 ^m 09 ^s .4 ± 0.5 s
Star A disappears	03 ^h 22 ^m 07 ^s .11 ± 0.02 s	
Stars A and B reappear	03 ^h 22 ^m 11 ^s ± 1 s	03 ^h 22 ^m 14 ^s .9 ± 0.5 s
End of observation	03 ^h 28 ^m 00 ^s .40	03 ^h 22 ^m 31 ^s .0 ± 0.5 s

Here h_1 refers to drop caused by the first occultation and h_2 is related to the second one. It is clear that the fainter star was occulted first, as $h_1 < h_2$. It follows that the magnitude difference of the observed pair is $\Delta\text{mag} = 0.7 \pm 0.3$. Hence, considering the combined G-magnitude 8.4265 ± 0.0012 (Gaia DR2 catalog), which is similar to the visual magnitude, it follows that $M_A = 8.9 \pm 0.2$ and $M_B = 9.6 \pm 0.2$.

For the derivation of the position angle and separation we applied the method discussed in (Herald et al., 2010) and used the software Occult, version 4.6.5.1 (Herald, 2019). A solution for the asteroid elliptical profile at the moment of the occultation and the double star is defined by seven parameters. Since the images obtained in Alta Italia suggest that the secondary star was occulted in this station too, and in view of the discussion in the preceding section, we can set the events for the B star as occurring almost simultaneously to the A component, with a relative uncertainty of 0.15 s. Therefore, the four chords determine eight points in the celestial plane, allowing a single best-fit solution for the free parameters.

However, as the uncertainty in the reappearances in General Pico are very large, we omitted one of the points in the process of finding the best-fit solution, which is depicted in the Figure 4a. It turns out that there is a huge uncertainty especially for the parameters of the asteroid, because of the small number of chords and the large time error bars. In fact, we recall that with only two chords by the same star it is not even possible to find a unique solution to an elliptical profile.

For the above reason, in order to derive the uncer-

tainties, we also considered solutions constrained by the oblateness of the ellipse, in view of the fact that rotation curves for (392) Wilhelmina suggest that this asteroid might have an apparent oblateness of at most 0.52, assuming an elliptical profile (Herald, 2019). Then, by varying the double star parameters and those of the asteroid, subjected by the maximum axis ratio constraint, we derived the parameters and uncertainties presented in Table 3. Some of the possible solutions are depicted in the Figure 4. It is possible to verify that more oblate solutions yield a pair with larger separation (Figure 4b) and smaller position angle (PA). On the other hand, less oblate solutions are compatible with small separations and larger PA (Figure 4c).

In what concerns the asteroid solutions, we point out that the uncertainties for the major axis and orientation are not symmetric. For the former, its lower bound is set by the length of the largest chord (Alta Italia), which is equivalent to 56 ± 3 km. For the latter, the decrease of the ellipse's position angle can only be accounted for by increasing its oblateness, hence the lower bound comes from the constraint $\epsilon < 0.52$, where the apparent oblateness ϵ is defined by

$$\epsilon = 1 - b/a,$$

with a and b being, respectively, the apparent major and minor axis.

Conclusions

The results of the occultation of TYC 0152-00753-1 by the asteroid (392) Wilhelmina on 2018 January 29 presented in this work suggest that this star is a close

Table 3: Results of limb and double star fitting to the observed data.

Asteroid parameters			Double star parameters	
Major axis (km)	Minor axis (km)	Orientation (deg)	Separation (mas)	Position angle (deg)
63 $^{+20}_{-5}$	42 ± 11	320 $^{+30}_{-15}$	3 ± 2	3 ± 10

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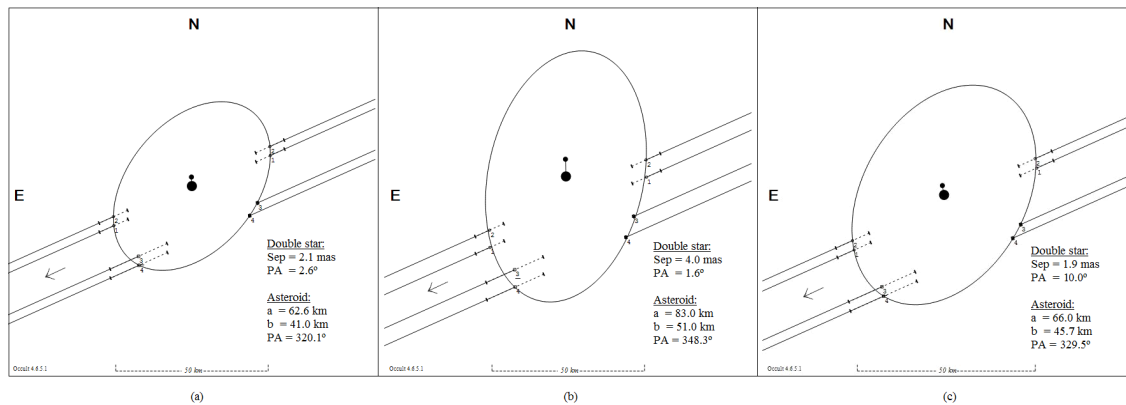


Figure 4. Limb and double star fits for the occultation chords using the times from Table 2. Chords 1 and 2 are from Alta Italia, and 3 and 4 from General Pico. The arrows indicate the direction of motion. 4a: Best fit for the asteroid and double star.

double, with separation on the order of only a few milliarcseconds. Based on the data presented in this work, the double star characteristics of the pair is:

- Star Tycho-2 0152-00753-1.
- UCAC4 461-023559.
- Gaia DR2 3126362567994357376.
- Coordinates (J2000) [Gaia DR2].
RA 06h47m28.669s Dec +02°03'01.365"
- V-Mag A 8.9 ± 0.2 .
- V-Mag B 9.6 ± 0.2 .
- Separation 3 ± 2 mas.
- Position Angle 3 ± 10 deg.

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Recovery of Proposed Young Star Binaries in Gaia DR2

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Abstract: A recent paper (Bowler et al. 2019) reports the identification of 221 young star binaries in the solar neighborhood. A common proper motion assessment scheme was used for the purpose to declare a pair as likely binary based on the comparison of multi-epoch images if available. For the remainder of the reported pairs without multi-epoch images available the authors assumed that the vast majority are likely physical binaries due to the low density of comparably bright stars nearby.

This report counterchecks this proposition using GAIA DR2 parallax data allowing to check the likelihood for gravitational relationship by calculating the spatial distance between the components of the proposed binaries. Only 49% of the 221 proposed young star binaries could be successfully cross-matched with GAIA DR2 and only 25% got confirmed as likely binaries but most of these are already known doubles listed in the WDS catalog while the confirmation rate drops dramatically for pairs considered as newly detected. The overall low recovery rate suggests an issue with the GAIA DR2 object coverage in the solar neighborhood.

1. Introduction

Bowler et al. reported in a recent (May 2019) paper the identification of over 200 late-type ($\approx K7$ – $M5$ means late-K and M dwarfs) star binaries in the solar neighborhood selected primarily on the basis of activity indicators from GALEX (Galaxy Evolution Explorer) and ROSAT (All-Sky Survey Bright Source Catalogue). The identification of pairs as “young binaries in the solar neighborhood” is the declared focus of the report and not the detection of new binaries although it is claimed that the vast majority of the reported pairs are new discoveries. This project was started before the release of GAIA DR2 so the meanwhile available parallax values were not used for binary assessment. Instead multi-epoch images were used to test whether components of pairs are likely background stars or physically bound by means of common proper motion. For a good part of the reported pairs no multi-epoch images were available but these were assessed as being physical due to the low density of comparably bright stars nearby. This report checks this proposition using GAIA DR2 parallax data allowing to assess the likelihood for gravitational relationship by calculating the spatial distance

between the components.

2. Cross-matching of the Reported Objects with Gaia DR2 and WDS

As the number of objects is reasonable small I decided to follow a simple manual approach with entering the given 2MASS ID into CDS Aladin using DSS or 2MASS images, loading the GAIA DR2 and WDS catalog data for the given view and selecting then the components matching with separation and position angle given by Bowler et al. 2019 in table 4. In some cases with missing proper motion data for one component it was necessary to move the Aladin epoch slider to 2015/16 to identify the correct match.

For the pairs with successful GAIA DR2 matches for both components the data was copied into a spreadsheet calculating epoch 2015.5 separation and position angle, assessing the likelihood for common proper motion in case of existing proper motion values for both components and calculating the spatial distance between the components in case of existing parallax values for both components. To cover the full error range of the given GAIA DR2 values for RA, Dec and Plx a Monte Carlo simulation with a sample size of 120,000

Recovery of Proposed Young Star Binaries in Gaia DR2

was used to identify significant properties of the resulting distribution of the distance between the components. The smallest possible distance from the simulation was used as most optimistic estimation for the minimum value for the semi-major axis of a potential orbit allowing for the calculation of a smallest possible orbit period assuming zero inclination and in total double Sun mass (approach similar to Farihi et al. 2010). As the likelihood for such a small spatial distance is usually extremely small the same calculation was also done for the median simulation distance to get a more realistic view. Both values should be taken with caution:

- To take the currently measured spatial distance between the components as value for the semi-major axis ignores the influence of eccentricity as it is most likely that the observed separation for high eccentricity pairs is near apastron so the “real” semi-major axis would tend to be somewhat smaller
- The assumed mass of the components as equal to one Sun mass might be considered as very upper limit for the Bowler et al. 2019 objects as these are declared as mostly red dwarfs so an average of 1/3 Sun mass would be more reasonable.

In the few cases with luminosity values available for both components like for example SKF 220 it would have been possible to estimate the mass with the rough relationship $L \sim M^{3.5}$ and with effective temperature values given this estimation might even be enhanced with a stellar class specific luminosity relationship. But the huge spread caused especially by the error range of the DR2 parallax values most likely overcompensates these simplifications anyway.

The results of the matching process including CPM assessment are given in Table 1.

All deltas between the position angle of reported and successfully cross-matched pairs are (with the exception of one case with an exceptionally large GAIA DR2 position error) below 7 degrees and the deltas between the separations of reported and cross-matched pairs are all less than 10%. For about 10% of the successfully cross-matched pairs the visual magnitude of the secondary is more than 1 magnitude fainter than the 15mag threshold declared by the authors.

From 83 pairs reported as likely CPM pairs 43 were successfully cross-matched with GAIA DR2 – the CPM assessment based on GAIA DR2 data confirms common proper motion for only 9 objects. This disappointing result might at least for a part be explained by the high precision of the GAIA DR2 values giving little room for interpretations within the given error range.

The results of the assessment for potential gravita-

tional relationship (PGR) are given in Table 2.

The assessment for potential gravitational relationship is based on the results of a Monte Carlo simulation using the GAIA DR2 values as mean values of normal distributions with the given error ranges as standard deviations (see Appendix for details). In many cases the spread caused by large relative parallax errors is huge and requires even with a sample size of 120,000 repeated simulation runs to cover the full range of possible results.

55 out of 94 objects suitable for potential gravitational relationship (PGR) assessment remained with a likelihood >50% inside the threshold of ~1 parsec distance between the components suggesting these might be likely bound by gravitation with the rest of 40 objects assessed as likely rather optical pairs. This means that 58% of the reported and successfully cross-matched objects are indeed likely binaries with two third of these even with 100% likelihood below the applied threshold of ~1 parsec. On the other side 42% of the reported objects are likely optical pairs with half of these with 100% likelihood outside the threshold meaning zero likelihood for being physical.

From the 102 pairs already known 60 were successfully cross-matched with GAIA DR2 with 51 of them assessed positively for potential gravitational relationship (PGR). From the 119 pairs considered as new discoveries 46 were successfully cross-matched with GAIA DR2 with only 5 of them assessed with a likelihood >50% for PGR plus 9 with a likelihood of at least >10%. This comparison might be a bit unfair as the already known binaries include a few discoveries based on GAIA DR2 data mining – still this result raises questions about the binary attribute of the vast majority of the reported objects considered new discoveries.

3. Discussion of the Results

Out of the 221 listed assumed young binaries 102 are ident with already known double stars (listed in the WDS catalog or already published but per end of April 2019 not yet included in the WDS catalog) and six objects overlap with a component of such double stars. In most such cases a corresponding reference was given by the authors of the report (clearly with exception of the objects not yet listed in the WDS catalog at the time the report was written) but a few matching WDS objects were missed (as for example CRC 74 for J17340562+4447082).

Having begun this study prior to GAIA data releases, the authors approach to selecting targets for follow-up observations has relied only on proper motions and sky positions without the advantage of having parallaxes.

(Text continues on page 572)

Recovery of Proposed Young Star Binaries in Gaia DR2

Table 1.

Object	WDS_Desc	Comp?	PA	Sep	PA_DR2	e_PA	Sep_DR2	e_Sep	Vest1	e_Vest1	Vest2	e_Vest2	pmA1	pmE1	pmA2	pmE2	CPMR	CPMS
J00074264+6022543	JNN 247	SE	94	0.86														
J00133841+5245050	KPP+ 32	BG?	110	3.13	110.425	0.001	3.10005	0.00005	12.34308	0.00173	15.31586	0.02345	61.362	-42.181	59.673	-40.570	ADAA	5
J00160486+2319090	KPP+ 39	SE	94	2.66	96.160	0.003	2.61028	0.00014	14.15838	0.00467	14.57660	0.00354	140.262	-45.645	138.185	-59.868	DCAA	0
J00164045+3000598		SE	174	0.98														
J00165678+2003551		SE	102	1.03														
J00171046+2931520		CPM?	218	1.02														
J00215781+4912379	SKF1600	CPM	303	2.27	300.885	0.003	2.27468	0.00012	12.97999	0.00348	15.53071	0.03149	208.768	-35.025	209.999	-29.251	BAAA	80
J00233468+2014282	SKF2457	SE	136	1.73	139.415	0.004	1.72542	0.00013	11.16978	0.02986	12.01230		65.966	-37.381	56.442	-42.711	DDAA	0
J00285391+5022330	DAE 1	SE	85	0.32														
J00302927+0420204		SE	66	1.70														
J00323480+0729271	MCT 1	CPM	338	0.74														
J00340843+2523498	SKF 220	CPM?	100	1.55	102.342	0.008	1.53405	0.00022	11.83697	0.02166	11.90715	0.05275	82.275	-97.322	86.005	-96.705	BBAA	64
J00414141+4410530	JNN 13	CPM	14	0.51														
J00423409+5439048		BG?	95	3.04														
J00425668+2239350	SKF 229	SE	336	2.96	334.917	0.009	2.91579	0.00048	11.72399	0.00188	14.60123	0.08534	400.509	21.948	400.316	22.505	AAAA	100
J00485822+4435091	MCT 2	CPM	254	1.04	257.168	0.089	1.00149	0.00156	13.09841	0.03122	12.99240		120.296	-130.668	123.185	-135.867	ADAA	5
J00503319+2449009	LD83203	CPM	324	0.94														
J00530648+4829385		SE	49	1.31	50.425	0.013	1.25273	0.00029	13.05911	0.01850	14.33110		229.279	-143.587	224.346	-152.752	CARA	20
J01001331+2135328		SE	148	2.63	148.441	0.003	2.62518	0.00014	11.38102	0.00425	12.92170		77.771	12.669	82.105	11.332	BDAA	4
J01001613+1251007		CPM?	359	1.11	358.365	0.656	1.08819	0.01245	11.74022	0.01350	14.13730		47.411	-31.572				
J01034013+4051288	LD83225BC	SE	97	2.53	97.535	0.003	2.48242	0.00014	13.45846	0.01329	14.51991	0.01196	132.858	-155.877	130.420	-162.474	BBAA	64
J01071194-1935359	BRG 3	SE	166	0.47														
J01093915+2931112		SE	125	0.56														
J01102943-1510071	LD83239	SE	65	2.38	66.877	0.002	2.32520	0.00008	14.75682	0.00698	14.93911	0.00781	174.194	23.951	173.998	19.823	BARA	80
J01105436+5822133		SE	81	0.73														
J01112542+1526214	BEU 2	SE	240	0.33														
J03092643+6732425		SE	357	2.78	357.860	0.011	2.57523	0.00049	13.52736	0.00269	18.47240		-67.072	54.409				
J03144720+1127272		BG?	179	0.70														
J03175221+5847431		CPM	67	2.43	68.099	0.005	2.38849	0.00021	11.58474	0.00455	15.44970	0.05884	72.676	-6.710	75.907	-8.481	BDAA	4
J03240643+2347073	WOR 4	CPM	341	2.63	339.848	0.002	2.58773	0.00009	11.02903	0.00495	11.61876	0.12848	215.050	-120.236	200.851	-114.325	ADAA	5
J03232578+2843554	JNN 24	SE	103	0.47														
J03340048+5835551		SE	110	0.81														
J03434696+5725557		SE	241	3.54														
J03520223+2439479	LEI 5	SE	316	0.45														
J04053888+0544408	MCT 3	CPM	253	0.81														
J04074484+0945220		SE	279	0.77														
J04112810+7544231		SE	104	0.27														
J04132663-0139211	MCT 4	SE	175	0.72														
J04134585-0509049	BWL 14AB	SE	104	3.37	107.664	0.004	3.23963	0.00024	14.12417	0.00215	18.67793	0.07951	177.386	-110.102	173.525	-106.544	ACAA	40
J04171645+1213557		CPM?	96	0.73	89.261	0.363	0.74741	0.00474	13.49307	0.01355	13.72010							
J04174337-1754222	KPP+ 618	SE	359	2.78	358.256	0.001	2.69894	0.00006	11.74934	0.00570	15.06992	0.03071	27.773	17.099	32.745	14.472	DDAA	0
J04174431+4103137	NSN 546	CPM?	248	2.46	249.724	0.003	2.43269	0.00013	13.29438	0.00437	15.34765	0.03050	67.514	-209.252	81.592	-215.755	CDAA	1
J04214271-1657543		SE	55	0.41														
J04244805+1552292	HDS 566Aa, Ab	CPM	344	0.31														
J04251456+1858250		SE	140	0.83														
J04282878+1741453	GUE 5	CPM	74	1.72	75.058	0.014	1.65820	0.00042	12.36034	0.01124	13.48420		108.164	-41.789	113.679	-23.714	DAAA	1
J04285080+1617204		CPM?	175	2.00	175.462	0.036	1.93704	0.00123	10.98313	0.00324	14.83000		101.211	-10.376	108.360	-20.265	CDCA	1
J04311384+2053436		SE	217	0.65														
J04325718+7407002	KPP+ 670	SE	323	2.86	321.764	0.001	2.85529	0.00007	12.14488	0.00568	13.76431	0.01605	78.381	-124.919	78.233	-134.382	BDAA	4
J04343992+1512325		SE	175	1.05														
J04350255+0839304		SE	97	0.32														

Table 1 continues on the next page.

Recovery of Proposed Young Star Binaries in Gaia DR2

Table 1 (continued).

Object	WDS_Disc	Comp?	PA	Sep	PA_DR2	e_PA	sep_DR2	e_Sep	Vest1	e_Vest1	Vest2	e_Vest2	pmRA1	pmDE1	pmRA2	pmDE2	CPMR	CPMS
J04381255+2813001	BEU 6	CPM	303	1.15	304.513	0.030	1.19322	0.00063	12.76016	0.04621	12.44280		395.646	-92.041	381.115	-83.134	ADAA	5
J04385352+2147549	JNN 262AC	SE	123	1.27	124.772	0.022	1.23643	0.00047	13.65900	0.04553	13.54820		187.715	-213.608	194.097	-208.197	BAAA	80
J04412780+1404340		SE	262	0.26														
J04485498+5527185		SE	262	0.51														
J04492947+4828459	JNN 265	CPM	250	0.63														
J04495635+2341029	KPP3177	CPM?	88	2.51	90.144	0.003	2.38674	0.00013	11.87409	0.01064	12.89471	0.00788	37.179	-170.125	23.076	-161.224	DDAA	0
J05024924+7352143	JNN 30	SE	74	0.34														
J05122408+1824086	KPP+ 798	SE	97	1.50	99.714	0.005	1.45227	0.00012	13.26668	0.05229	12.97760		64.286	-31.912	57.928	-34.583	DDAA	0
J05195513-0723399	JNN 35	SE	286	0.53														
J05252028+6510544	HDS 711	SE	230	1.63	231.210	0.012	1.61282	0.00034	10.68224	0.01391	12.26180		-108.745	19.512	-111.756	17.785	BCAA	32
J05285650+1231539		SE	162	0.23														
J05341064+4732033	KPP+ 890	BG?	14	2.53	14.562	0.002	2.40440	0.00010	12.56094	0.01671	13.78334	0.00949	-58.068	36.848	-47.102	39.608	DDAA	0
J05345873+6521435	SE	276	1.17	275.651	0.009	1.17246	0.00017	11.78648	0.04624	0.04624	11.69545	0.04376	47.633	-118.803	51.896	-120.795	BCAA	32
J05494518+2513331	CPM?	192	2.79	194.030	0.002	2.74189	0.00009	12.17058	0.02271	0.02271	14.01094	0.03411	12.678	-47.883	-0.889	1.132	DDAB	0
J05554690+5123592	CPM?	272	1.90	272.123	0.004	1.92394	0.00012	12.80213	0.00432	0.00432	15.95880		34.305	-105.940	31.057	-103.344	BDAA	4
J06073185+4712266	SE	11	3.45	8.129	0.044	3.54086	0.00271	14.23453	0.00942	0.00942	18.87619	0.51925	37.768	-188.426				
J06084814+4257182	KPP3189	CPM	354	1.30	352.973	0.006	1.26311	0.00014	13.72664	0.02299	14.12220		39.217	-238.523	45.854	-238.046	BAAA	80
J06101580+2119569	CPM?	51	1.93															
J06133437+4914051	CPM?	25	0.79															
J06462622+0521150	SE	256	4.17	257.300	0.003	4.16881	0.00019	11.35999	0.00187	0.00187	16.80823	0.08683	59.681	-0.694	1.069	-0.604	DDAB	0
J06584690+2843004	BG	247	1.08															
J07120481+5423473	CPM	336	1.07	333.005	0.032	1.05721	0.00059	13.41331	0.03273	0.03273	13.50480		12.615	-108.400	13.163	-110.174	ABAA	80
J07140450+5043334	KPP3199	CPM	257	1.91	256.530	0.012	1.90243	0.00039	11.70406	0.00239	14.61420		-130.348	-269.339	-107.017	-282.242	DAAA	1
J07161207+3315154	CPM	52	1.84	53.934	0.015	1.76957	0.00047	11.81721	0.00269	0.00269	15.82510		-80.561	-182.043				
J07194218+2954390	SE	119	0.48															
J07315773+3613102	BEU 11Aa,Ab	CPM	190	1.55	190.104	0.015	1.55884	0.00041	10.94567	0.01076	12.48550		-249.500	-246.329	-246.029	-248.840	AAAA	100
J07505369+4428181	JNN 59	CPM	142	2.08	142.954	0.004	2.07505	0.00013	12.84270	0.01594	14.18780	0.03117	66.254	-140.517	65.593	-147.670	BDAA	4
J08010582+0330406	SE	351	2.25	350.308	0.016	2.18065	0.00063	13.49355	0.00186	0.00186	18.83740		-176.781	-124.534	-184.069	-119.057	CBAA	16
J08014318+4959455	CPM	163	1.12	163.805	0.014	1.12045	0.00028	13.16498	0.03700	0.03700	13.70340		-77.620	-68.602	-69.748	-68.457	CDAA	1
J08083284+5304377	CPM?	139	1.26	140.896	0.013	1.21825	0.00028	13.93016	0.03955	0.03955	13.91640		-89.351	-91.104	-101.497	-89.248	DDAA	0
J08095207+0301106	KPP+1447	CPM?	34	2.43	34.184	0.001	2.34251	0.00005	12.38162	0.02508	13.14225	0.09762	-15.159	-39.245	-17.262	-39.799	CDAA	1
J08310177+4012115	SKF 207	CPM	119	1.93	121.525	0.002	1.91590	0.00007	14.09077	0.00893	13.52360		-88.340	-124.425	-85.481	-123.378	ABAA	80
J08444213+0044159	KPP+1586	CPM?	116	3.26	117.606	0.001	3.23237	0.00008	10.63284	0.00466	14.46600		-108.177	-9.325	-102.489	-3.659	CDAA	1
J08504234+0751517	VDK 3	CPM	176	1.20	180.641	0.005	1.19683	0.00010	9.47331	0.01099	9.75843	0.04272	-43.414	-26.487	-105.697	14.547	DDAA	0
J08593592+5343505	SE	210	0.37															
J09062111+1659235	SHN 16	SE	280	0.88														
J09132383+6852305	CPM	227	0.60															
J09174473+4612246	JNN 68	SE	348	0.19														
J09192291+6203170	SE	189	0.79															
J09200048+3052397	CPM?	66	0.42															
J09214911+4330284	LAW 17	CPM	126	0.72														
J10024936+4827333	SE	306	0.20															
J10043276+0533412	CPM	324	0.30															
J10143153+0213174	SE	157	0.67															
J10143194+0606409	SKF1633	CPM	268	2.13	268.318	0.003	2.18458	0.00011	13.18608	0.03741	13.48560	0.01599	-143.997	-69.535	-167.415	-73.335	CDAA	1
J10150690+3125110	NSN 601	CPM	305	1.81	306.411	0.005	1.82512	0.00017	14.10586	0.01061	13.57690		-55.054	-213.174	-61.432	-208.138	BBAA	64

Table 1 continues on the next page.

Recovery of Proposed Young Star Binaries in Gaia DR2

Table 1 (continued).

Object	WDS Disc	Comp?	PA	Sep	PA DR2	e_PA	Sep_DR2	e_Sep	Vest1	e_Vest1	Vest2	e_Vest2	pmRA1	pmDE1	pmRA2	pmDE2	CPMR	CPMS
J10452148+3830422	HO 532AC	SE	232	0.68														
J10482887+5852005		BG	307	1.80														
J10571139+0544547	BWL 27	CPM	152	1.01	176.762	4.160	1.01338	0.07371	12.87008	0.01985	13.93890		-59.137	-37.776				
J11030845+1517518		CPM	57	0.39														
J11161238+4942112		CPM?	160	0.79	160.562	0.040	0.81826	0.00057	12.12026	0.01006	13.17520		-74.478	-0.365				
J11432359+2518137		CPM	113	0.48														
J11470543+7001588	NSN 621	SE	138	0.91	138.641	0.032	0.88252	0.00050	13.40660		13.58835	0.01981	-331.166	-50.229	-342.704	-33.527	DCAA	0
J11474897+0459160		CPM	292	1.68	286.480	2.428	1.54102	0.06534	11.60405	0.00185	15.15010		-134.929	-95.433				
J11503435+2903407		N	352	0.51														
J11504306+3312180	SKF 8B	CPM	91	2.58	91.153	0.022	2.78452	0.00107	12.41312	0.00434	15.19782	0.06985	-209.715	5.622	-0.080	-0.070	DDDA	0
J121115308+1249135	CAB 22A	SE	3	1.17	2.529	0.006	1.14504	0.00013	12.84870		12.58870	0.02143	-74.267	-63.983	-71.618	-57.639	BDAA	4
J12121136+4849032	SKF1634	SE	167	2.85	167.997	0.001	2.84340	0.00006	13.06337	0.00168	15.04249	0.01305	197.821	-314.460	207.407	-321.060	ACAA	40
J12161505+5053376		SE	188	1.90														
J12174539+0653230		SE	21	2.63														
J12225061+0404462	BWL 29	SE	29	0.24														
J13020587+1222215	SKF1636	CPM	88	2.93	87.553	0.003	2.88676	0.00017	12.83316	0.00437	15.48353	0.01691	-217.298	-95.688	-223.351	-86.555	CAAA	20
J13034595+2837205		SE	161	1.86	161.608	0.014	1.85107	0.00046	10.99989	0.00665	16.09780		-33.152	20.249	-29.523	18.511	ADAA	5
J13061537+2043444	HU 739	SE	197	1.61	198.896	0.005	1.56411	0.00014	9.93842	0.00960	11.32330		-55.824	94.567	-42.929	60.756	DDAA	0
J13120689+3213179	JNN 90Aa,Ab	SE	315	0.24														
J13151846+0249516	JNN 91	SE	100	0.29														
J13162169+2905548	LDS6276	BG?	72	2.40														
J13252836+3743098	SKF 942	CPM	96	2.91														
J13260267+2735021	KPP+2228	SE	218	1.49	219.364	0.004	1.48482	0.00011	13.27359	0.03232	13.43530		-2.968	73.118	9.228	62.813	DDAA	0
J13282890+0514353		SE	250	0.93														
J13324347+1114521		CPM	86	1.45														
J13324460+1648397	VYS 6	SE	53	2.83	53.732	0.003	2.72252	0.00014	12.05845	0.00742	12.44915	0.01007	287.563	-206.787	288.972	-240.686	DDAA	0
J13373037+1048346		SE	325	0.41														
J13375120+4808174	ES 608	CPM	334	1.63	334.749	0.002	1.63042	0.00006	10.39370	0.02241	11.00138	0.12104	-241.526	-137.716	-201.171	-140.286	DDAA	0
J13420990+1600233	WSI 114	SE	40	0.62														
J13435058+5030053		CPM	50	1.06	51.971	0.024	1.02288	0.00043	13.19386	0.02249	12.94905	0.07285	-80.044	-10.504	-81.724	-12.344	BCBA	30
J13474241+2127374	HDS1939	SE	150	1.33	150.698	0.013	1.30305	0.00030	11.34174	0.01048	12.92500		79.919	-89.265				
J13534589+5210298	JNN 96	SE	349	1.06	350.681	0.062	1.02325	0.00111	13.24525	0.01531	13.36258	0.06253	-2.783	-130.260	12.804	-130.409	DAAA	1
J14040922+2044314	J 1128	CPM	359	0.43														
J14105956+0751398	KPP+2333	BG?	294	1.33	295.272	0.006	1.35850	0.00014	12.91205	0.04364	12.74910		-51.029	9.054	-56.444	-2.113	DDAA	0
J14141700+1521125		CPM?	76	1.61														
J14170294+3142472	DEL 5	SE	175	0.27														
J14170837+5000081		CPM	41	1.70	41.683	0.005	1.61928	0.00013	13.24210	0.01164	14.37890		-105.785	42.292	-104.498	41.268	ABAA	80
J14243178+0257158		SE	217	3.85	218.050	0.008	3.78305	0.00054	12.47388	0.00539	17.39859	0.25293	-66.953	-33.147	-70.224	-29.136	DBAA	1
J14303394+0305440		SE	160	2.69														
J14373999+6745316		BG?	112	0.88														
J14433804+0414354	JNN 100	CPM?	286	1.01	287.548	0.015	1.05390	0.00028	13.05591	0.01528	13.19970		-101.846	-69.609	-112.583	-66.234	DDAA	0
J14445989+5309251		SE	54	0.86	55.116	0.077	0.87004	0.00117	12.49979	0.01561	12.46809	0.01209	-102.145	11.012	-120.064	8.951	BDAA	4
J14514497+0530407		SE	48	0.48														
J15005557+4525343	HDS2118	SE	165	2.03	165.650	0.005	1.99336	0.00017	9.69492	0.00418	11.96700		224.768	328.980	257.599	315.348	DCAA	0
J15072382+4333531		CPM	312	0.55														
J151114542+1014222	DJU 3	SE	250	1.92	251.859	0.003	1.93564	0.00011	12.04352	0.03206	12.69960		-35.994	22.118	-32.144	19.739	ADAA	5
J15123818+4543464	MCT 8	CPM	217	0.54														
J15154371+0725208		SE	193	0.60														
J15233660+3837489		CPM	356	0.62														
J15402840+1841460	HDS2211	SE	37	0.76														
J15422038+5936528		CPM	247	1.58	247.343	0.008	1.60552	0.00023	14.79411	0.00514	17.27130		-88.396	20.796	-88.897	27.136	DCAA	0
J15424184+8005306		CPM?	240	2.08	243.691	0.007	2.02487	0.00024	13.30162	0.02449	13.14740		-45.974	67.326	-50.502	69.394	BDAA	4
J15452354+7514548		SE	143	0.96	142.882	0.080	0.92298	0.00128	13.19253	0.01784	13.57460		-63.378	-63.378	-24.593	-56.745	ADAA	5

Table 1 continues on the next page.

Recovery of Proposed Young Star Binaries in Gaia DR2

Table 1 (continued).

Object	WDS Disc	Comp?	PA	Sep	PA_DR2	e_PA	Sep_DR2	e_Sep	Vest1	e_Vest1	Vest2	e_Vest2	pmRA1	pmRA2	pmDE2	CPMR	CPMS
J1552162+3414537	LD5848	CPM	107	1.80	107.382	0.001	1.83490	0.00003	13.37417	0.02999	13.08840		-78.991	-65.397	185.422	DDAA	0
J1553178+3512028	MCT	CPM	252	1.64	252.711	0.006	1.62802	0.00017	13.73360	0.01083	14.68230		-232.356	-229.675	137.228	DDAA	0
J15575497+6010263		CPM	297	0.70													
J16015690+1825127		SE	156	1.25	158.400	0.024	1.23786	0.00053	11.99334	0.00728	16.15250		-36.345	-28.461	-91.703	DBAA	1
J16043736+7022142		SE	5	0.76													
J16060319+0333215		CPM	305	0.56													
J16102225+4509347	CAB	BC?	59	2.43	60.817	0.002	2.31655	0.00009	12.71188	0.01607	15.98012	0.10358	-11.049	-16.515	33.394	DDAA	0
J16171135+7733477		SE	263	0.81													
J16250150-1215254		SE	105	0.31													
J16455062+0343014		CPM	188	2.06	189.229	0.004	2.00759	0.00014	12.56191	0.00986	15.53890		-37.665	-47.761	-100.607	DAAA	1
J16510995+3555071	JNN	CPM	316	1.07													
J16582055+0733079		CPM?	131	0.50													
J17021204+5103284	JNN	CPM	62	0.78													
J17035283+3211456	DAE	CPM?	150	1.44	150.523	0.031	1.38408	0.00076	12.07902	0.01009	13.08490		192.410	99.967	164.674	DDAA	0
J17152512+1328342		SE	222	0.74	225.127	0.049	0.74864	0.00065	13.15363	0.00786	13.64950		30.403	23.223	23.076	DBAA	0
J17183470+3400290	WIS	CPM?	83	1.32	85.984	0.010	1.24156	0.00022	13.06807	0.01153	14.58440		-14.624	172.979	169.421	BCAA	32
J17340562+4447082	CRC	CPM?	145	0.59													
J17380077+3329457	JNN	CPM	151	0.97													
J17530062+1655029	CRC	SE	112	0.88													
J17544786+4109310		CPM?	101	0.83													
J18132028+0751536		SE	34	0.98													
J18254891+0409280		SE	181	3.62	181.133	0.002	3.47313	0.00012	12.78057	0.01557	16.96871	0.07448	7.882	-90.950	-5.492	DDAA	0
J18320290+2030581	LAW	BC?	19	1.38	17.956	0.009	1.38699	0.00022	15.45695	0.02814	16.04609	0.06875	-47.480	-214.651	-211.436	BBAA	64
J19011166+2550384		SE	142	1.34	143.151	0.014	1.27627	0.00032	11.77772	0.01344	13.22040		-11.180	36.688	45.705	DDAA	0
J19031729+6359341	JOD	SE	64	3.69	65.414	0.014	3.58386	0.00089	10.89090	0.00187	12.42720		78.139	121.301			
J19133270+5644363		SE	167	1.17	167.938	0.015	1.12281	0.00030	13.39159	0.02605	13.73990		-5.845	33.939	34.584	DDAA	0
J19205158+1903362	SKF1087A	SE	196	0.51													
J19370113+3147214		BC?	303	0.51													
J19433674+3225206	HJ	SE	73	0.40													
J19471438+6402377		SE	203	0.17													
J19515537+3811071		SE	69	2.32													
J19543755+2013065		SE	113	4.20													
J20013373+2814101	SKF2391	CPM?	119	1.54	121.756	0.003	1.48735	0.00007	13.06801	0.04025	12.78290		114.159	79.540	92.455	DDAA	0
J20194925+2256367	KPP+3518	SE	357	1.96	355.774	0.004	1.90912	0.00012	12.14114	0.01031	13.15940		83.531	106.694	63.049	DBAA	1
J2032012+5047455		SE	157	0.82													
J20393474+4822450		CPM?	122	1.86	123.750	0.027	1.83649	0.00088	12.26762	0.01392	13.98130		88.106	48.715	86.638	DBAA	1
J20395460+0620118		SE	334	2.48													
J20422203+5311332		SE	36	0.29													
J20424915+4122599		CPM	143	0.48													
J20560274-1710538	JAY	SE	139	2.21	140.368	0.003	2.18199	0.00012	10.74630	0.00964	13.02240		57.311	-62.141	54.711	CAAA	20
J21000529+4004136	KUI	SE	56	0.89													
J21010182+2615397		SE	99	0.43													
J21143673+1952557		CPM	133	2.86	134.314	0.003	2.86395	0.00014	11.95503	0.00442	15.81566	0.05632	85.763	-48.514	88.104	BBAA	64
J21175904+3404301		CPM?	293	1.12	292.678	0.021	1.13822	0.00041	11.76239	0.00963	13.11920		51.540	-23.682	52.424	DDAA	0
J21294054+6405399		SE	320	2.44	318.682	0.001	2.51520	0.00005	14.50259	0.01292	15.45302		0.01317	90.903	-0.211	DDCA	0
J21322198+2433419	MCT	SE	240	1.55	241.192	0.004	1.53164	0.00011	13.11070	0.04726	12.59849	0.04218	229.542	-8.707	211.917	DDAA	0
J21363852+3927206	VYS	SE	263	1.09													
J21374019+0137137	JNN	SE	345	0.42													
J21411161-1011001		SE	14	1.02													
J21501406+0922295		SE	332	1.51	330.699	0.015	1.49319	0.00040	12.70607	0.00575	15.39140		201.509	-295.379	198.080	AAAA	100
J21512893-0236147		SE	255	1.43													

Table 1 concludes on the next page.

Recovery of Proposed Young Star Binaries in Gaia DR2

Table 1 (conclusion).

Object	WDS_Disc	Comp?	PA	Sep	PA_DR2	e_PA	Sep_DR2	e_Sep	Vest1	Vest2	e_Vest1	Vest2	pmRA1	pmDE1	pmRA2	pmDE2	CPMR	CPMS
J21521039+0537356	JOD 23AC	SE	16	0.64														
J21543507+5445122	LD56365	SE	72	3.19	72.737	0.001	3.11957	0.00006	11.80678	0.00122	0.00536	13.45540	171.349	142.350	173.400	140.914	AAAA	100
J21552437+5938371	JNN 292	SE	76	0.36														
J22073842-0650034		SE	287	0.95														
J22300418+4851347	JNN 294	SE	251	2.32	252.470	0.002	2.34027	0.00009	14.08539	0.01318	0.01060	15.28594	-73.658	-61.549	-79.758	-69.964	BDA A	4
J22413501+1849277		SE	264	0.23														
J22413577+2602128		BG?	72	3.70	74.891	0.004	3.61672	0.00026	13.00375	0.00440	0.17469	18.11566	-20.895	59.666	15.993	-6.667	DDAA	0
J22424884+1330532	TDT3670	SE	309	2.24	308.990	0.003	2.26000	0.00013	11.53709	0.07855	0.06268	11.85263	57.145	-34.618	64.156	-34.948	CDA A	1
J22594127+2154070		CPM?	36	2.28	35.238	2.608	2.09310	0.09534	11.00230	0.00443	0.00000	13.65970	127.972	-59.088				
J23002791-2618431	RST1154	SE	237	2.27	239.293	0.002	2.27603	0.00009	10.51183	0.01100	0.02006	10.83448	116.721	-159.842	99.499	-164.570	DCA A	0
J23024391+7506019	LD52024	SE	208	3.73	209.050	0.001	3.66919	0.00004	11.51675	0.00190	0.00325	12.65125	285.302	22.953	286.352	17.550	BAA A	80
J23040837+0318214		BG?	300	2.16	300.504	0.006	2.17656	0.00021	11.85066	0.00958	0.18944	15.74104	104.941	-53.343	99.883	-50.932	ADAA	5
J23060295-1956151		SE	25	0.81	24.040	0.250	0.76371	0.00334	13.69815	0.03636	0.01572							
J23062378+1236269	HD53291Aa, Ab	CPM	329	0.46														
J23220944+5756296		SE	312	0.35														
J23450477+1458573	JNN 140AC	CPM?	180	1.15	178.588	0.007	1.15485	0.00015	12.69212	0.02224		12.97740	237.549	-28.932	230.882	-19.235	CDA A	1
J23473777-2316060		SE	64	6.20														
J23574989+3837468	MCT 14	CPM	231	0.47														
J23581366-1724338	DAE 8	SE	176	2.09														
J23590042+2051387	JNN 247	SE	168	0.56														

Content description for table 1:

Object	Given 2MASS ID
WDS_Disc	WDS discoverer code
Comp?	Status of the companion according to Bowler et al. 2019: SE = single epoch without CPM assessment, CPM = common proper motion assumed, BG = background star assumed
PA	Position angle according to Bowler et al. 2019
Sep	Separation according to Bowler et al. 2019
PA_DR2	PA from GAIA DR2 epoch 2015.5 positions (no successful GAIA DR2 cross-match if blank)
e_PA	Error PA from GAIA DR2 positions
Sep_DR2	Separation from GAIA DR2 epoch 2015.5 positions
e_Sep	Error separation from GAIA DR2 positions
Vest1	Estimated primary visual magnitude from GAIA DR2 G/B/R-mags (see Appendix)
Vest2	Error estimated primary visual magnitude from GAIA DR2 G/B/R-mags (blank if Vest1 is estimated only from Gmag)
e_Vest1	Estimated secondary visual magnitude from GAIA DR2 G/B/R-mags (see Appendix)
e_Vest2	Error estimated secondary visual magnitude from GAIA DR2 G/B/R-mags (blank if Vest2 is estimated only from Gmag)
pmRA1	Proper Motion RA primary from GAIA DR2
pmDE1	Proper Motion Dec primary from GAIA DR2
pmRA2	Proper Motion RA secondary from GAIA DR2
pmDE2	Proper Motion Dec secondary from GAIA DR2
CPMR	Common proper motion rating (see Appendix)
CPMS	Common proper motion score (see Appendix)

Recovery of Proposed Young Star Binaries in Gaia DR2

Table 2

Object	WDS Disc	Plx1	e Plx1	Plx2	e Plx2	Min AU	Med AU	Max AU	L PGR	P min yrs	P med yrs	E Plx1	E Plx2	Notes
J00074264+6022543	JNN 247													1)
J00133841+5245050	KPF+ 32	18.3065	0.0303	18.4083	0.0573	169	62343	273437	100	1561	11068006	OK	OK	2)
J00160486+2319090	KPF+ 39	26.3998	0.0972	26.5100	0.0669	98	34610	196944	100	694	4578133	OK	OK	2)
J00164045+3000598														1)
J00165678+2003551														1)
J00171046+2931520														1)
J00215781+4912379	SKF1600	33.8287	0.0602	33.7578	0.1084	67	17621	113853	100	391	1663132	OK	OK	
J00233468+2014282	SKF2457	15.8999	0.0623	15.8349	0.0720	109	65437	385143	97	805	11902031	OK	OK	
J00285391+5022330	DAE 1													1)
J00302927+0420204														1)
J00323480+0729271	MCT 1													1)
J00340843+2523498	SKF 220	20.9735	0.1253	19.8590	0.1620	84525	551645	1026250	0	17472783	291321490	!!!	!!!	3)
J00414141+4410530	JNN 13													1)
J00423409+5439048														1)
J00425668+2239350	SKF 229	31.5702	0.1152	31.3449	0.4987	92	78926	550280	91	629	15765638	OK	!!!	
J00485822+4435091	MCT 2	30.3089	0.7965	27.5145	0.9672	62	690487	2299089	6	348	407959081	!!!	!!!	4)
J00503319+2449009	IDS3203													1)
J00530648+4829385		15.3287	0.1077	11.7376	0.2716	2446892	4115022	6173324	0	2721483766	5935287971	!!!	!!!	3)
J01001331+2135328		12.1843	0.1014	11.6418	0.1081	2858	788960	1713703	0	108648	498271751	!!!	!!!	3)
J01001613+1251007		10.6210	0.0468									OK		5)
J01034013+4051288	IDS3225BC	32.4949	0.0604	32.7415	0.1185	76	47831	175975	100	474	7437950	OK	OK	6)
J01071194-1935359	BRG 3													1)
J01093915+2931112														1)
J01102943-1510071	IDS3239	22.9845	0.0523	23.0986	0.0532	101	44459	164156	100	718	6665367	OK	OK	
J01105436+5822133														1)
J01112542+1526214	BEU 2													1)
J03092643+6732425		19.7872	0.2785									!!!		5)
J03144720+1127272														1)
J03175221+5847431		9.9720	0.0343	10.6111	0.1936	535	1245118	2640573	0	8804	987869369	OK	!!!	3)
J03240643+2347073	WOR 4	48.2954	0.0494	48.0921	0.0617	54	18061	49565	100	280	1725883	OK	OK	
J03323578+2843554	JNN 24													1)
J03340048+5835551														1)
J03434696+5725557														1)
J03520223+2439479	LEI 5													1)
J04053888+0544408	MCT 3													1)
J04074484+0945220														1)
J04112810+7544231														1)
J04132663-0139211	MCT 4													1)
J04134585-0509049	BWL 14AB	33.7578	0.2165	33.8695	0.2002	95	38402	242591	100	656	5350739	!!!	!!!	
J04171645+1213557														5)
J04174337-1754222	KPF+ 618	13.6412	0.0362	13.7054	0.0550	197	74940	402994	96	1966	14586509	OK	OK	2)
J04174431+4103137	NSN 546	32.7314	0.0710	33.0888	0.1122	74	67943	193920	100	455	12592280	OK	OK	7)
J04214271-1657543														1)
J04244805+1552292	HDS 566Aa, Ab													1)
J04251456+1858250														1)
J04282878+1741453	GUE 5	21.3301	0.2602	21.8172	0.2314	78	215932	872147	46	486	71344388	!!!	!!!	4)
J04285080+1617204		18.3652	1.1446	20.8078	0.1219	94	1323069	5863977	3	644	1082074296	!!!	!!!	4)
J04311384+2053436														1)

Table 1 continues on the next page.

Recovery of Proposed Young Star Binaries in Gaia DR2

Table 2 (continued)

Object	WDS Disc	Plx1	e_Plx1	Plx2	e_Plx2	Min_AU	Med_AU	Max_AU	L_PGR	P_min_yrs	P_med_yrs	E_Plx1	E_Plx2	Notes
J04325718+7407002	KPF+ 670	29.5407	0.0443	29.3179	0.0521	105	53047	127573	100	762	8687185	OK	OK	2)
J04343992+1512325														1)
J04350255+0839304														1)
J04381255+2813001	BEU 6	73.4184	0.4604	75.4857	0.1877	74	76968	158900	100	450	15182693	!!!	OK	
J04385352+2147549	JNN 262AC	24.3883	0.3885	21.8398	0.1331	313289	986382	1585797	0	124681541	696548754	!!!	!!!	3)
J04412780+1404340														1)
J04485498+5527185														1)
J04492947+4828459	JNN 265													1)
J04495635+2341029	KPF3177	24.3598	0.0934	24.5521	0.0547	97	66316	240951	100	683	12142547	OK	OK	7)
J05024924+7352143	JNN 30													1)
J05122408+1824086	KPF+ 798	18.8345	0.0675	18.6814	0.0709	77	89671	344895	97	481	19092487	OK	OK	2)
J05195513+0723399	JNN 35													1)
J05252028+6510544	HDS 711	26.2810	0.0279	26.1718	0.2407	61	54160	346216	99	342	8961904	OK	!!!	8)
J05285650+1231539														1)
J05341064+4732033	KPF+ 890	30.0792	0.0452	30.0718	0.0734	80	13251	90974	100	507	1084588	OK	OK	2)
J05345873+6521435		19.1742	0.0778	18.6521	0.1506	67	300679	765420	16	387	117230084	OK	!!!	4)
J05494518+2513331		9.6659	0.0582	0.3813	0.0388	34877039	5193601	99153506	0	4631193312157	8415625819857	!!!	!!!	3)
J05554690+5123592		16.4271	0.0376	16.6977	0.1025	117	203417	543597	48	902	65232661	OK	!!!	4)
J06073185+4712266		35.3362	0.1100									OK		5)
J06084814+4257182	KPF3189	20.9978	0.0628	21.2296	0.0905	61	107255	320011	97	338	24975360	OK	OK	7)
J06101580+2119569														9)
J06133437+4914051														1)
J06462622+0521150		23.3429	0.0511	0.4962	0.2039	14516388	4064510	30316300	0	1243830200713	5826341244245	OK	!!!	3)
J06584690+2843004						0	77	01370						1)
J07120481+5423473		13.0040	0.6431	17.1461	0.0889	996853	3833859	8479756	0	707669312	5337498203	!!!	!!!	3)
J07140450+5043334	KPF3199	35.1701	0.0344	34.7427	0.0887	1203	72103	151373	100	29673	13766140	OK	OK	7)
J07161207+3315154		34.9370	0.0675									OK		5)
J07194218+2954390														1)
J07315773+3613102	BEU 11Aa,Ab	83.3360	0.0462	81.8459	0.3420	2196	44973	90882	100	73193	6781168	OK	OK	
J07505369+4428181	JNN 59	20.0063	0.0357	20.4367	0.1246	372	216984	523161	40	5110	71866462	OK	!!!	4)
J08010582+0334064		21.2928	0.0466	21.7093	0.8196	102	282223	1726098	37	733	106603718	OK	!!!	4)
J08014318+4959455		17.6589	0.2652	16.0828	0.0970	270096	1145034	1945519	0	99807159	871186648	!!!	!!!	3)
J08083284+5304377		28.5698	0.2544	29.7167	0.1340	875	278666	594533	14	18403	104594508	!!!	OK	4)
J08095207+0301106	KPF+1447	10.2325	0.0356	10.2347	0.0379	228	69291	422970	95	2445	12968700	OK	OK	2)
J08310177+4012115	SKF 207	29.6987	0.0626	29.6311	0.0487	65	17472	88671	100	369	1642093	OK	OK	
J08444213+0044159	KPF+1586	15.3762	0.0381	15.2787	0.0557	210	86081	351416	97	2164	17957328	OK	OK	2)
J08504234+0751517	VDK 3	56.1890	0.0685	56.1155	0.0647	21	5513	31314	100	70	291055	OK	OK	
J08593592+5343505														1)
J09062111+1659235	SHN 16													1)
J09132383+6852305														1)
J09174473+4612246	JNN 68													1)
J09192291+6203170														1)
J09200048+3052397														1)
J09214911+4330284	LAW 17													1)
J10024936+4827333														1)
J10043276+0533412														1)
J10143153+0213174														1)

Table 1 continues on the next page.

Recovery of Proposed Young Star Binaries in Gaia DR2

Table 2 (continued)

Object	WDS Disc	Plx1	e_Plx1	Plx2	e_Plx2	Min_AU	Med_AU	Max_AU	L_PGR	P_min_yrs	P_med_yrs	E_Plx1	E_Plx2	Notes
J10143194+0606409	SKF1633	30.9057	0.0563	31.0992	0.0674	70	41617	122568	100	420	6036540	OK	OK	
J10150690+3125110	NSN 601	29.7933	0.0726	30.0216	0.0811	61	52786	162713	100	340	8623184	OK	OK	7)
J10452148+3830422	HO 532AC													1)
J10482887+5852005														1)
J10571139+0544547	BWL 27	9.5289	0.4461									!!!		5) 19)
J11030845+1517518														1)
J11161238+4942112		12.6285	0.3654									!!!		5)
J11432359+2518137														1)
J11470543+7001588	NSN 621	32.8054	0.0755	32.5949	0.3916	27	59457	373792	98	99	10308348	OK	!!!	7)
J11474897+0459160		26.2972	0.0538									OK		5)
J11503435+2903407														1)
J11504306+3312180	SKF 8B	20.4047	0.8202	0.6751	0.2849	98557089	294655431	5856173227	0	695689265992	3596293896331	!!!	!!!	3) 10)
J12115308+1249135	CAB 22A	16.1273	0.0976	16.3878	0.0793	70	203539	615083	49	420	65291328	!!!	OK	11)
J12121136+4849032	SKF1634	37.6051	0.0343	37.8615	0.0631	79	37157	86433	100	502	5092606	OK	OK	
J12161505+5053376														1)
J12174539+0653230														1)
J12225061-0404462	BWL 29													1)
J13020587+1222215	SKF1636	33.0956	0.0782	33.1929	0.1318	87	23540	145681	100	576	2568014	OK	OK	
J13030459+2837205	J13030459+2837205	4.6654	0.0363	3.8962	0.3847	560	8737383	46547389	1	9412	18363505711	!!!	!!!	4)
J13061537+2043444	HU 739	50.9035	0.0435	50.7329	0.1295	31	13814	64447	100	121	1154391	OK	OK	
J13120689+3213179	JNN 90Aa,Ab													1)
J13151846-0249516	JNN 91													1)
J13162169+2905548	IDS6276													1)
J13252836+3743098	SKF 942													1)
J13260267+2735021	KPF+2228	22.1232	0.0786	21.9462	0.0550	67	75412	271785	100	394	14724711	OK	OK	2)
J13282890+0514353														1)
J13324347+1114521														1)
J13324460+1648397	VYS 6	60.3012	0.1130	60.3748	0.0826	45	6097	38043	100	215	338511	OK	OK	
J13373037-1048346														1)
J13375120+4808174	ES 608	47.1938	0.0302	47.2225	0.0321	35	3376	21507	100	144	139451	OK	OK	
J13420990-1600233	WSI 114													1)
J13435058+5030053		16.0118	0.3808	15.7766	0.0914	65	257859	1486520	40	371	93101552	!!!	!!!	4)
J13474241+2127374	HDS1939	33.4010	0.0404									OK		5)
J13534589+5210298	JNN 96	17.8099	0.8939	21.6613	0.3092	182	2060734	5221024	0	1740	2103374154	!!!	!!!	3)
J14040922+2044314	J 1128													1)
J14105956+0751398	KPF+2333	29.1804	0.0915	29.3457	0.0975	47	40588	179774	100	226	5814127	OK	OK	2)
J14141700-1521125														1)
J14170294+3142472	DEL 5													1)
J14170837+5000081		15.5384	0.0864	15.5979	0.0810	103	77289	474693	92	748	15277839	!!!	!!!	12)
J14243178-0257158		7.6029	0.2839	7.2458	0.4900	506	1715399	12350461	6	8093	1597463951	!!!	!!!	4)
J14303394+0305440														1)
J14373999+6745316														1)
J14433804-0414354	JNN 100	19.3726	0.1992	19.4511	0.1454	54	95840	631739	84	279	21096175	!!!	!!!	
J14445989+5309251		16.9706	0.6239	17.9050	0.6905	50	670954	3441820	15	250	390771056	!!!	!!!	4)
J14514497-0530407														1)

Table 1 continues on the next page.

Recovery of Proposed Young Star Binaries in Gaia DR2

Table 2 (continued)

Object	WDS_Disc	Plx1	e_Plx1	Plx2	e_Plx2	Min_AU	Med_AU	Max_AU	L_PGR	P_min_yrs	P_med_yrs	E_Plx1	E_Plx2	Notes
J1500557+4525343	HDS2118	85.3753	0.0367	85.3829	0.1132	23	2290	14586	100	80	77919	OK	OK	
J15072382+4333531														1)
J15114542+1014222	DJU 3	9.1826	0.0468	9.0769	0.0768	211	266424	1297435	37	2172	97778624	!!!	!!!	4)
J15123818+4543464	MCT 8													1)
J15154371-0725208														1)
J15233660+3837489														1)
J15402840-1841460	HDS2211	22.4619	0.0334	22.6702	0.1522	71	85077	358678	97	428	176444305	OK	!!!	12)
J15422038+5936528		13.0841	0.0187	12.1865	0.1797	139611	1161541	2271036	0	37090500	890092433	OK	!!!	3)
J15452354+7514548		20.2010	0.9409	16.7651	0.0512	1111	2092139	4078920	0	26345	2151638606	!!!	OK	3)
J15521824+3414537	LDS848	21.9104	0.0203	21.9590	0.0209	84	20792	76498	100	544	2131745	OK	OK	
J15553178+3512028	MCT 9	35.9423	0.0441	36.1520	0.1320	45	33265	131265	100	217	4313848	OK	OK	
J15575497+6010263														1)
J16015690+1825127		15.3177	0.0505	13.3188	0.4637	18132	2020175	4683308	0	1736010	2041582089	OK	!!!	3)
J16043736+7022142														1)
J16060319+0333215														1)
J16102225+4509347		9.9047	0.0470	9.7932	0.0591	234	237509	1044972	41	2547	82300688	OK	!!!	4)
J16171135+7733477	CAB 23A													1) 13)
J16250150-1215254														1)
J16455062+0343014		22.2755	0.0409	21.9823	0.1205	90	123484	351915	92	611	30853193	OK	!!!	12)
J16510995+3555071	JNN 110													1)
J16582055+0733079														1)
J17021204+5103284	JNN 112													1)
J17035283+3211456	DAE 6	52.2800	0.3416	53.3747	0.4858	27	80764	255757	100	97	16319545	!!!	!!!	
J17152512+1328342		18.5272	0.4927	16.3825	0.2464	17950	1457330	2886724	0	1709923	1250893444	!!!	!!!	3)
J17183470+3400290	WIS 315	19.7804	0.0265	19.6978	0.1337	63	58059	357043	98	354	9946861	OK	!!!	14)
J17340562+4447082	CRC 74													1)
J17380077+3329457	JNN 115													1)
J17530062+1655029	CRC 27Aa,Ab													1)
J17544786+4109310														1)
J18132028+0751536														1)
J18254891+0409280		18.1840	0.0347	0.3628	0.0861	27293344 4	5580748 00	39234638 6786	0	3206037758758	9373938885129	OK	!!!	3)
J18320290+2030581	LAW 18	32.0541	0.1700	31.9576	0.0978	43	30262	201200	100	203	3743158	!!!	OK	
J19011166+2550384		20.4640	0.0578	19.5055	0.1992	38322	495372	1011607	0	5334033	247902225	OK	!!!	3)
J19031729+6359341	JOD 16A			27.4538	0.0345								OK	5) 15)
J19133270+5644363		14.4455	0.1406	14.6150	0.1026	77	175241	886055	56	479	52159783	!!!	!!!	
J19205158+1903362	SKE1087A													1) 16)
J19370113+3147214														1)
J19433674+3225206	HJ 1433B													1) 17)
J19471438+6402377														1)
J19515537+3811071														1)
J19543755+2013065														1)
J20013373+2814101	SKE2391	29.5022	0.0502	29.5712	0.0587	50	17733	94174	100	253	1678990	OK	OK	

Table 1 concludes on the next page.

Recovery of Proposed Young Star Binaries in Gaia DR2

Table 2 (conclusion)

[illegible]

Recovery of Proposed Young Star Binaries in Gaia DR2

Content description for table 2:

- Object Given 2MASS ID
- WDS_Disc WDS discoverer code
- Plx1 Parallax primary from GAIA DR2
- e_Plx1 Error parallax primary from GAIA DR2
- Plx2 Parallax secondary from GAIA DR2
- e_Plx2 Error parallax secondary from GAIA DR2
- Min_AU Minimum distance between components in AU (see Appendix)
- Med_AU Median distance in AU (see Appendix)
- Max_AU Maximum distance in AU (see Appendix)
- L_PGR Likelihood for distance < 200,000 AU
- P_min_yrs Minimum orbit period in years (see Appendix)
- P_med_yrs Medium orbit period in years (see Appendix)
- E_Plx1 Relation e_Plx/Plx for primary ("OK" for <0.5%, else "!!!")
- E_Plx2 Relation e_Plx/Plx for secondary ("OK" for <0.5%, else "!!!")
- Notes Notes (see below)

Notes:

1. Not resolved in DR2
2. Reported in Knapp 2019, Physical Pairs found in GAIA DR2, DSSC27, Pages 55-72
3. Most likely optical
4. Likelihood optical >50%
5. Resolved in DR2 w/o Plx
6. Wrong 2MASS ID, should be J01034013+4051288. Given ID is for LDS3225A. Physical triple
7. Reported in Knapp and Nanson 2019, A Catalog of High Proper Motion Stars in the Northern Sky (HPMSNS Catalog), JDSO Vol. 15 No. 1, Pages 42-58
8. B double itself?
9. Resolved in DR2 but with Sep and PA too different to be considered a valid match
10. Overlap with SKF 8B
11. Overlap with CAB 22A
12. Plx error too large to be included in 2)
13. Overlap with CAB 23A
14. Overlap with WIS 315A
15. Overlap with JOD 16A
16. Overlap with SKF1087A
17. Overlap with HJ 1433B
18. Might be bogus – no object for the secondary to locate at the given position. May be typo for separation with 6.2 instead of 1.2". Object for secondary given here but without data for CPM and PGR assessment

Recovery of Proposed Young Star Binaries in Gaia DR2

(Continued from page 560)

es. This seems to have worked reasonable well as with a few exceptions all matched objects are according to the GAIA DR2 parallaxes clearly within the declared search radius of 100 parsecs – only 10% of the objects with GAIA DR2 parallax data available are listed with parallax values <10 and only 6 of the assumed companions are obviously background stars with parallax values <1 . The assessment of the identified pairs for being physicals was done on base of assumed common proper motion based on tests using multi-epoch images – as common proper motion is not a sufficient criterion for such an assessment (Knapp 2019) this has the unavoidable consequence of declaring pairs as likely physical while the components are due to the given spatial distance clearly without any reasonable likelihood for gravitational relationship. As comparison of multi-epoch images was only available for a part of the reported pairs the authors assumed that the vast majority of the single epoch objects are expected to be physical binaries based on the low number density of comparably bright stars nearby – this might be a case of motivated perception rather than a serious assessment.

Out of the 221 listed assumed young binaries 106 could be successfully matched with GAIA DR2 objects with 94 of them with proper motion and parallax data available for common proper motion and potential gravitational relationship (PGR) assessment.

In total 115 reported objects could not be matched with corresponding GAIA DR2 objects giving a meagre overall recovery rate of 49% compared with for example the 99% for SKF objects (Knapp 2019).

But 24 objects are listed with a separation <0.4 arcseconds below the resolution limit of GAIA DR2 (Arenou et al. 2018) and 73 with a separation <1 arcsecond which means in a range known for a bad GAIA DR2 resolution performance – yet in this case this performance is especially bad: Only 7 out of 73 objects with a separation <1 arcsecond are resolved.

24 out of 123 objects listed with a separation $>1''$ remain also without resolution in GAIA DR2 – this gives a recovery rate of $\sim 80\%$ for such objects. This result is in comparison with other known double stars of similar separation rather modest yet does not allow for a prematurely conclusion that some of the proposed binaries might be bogus – the provided image material looks despite some gaps (for example images for J19543755+2013065 and J20194925+2256367 are missing) and some mislabeling (for example J22413577+2602128 instead of J22413501+1849277 or J01001613+1251007 instead of J01034013+4051288) very convincing.

4. Summary

Only 49% of the 221 proposed young star binaries could be successfully cross-matched with GAIA DR2 and only 42.5% with proper motion and parallax data available for both components. 25% are confirmed as likely binaries but most of these are already known doubles listed in the WDS catalog while this confirmation rate drops dramatically for pairs reported as newly detected.

The overall low recovery rate indicates either an issue with the data of the reported young binaries or an issue with GAIA DR2 data quality - the known weakness of GAIA DR2 with very high proper motion objects in the solar neighborhood (Knapp and Nanson 2019) suggests the latter. This conclusion is supported by several cases of GAIA DR2 cross-match mishits with obviously existing objects in PanSTARRS1 images in the given positions.

5. Acknowledgements

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

- Washington Double Star Catalog
- GAIA DR2 catalog
- DSS, 2MASS and Pan-STARRS (PS1) images
- Aladin Sky Atlas

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Recovery of Proposed Young Star Binaries in Gaia DR2

Knapp, Wilfried R.A., 2019, “Physical Pairs Found in Gaia DR2, DSSC27, Pages 55-72.

Knapp, Wilfried R. A., 2019, “The ‘True’ Movement of Double Stars in Space”, *JDSO*, 15 (3), 464-488.

Appendix

Description of the CPM rating procedure (according Knapp and Nanson 2017 and Knapp 2018):

- Four rating factors are used: Proper motion vector direction, proper motion vector length, size of position error in relation to proper motion vector length and relation separation to proper motion speed
- Proper motion vector direction ratings: “A” for within the error range of identical direction, “B” for similar direction within the double error range, “C” for direction within the triple error range and “D” for outside
- Proper motion vector length ratings: “A” for identical length within the error range, “B” for similar length within the double error range, “C” for length within the triple error range and “D” for outside
- Error size ratings: “A” for error size of less than 5% of the proper motion vector length, “B” for less than 10%, “C” for less than 15% and “D” for a larger error size
- Relation separation to proper motion speed: “A” for less than 100 years, “B” for less than 1000 years, “C” or less than 10000 years and “D” for above

To compensate for the extremely small proper motion GAIA DR2 errors resulting in a worse than “A” rating despite only very small deviations an absolute lower limit is applied regardless of calculated error size:

- Proper motion vector direction: Max. 1° difference for an “A”
- Proper motion vector length: Max. 1% difference for an “A”

The letter based scoring is then transformed into an estimated probability and a verbal assessment for being CPM.

Description of the PGR assessment procedure (according to Knapp 2019):

- GAIA DR2 data for RA/Dec and Plx are used for a Monte Carlo simulation assuming a normal distribution for these parameters with the given error range as standard deviation. The distance between the components is calculated from the inverted simulated parallax data and the simulated angular separation using the law of

$$\sqrt{a^2 + b^2 - 2ab \cos \gamma}$$

cosine with a and b = distance vectors for the stars A and B in lightyears calculated as $(1000/\text{Plx}) \cdot 3.261631$ and γ = angular separation in degrees calculated as

$$\gamma = \arccos \left[\sin(DE1) \sin(DE2) + \cos(DE1) \cos(DE2) \cos(\text{abs}(RA1 - RA2)) \right]$$

- The potential gravitational relationship score (PGRS) is the percentage of simulation results <200,000 AU (~1 parsec) out of the simulation sample with a size of 120,000 corresponding with the likelihood that the real distance is smaller than 200,000 AU
- The smallest, median and largest distance is the smallest, median and largest result of the simulation sample
- The smallest/median/largest distance is also used as estimation for the minimum value for the semi-major axis of a potential orbit allowing for the calculation of a smallest/median/largest possible orbit period assuming zero inclination and in total double Sun mass.

Estimation of visual magnitudes (according Knapp and Nanson 2018):

The estimation of the visual magnitudes is based on GAIA DR2 G/B/R-mags using the formula

Recovery of Proposed Young Star Binaries in Gaia DR2

$$V_{est} = 3.9379083526304 + 0.269235360436179 * Gmag^{1.36701081887491} - 0.123879978164097 * [Gmag - Rmag] - 0.943379695375539 * [Gmag - Bmag]$$

with a regression coefficient of 0.999 and a standard deviation of 0.064 derived by statistical analysis using nonlinear regression with the UBVRI catalogs of Landolt&Clem (VizieR II/183A, J/AJ/146/88 and J/AJ/152/91) after eliminating a few outliers due to questionable cross-match results with GAIA DR2. This estimation formula shares the photometry caveats of GAIA DR2 for very bright (<10Gmag) and very faint (>18Gmag) objects according to Evans et al. 2018 and Riello et al. 2018. In case of missing GAIA DR2 Bmag and Rmag data the visual magnitude was estimated with an average delta of +0.318 to Gmag.



Measurements of Visual Binary Stars with a SWIR Camera and a 280 mm Reflector – Part 2

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Abstract: This paper is a continuation of that published in [1]. It presents the measurements of visual binary stars obtained by means of an 11" reflector telescope and a VIS-SWIR camera covering the 450 - 1700 nm band. Compared to the results presented in [1] with a similar instrumentation, the observed targets are closer pairs, with separations between 1 and 5 arcsec and reduction was performed using bispectrum-based techniques. Our measurements show a good agreement with astrometric parameters derived from the GAIA DR2. Attempt to correlate the measured differential magnitudes in several bands (450-600 nm, 550-670 nm and 800 - 1700 nm resp.) and the GAIA Teff parameters - viewed as an indirect indicator of the spectral types – did not produce any convincing result.

1. Introduction

In [1], we presented some preliminary results of observation and measurement of visual binary stars with a small telescope and a camera operating in the short wave infrared (SWIR[†]) band. As a consequence of the target selection process, which focused on stars with late spectral types companions (M, typically), most of results described [1] concern pairs having large separations (in the range 10-100 arcsec typically) and measurements were performed on images obtained by classical select-shift-and-add techniques.

It therefore remained to be investigated whether speckle-based reduction techniques – which we have been using regularly to obtain measurements of close visual binary stars in the optical band [2,3] – could be applied to obtain measurements of closer pairs observed with the same instrumentation.

This was the main motivation of the work described in this paper. The other one was to assess whether measuring the difference in magnitude (ΔM) between the components at different wavelengths could, at least qualitatively, be related to the spectral types of the components.

The paper is organized as follows. Sections 2 and 3 briefly recall the characteristics of our instrumental setup and of the data reduction process. Sections 4 and 5 present the target stars and the related measurements. Section 6 concludes the paper.

2. Instrumental setup

As described in [1], the detector is an Owl 640 VIS-SWIR camera manufactured by Raptor Photonics [4]. It features a 640x512 InGaAs PIN-photodiode sensor (15x15 μm pixels), a QE > 80% between 800 and 1600 nm and is equipped with an on-board Non Uniformity Compensation system (NUC) which can perform on the fly offset correction, gain dispersion compensation, dark current subtraction and hot pixel correction. The results described here were obtained with the following settings:

- sensor cooled to -15°C
- NUC level 2 (offset + gain correction)
- Hi gain mode, gain = 6-8

Control of the camera and acquisition are carried out by the Genika software (version 2.8.0) [5].

The telescope is a 280 mm Schmidt-Cassegrain reflector (Celestron C11). Because of the relatively large pixels of the camera (15 x 15 μm), and as described in [1], we had to use eyepiece projection to get a plate scale compatible with the measurement of pairs with separation between 1 and 5 arcsec. The effective plate scale, in this experiment was 0.32 arcsec/pixel.

Three filters were used

- ThorLabs FGL-1000M for observing in SWIR
- Astronomik G and R filters from a RGB type IIc set for observing in the optical band.

The combination of the transmission curve of these

[†] Typically from 1 to 2.5 μm

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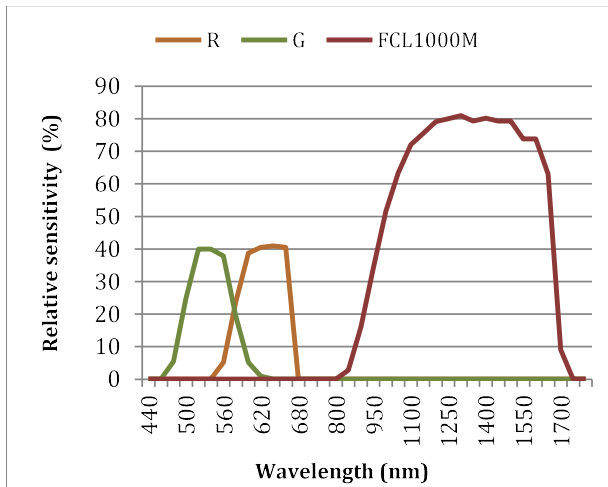


Figure 1. Combined response curve for the Owl 640 camera and the used filters

filters with the QE curve of the Owl 640 gives the relative response curves reproduced in Figure 1. The two following points should be noted. First, despite being a VIS-SWIR camera, the QE of the Owl 640 is significantly lower in the visible part of the spectrum (the QE drops from 90% at $\lambda=1100$ nm to 40% at $\lambda=500$ nm). This explains the difference in height for the curves associated to the G et R filters on the one side and the FCL-1000M filter on the other side. This difference is not a problem as long as we are interested in *differential* photometry. Second, the sensitivity range in SWIR includes both the J and H photometric bands (1-1.4 and 1.4-1.8 μ m resp.). In the sequel of this paper, for brevity, we will refer to the used filters (and corresponding passbands) as “G”, “R” and “JH”.

3. Acquisition and processing

For each target, seven sequences of 500 frames were acquired:

- one sequence with the G, R and JH filter
- one sequence with the same filters on a nearby reference (single) star, to be used by the deconvolution step in the reduction process,
- one sequence of «dark» frame (obtained with the same gain and exposure time on the sky background).

Individual exposure times ranged from 50 to 75 ms.

Calibration is carried out using the sidereal drift method using the dedicated module of the SPECKLE-TOOLBOX software [6].

All acquired sequences are pre-processed using Reduc [7] and reduced using the bispectrum reconstruction technique supported by the SpeckleToolbox soft-

ware, following the processing pipeline described in [8].

4. Target selection

The selection of potential targets was driven by three criteria:

1. the separation and magnitudes of the components
2. practical observability
3. the possibility to record variations in observed differential magnitudes

The selected range in separation was 1-5 arcsec and the magnitude limit was 10 for the primary and 12 for the secondary. These limits take into account both our goal to measure closer pairs than those reported in [1] and the effective plate scale of approximately 0.30 arcsec/pixel associated to the instrumental setup (which both limit the resolution and the detectivity of faint stars).

Because observations were performed near the meridian and taking into account the pointing limits in our observatory, the range in RA and Dec were respectively set to 16H-19h and 10-55°.

Our initial idea was, as in [1], to restrict our observations to pairs for which the secondary has a late (M) spectral type. In this case, the variation in Δm according to the observing wavelength is likely to be the most significant. Unfortunately, very few entries in the WDS catalog [9] have a spectral type for the secondary component and virtually none for pairs having a separation under 5 arcsec[†]. As a workaround, we decided to use the stellar effective temperature parameter (Teff) provided by the GAIA DR2 [10]. Using the GDS tool described in [11], we therefore selected pairs for which both components have a Teff entry in GAIA DR2 and, among these, those for which the difference in Teff was the greatest. This is clearly a very crude filter. First because the Teff parameter is actually inferred from the G, RP and BP photometric data (which do not include J nor H-band photometry). Second because the relationship between the Teff parameter and the spectral type is far from straightforward. But, since our objectives in this experiment were purely qualitative it appeared as an acceptable choice. This left us with a list of 25-30 potential targets, which was far enough.

5. Results

Observations have been conducted during three nights, between 2018-06-26 and 2018-06-30. For each target, and for each filter we had to successively point the target, record a FITS cube, point to a nearby reference star, record a FITS cube and go back to the target

[†] The only exception in our data set is 18443+3940 (STF2382AB) but it was included in the list only for calibration purposes.

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for the next filter. This rather inconvenient way of proceeding was due to the necessity to refocus when changing filters[†]. As a result, only ten targets were observed.

The observed targets are described in Table 1 and our measurements reported in Table 2.

In Table 1, columns 1-8 respectively give

- the WDS identifier
- the WDS discoverer code
- the position angle (PA) and separation (SEP) computed from the exact coordinates of the components supplied by the GAIA DR2^{††}
- the G magnitude and effective temperature of the two components, as given in the GAIA DR2[‡]

In Table 2, columns 1-12 respectively give

- the WDS identifier
- the (Besselian) date of the observation
- the measured position angle, separation and differential magnitude (ΔM) when using the G, R and JH filter

The bispectrum-reconstructed images used for the measurements are reproduced in Plate 1.

Two of the measured pairs, BU 627A,BC and STF2382AB have an entry in the Sixth Catalog of Orbits [12]. The O-C computed from our measurement are given in Table 3.

Concerning astrometry (PA and SEP), the measurements in the three observed bands (G, R and JH) are in good agreement. If we except the case of 17344+1310 (A 2184AB), for which the G image is obviously biased, the dispersion between the three values is smaller than 4.3° for PA and 0.33 arcsec for SEP respectively (with a statistical mean of 1.70° and 0.186 arcsec resp.). These dispersions are yet significantly higher than those computed from several measurements of the same pairs in a single, optical, band, as reported in [2] for instance. This can be probably attributed to the much coarser plate scale used here (0.32 arcsec/pixel, compared to 0.09 in [2]) and also to the variability in the quality of the reconstructed images according to the observing wavelength^{‡‡}.

Comparing the measurements obtained in the JH

band with those derived from the individual positions given by GAIA DR2 gives a maximum deviation of 3.2° for PA and 0.25 arcsec for SEP. Again, these deviations are significantly higher than those reported in our previous work on similar pairs in the optical band (in [11], for example the differences between our measurements and the astrometric values deduced from GAIA DR2 showed an average and standard deviation of only $-0.009^\circ / 1.08^\circ$ and 0.004 arcsec / 0.028 arcsec for PA and SEP respectively). This can probably be attributed, again, to the coarser plate scale but also to the fact that, in our previous work, each reported measurement was computed from several acquisition sequences, each reduced separately, whereas the values used here are computed from a single acquisition sequence.

Concerning photometry, the passband of our filters on the one hand and of GAIA filters on the other hand are too different to allow even an approximate comparison (and, especially, because GAIA photometry does not extend beyond $1 \mu\text{m}$ [13]). We are not aware of any data source providing J-band and/or H-band differential magnitudes for binary stars in that range of separation. It is therefore very difficult to assess the accuracy of the $\Delta M(\text{JH})$ values reported in Table 2. The only thing we could do was therefore to try drawing some conclusions from the variations of Δm observed when going from our G or R band to the JH one (i.e. from the differences between the values reported in columns 5 or 8 and 11 in Table 2). Indeed, Table 2 shows that the latter is almost systematically lower than the former(s) (with a min/max/mean value of $-1.30/0.03/-0.35$ for $\Delta M(\text{JH})-\Delta M(\text{G})$ and $-1.5/0.17/-0.31$ for $\Delta M(\text{JH})-\Delta M(\text{R})$). Unfortunately, we were unable to correlate this general trend to the GAIA Teff parameters which, as explained in Section 4, were the best indirect indicator we had of the involved spectral types. The linear correlation coefficient between the measured $\Delta M(\text{JH})$ and $\Delta \text{Teff} = \text{Teff2} - \text{Teff1}$, in particular, is very small (0.26). We also tried to correlate $\Delta M(\text{JH})$ with other «physically-bound» DR2 parameters such as single Teff values or color indices (BP-RP) without success.

The small size of the data set and our limited knowledge on photometry and astrophysical issues make it difficult to decide whether the previous negative results are due to incorrect measurements (intrinsic accuracy and/or too wide passbands), badly chosen physical indices (with Teff not being a good estimator of the spectral type for instance) or both.

6. Conclusion

The results reported in this paper confirm that observing and measuring visual binary stars in SWIR is

(Text continues on page 579)

[†] Contrary to pure reflectors, and because of the correcting plate, the position of focus in a Schmidt-Cassegrain telescope depends on the observed wavelength.

^{††} This computation was carried out using the GDS [11] software.

[‡] The GAIA G mag corresponds to a passband going from 300 to 1000 nm approximately. It therefore should not be confused with the passband of our Astronomik «G» filter.

^{‡‡} As clearly evidenced on the images reproduced in Plate 1. This is a consequence of the classical dependence of the turbulence effects on the wavelength.

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Table 1. Observed Pairs

WDS		GAIA DR2					
ID	NAME	GPA (°)	Gsep (arcsec)	Gmag1	Teff1 (K)	Gmag2	Teff2 (K)
16315+3331	BU 816	221.1	5.04	7.08	7982	11.48	5172
16492+4559	BU 627A, BC	42.4	2.11	4.80	8974	8.29	5096
16530+4045	A 1868	302.3	2.13	9.46	5069	9.82	4707
17344+1310	A 2184AB	31.4	1.93	7.22	7412	10.20	5287
17561+2130	STT 339	170.0	4.19	8.13	5806	10.40	4774
17564+1820	STF2245BA	111.9	2.64	7.14	5038	7.39	9554
17571+4551	HU 235	286.2	1.59	6.70	6268	8.91	5096
18222+1126	STF2311AB	86.7	3.03	9.19	4802	9.49	3813
18338+1744	STF2339AB, CD	276.6	1.55	7.30	6876	8.69	5096
18443+3940	STF2382AB	346.1	2.29	4.95	8400	6.02	6497

Table 2. Measurements

ID	Date	G			R			JH			NOTE
		PA (°)	SEP (arcsec)	ΔM	PA (°)	SEP (arcsec)	ΔM	PA (°)	SEP (arcsec)	ΔM	
16315+3331	2018.484	219.4	5.11	5.2	220.9	5.03	4.5	219.5	5.35	4.1	1
16492+4559	2018.495	43.6	2.22	2.3	n/a	n/a	n/a	42.0	1.96	2.4	2
16530+4045	2018.484	303.3	2.27	2.3	303.8	2.38	2.5	304.4	2.06	1.0	3
17344+1310	2018.495	41.0	1.64	2.3	34.2	1.82	2.3	31.3	1.88	2.4	4
17561+2130	2018.484	168.0	4.26	2.5	169.4	4.20	2.5	169.4	4.21	2.1	
17564+1820	2018.495	112.5	2.52	2.0	112.3	2.45	1.7	112.5	2.60	1.9	5
17571+4551	2018.495	285.1	1.85	2.2	289.4	1.82	2.4	286.8	1.60	2.0	6
18222+1126	2018.484	264.4	3.08	1.4	265.1	3.09	1.3	264.4	3.06	1.1	7
18338+1744	2018.495	274.1	1.63	1.1	275.9	1.46	1.2	277.4	1.69	1.1	
18443+3940	2018.495	346.3	2.22	0.8	345.1	2.21	0.8	345.1	2.25	0.8	8

Notes for Table 2

1. B faint on G image. Large ΔM
2. G image slightly elongated due to imperfect ADC setting. Companion not detected on R image
3. Companion significantly brighter on J image
4. G image imperfectly reconstructed
5. J image slightly elongated
6. Companion on first diffraction ring
7. Artefact on all images due to imperfect bispectrum-based reconstruction
8. ε1 Lyrae

Table 3 – O-C residuals for pairs having a known orbit

NAME	WDS ID	DATE	O-C PA (°)	O-C SEP (")	GRADE	REF
BU 627A, BC	16492+4559	2018.495	1.95	-0.145	5	Fmr2012a
STF2382AB	16492+4559	2018.495	0.33	0.022	4	Nov2006e

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(Continued from page 577)

technically feasible by amateurs with a relatively modest equipment (there are now several companies selling small SWIR cameras at affordable prices). To the best of our knowledge this is the first time that a combination of SWIR imaging and speckle-based reduction techniques are used in the amateur field.

The best usage of such observations, however, should be carefully thought of. Photometric issues, in particular, should be investigated to see whether differential magnitude measurements in J and/or H bands can really help the determination of spectral types.

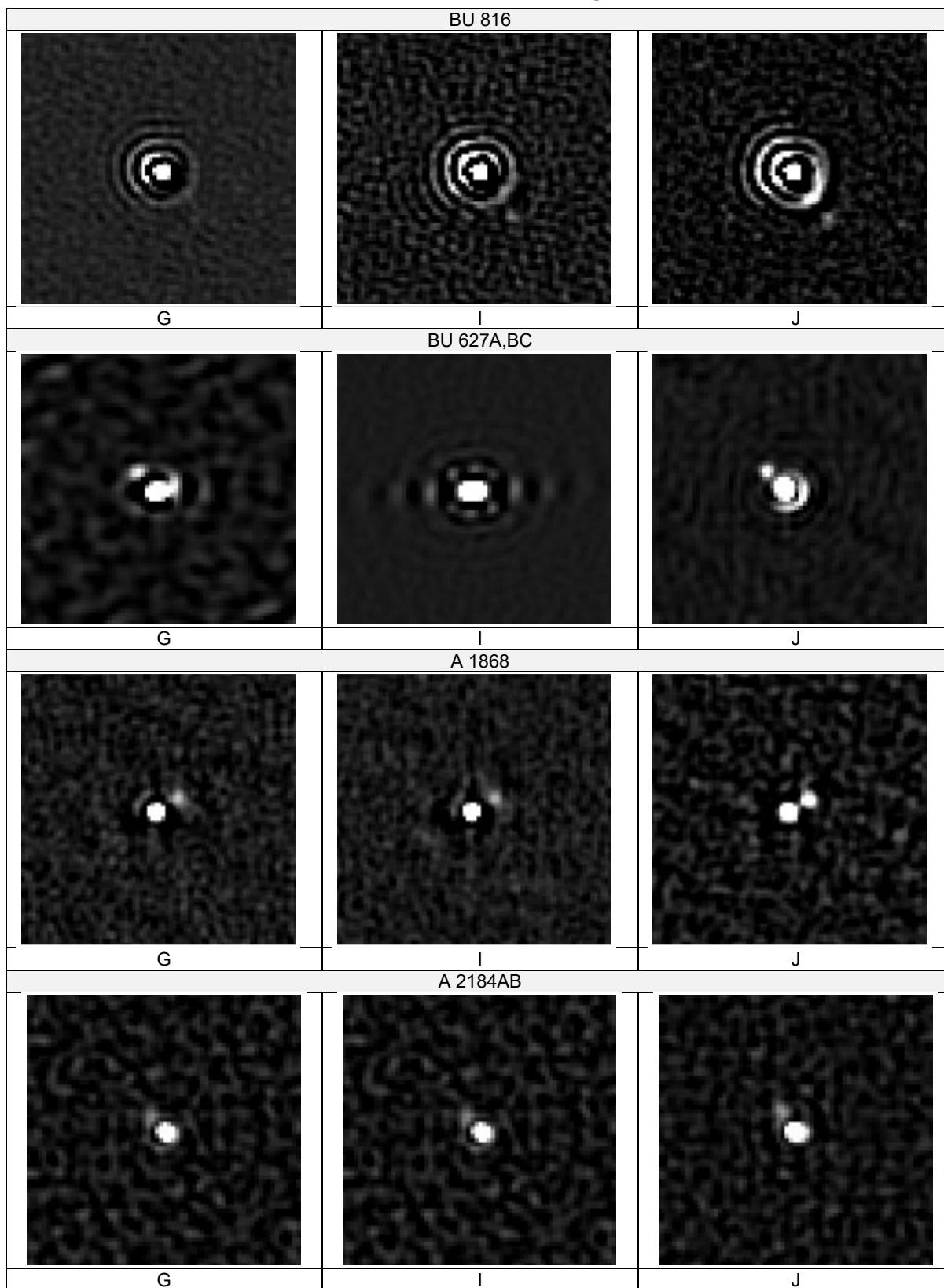
As already stated in our first paper on this subject, the systematic search of companions of late (M) spectral types which could have been left uncovered by optical surveys such as GAIA is also a interesting application of the instrumental techniques described here.

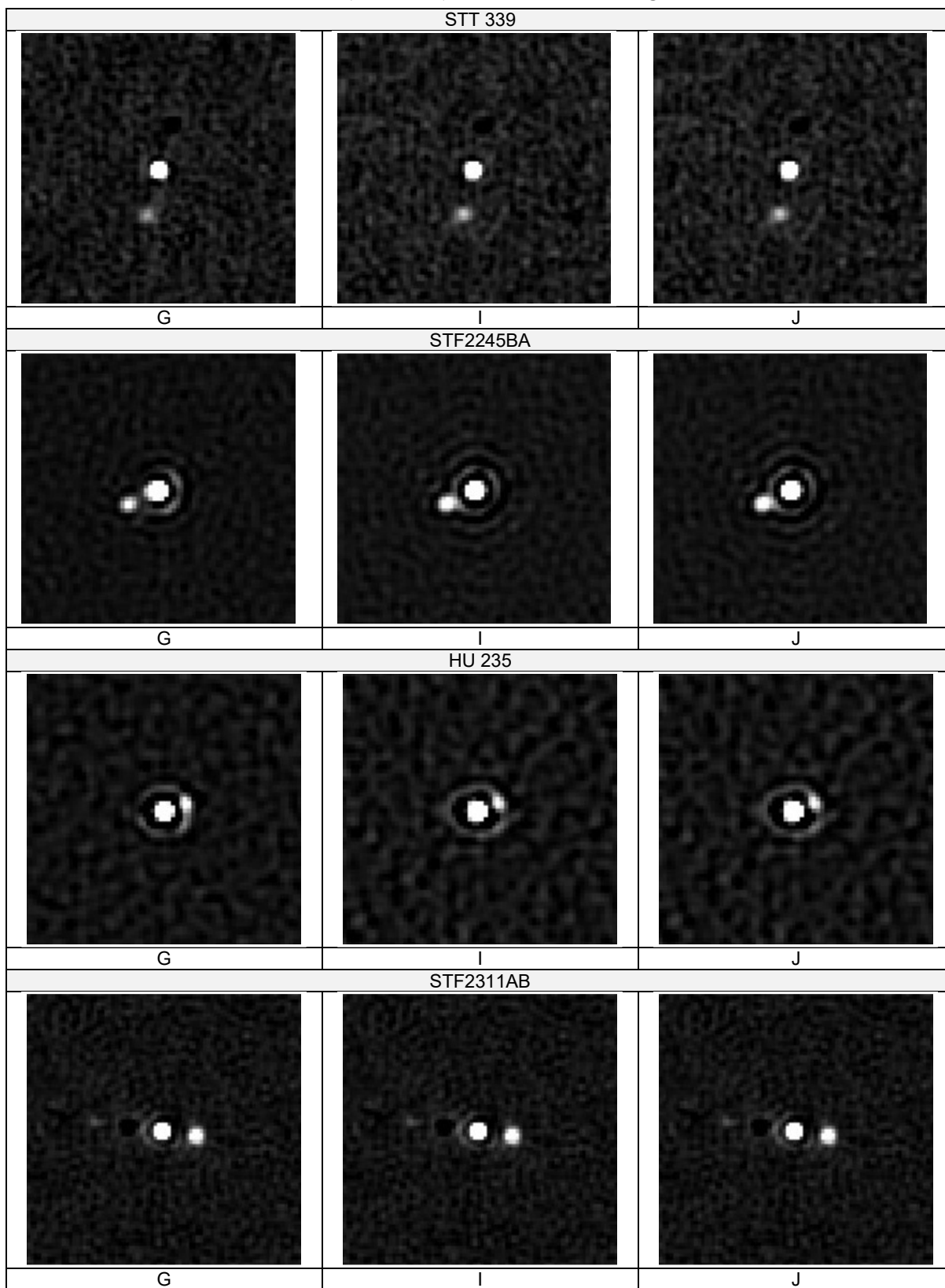
7. Acknowledgments

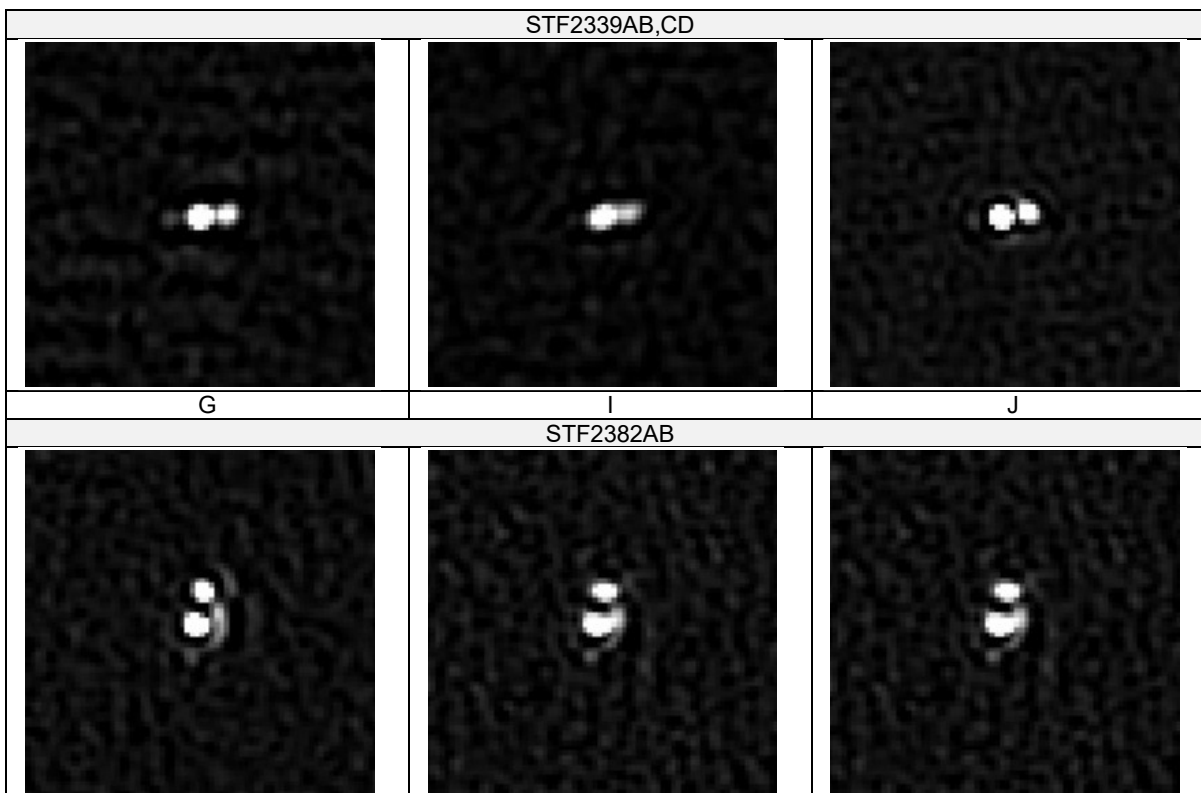
This research has made use of the Washington Double Star and 6th Orbit catalogs maintained at the U.S. Naval Observatory and of data from the European Space Agency (ESA) mission Gaia (www.cosmos.esa.int/gaia), processed by the Gaia Data Processing and Analysis Consortium [10]. Data reduction was carried out using the Reduc software developed and maintained by F. Losse and the SpeckleToolbox software developed and maintained by D. Rowe. We have been using the Owl 640 camera courtesy of J.E. Communal (Raptor Photonics)

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Measurements of Visual Binary Stars with a SWIR Camera and a 280 mm Reflector – Part 2*Plate 1. Post-Reduction Images*

Measurements of Visual Binary Stars with a SWIR Camera and a 280 mm Reflector – Part 2*Plate 1 (continued). Post-Reduction Images*

Measurements of Visual Binary Stars with a SWIR Camera and a 280 mm Reflector – Part 2*Plate 1 (conclusion). Post-Reduction Images*

The Enigmatic Object A2909AB: Double, but not Binary

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Abstract: The 0.1" classical visual pair A2909AB (HD 21161) is a single star, despite its computed orbit with a period of 11 years. This is evidenced by the speckle non-resolutions at 4.1-m telescope during 12 years, constant radial velocity, and the absolute magnitude corresponding to a single main-sequence star. This object resembles another “ghost” pair A3010, also a single star. We argue that all documented resolutions of these single stars cannot be spurious. The occasional image doubling could instead be caused by a yet unexplored phenomenon. One speckle resolution of A2909AB in 2013.7 is critically examined and found to be reliable.

1. Introduction

In this note, we discuss observations of the visual double star A2909AB and show that it is a single star, not a binary. Yet, several resolutions of this star by visual observers and one speckle resolution cannot be easily dismissed as spurious. If these resolutions are real, the occasional image doubling should be caused by some new, yet unexplored phenomenon. Therefore, the available data merit a close examination.

Cases of visual observers reporting spurious measurements are quite common. If a reliable orbit of the binary system is computed, its past “resolutions” at times when it was too close to be resolved clearly stand out as spurious. Other techniques (e.g. lunar occultations and speckle interferometry) also supplied a number of well-documented spurious resolutions, for various reasons that are, mostly, well understood.

However, when a given single star has been resolved repeatedly by different observers, it is unlikely that all those resolutions are spurious. Such is the case of A3010 (WDS 05074+1839, 104 Tau, HD 32923) discussed by Tokovinin (2012). This is a nearby (16 pc) dwarf of spectral type G4V with a constant radial velocity (RV). Speckle monitoring at different telescopes, started at Kitt Peak in 1976.9 and continued at SOAR until 2018, shows the star to be unresolved and certainly invalidates its orbit with a period of 1.1 yr computed

by O. Eggen from the visual resolutions. Such objects – single stars occasionally seen as double – were named “ghosts”.

The object of this note is a bright nearby star HIP 15868 (HD 21161, WDS J03244-1539, ADS 2524). Aitken (1918) resolved it for the first time in 1918 into a triplet consisting of the close pair AB at 0.13" separation and the distant and faint companion C at 17" from AB; the object is designated as A2909. According to the recent astrometry by Gaia (Gaia collaboration, 2018), the stars AB and C have common parallaxes, proper motions (PMs), and RVs, and, therefore, form a wide physical binary system. Their parameters are listed in Table 1.

The inner pair AB has been repeatedly measured by visual observers; the last visual resolution of AB was recorded in 1962. The WDS database lists 7 visual resolutions of AB and 6 non-resolutions. The orbit of AB with a period of 11.35 yr was computed by Docobo et al. (2016). The triple system is featured in the Multiple-Star Catalog (Tokovinin, 2018a). Yet, here we present compelling evidence that the binary AB does not exist and argue that this is yet another case of unexplained “ghost” pairs (Tokovinin, 2012). However, in this case one resolution of AB by speckle interferometry has been reported.

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2. Observations of A2909AB at SOAR

Owing to the orbit with a relatively short period, the pair AB has been observed by speckle interferometry at the 4.1-m SOAR telescope 14 times, from 2007.8 to 2019.6. The instrument and data processing are described by Tokovinin (2018b). Only once, in 2013.74, the star was resolved at 140.15° , $0.032''$, and $\Delta m = 0.59$ mag. The remaining non-resolutions contradict the orbit by Docobo et al. (2016), which predicts separations from $0.09''$ to $0.17''$ for the epochs of these observations, while WDS gives $\Delta m = 0$ mag. The SOAR measurement on 2013.74 was used in the orbit calculation and, consequently, it fits the orbit.

We examined all archival speckle data from SOAR and confirmed that they are of adequate quality. Hence, the non-resolutions of A2909AB are reliable and not caused by the poor data. The resolution in 2013.74 merits a special discussion. As usual, two consecutive data cubes, of 400 frames each, were recorded with individual exposure time of 5 ms. The filter y (wavelength 543 nm, bandwidth 22 nm) was used. The zenith distance was 24.2° , and the atmospheric dispersion was corrected in the instrument. The power spectra computed from the two data cubes are similar and show an obvious elongation (Figure 1). The two objects observed just before, STF 147 and HDS 441, do not have such elongation; the first is used as a reference for deriving the separation, position angle, and Δm of A2909AB.

Could the observed elongation of the power spectrum be spurious? It corresponds to the horizontal direction, hence should not be caused by the uncorrected atmospheric dispersion. Moreover, we checked that the prisms were positioned correctly by comparing their settings with preceding and following observations (the prism angles are recorded in the FITS headers). Telescope vibration can blur the speckles as well. The SOAR telescope is known to vibrate occasionally at 50 Hz (Tokovinin, 2018b). However, the short exposure time of 5 ms (1/4 of the vibration period) largely mitigates the elongation caused by vibrations. Furthermore, we do not see such elongation in other objects observed

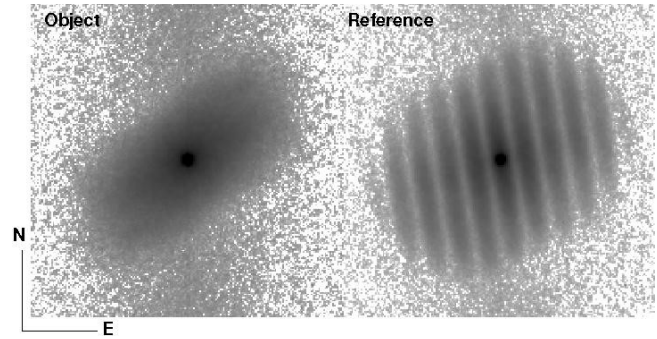


Figure 1: Power spectrum of A2909AB recorded at SOAR in the y filter on 2013.74. It is displayed on the negative logarithmic stretch on the left and is accompanied by the reference spectrum (binary STF 147) on the right, used to derive the position and Δm of A2909AB. Two similar data cubes of the object and reference recorded on the same night are available.

before and after A2909AB. In conclusion, the doubling of A2909AB observed at SOAR on 2013.74 appears to be real, although its instrumental nature cannot be totally ruled out. The non-resolutions on other visits are very secure. The star C, at $17''$ from AB, is much fainter than AB and could not be confused with it.

3. Previous Resolutions, Orbit, and Other Data

All 13 visual observations of A2909AB recorded in the WDS database were kindly provided by B. Mason. In 7 cases the pair was measured (separations from $0.12''$ to $0.14''$), in one case only the elongation was noted, and in 5 other visits the pair was unresolved. The pair was also unresolved by Hipparcos and by Gaia (otherwise Gaia would not measure accurate parallax and PM). Comparison between the PMs and positions measured by these satellites shows that the astrometric acceleration does not exceed 0.1 mas yr^{-1} – a strong indication that this star is not a binary.

The orbit of A2909AB computed by Docobo et al. (2016) is shown in Figure 2. It is based on the 7 visual measures and on one speckle measure at SOAR, depicted by the blue circle and flipped to $\theta = 320^\circ$. With the

Table 1: Main parameters of A2909AB and A2909C

Parameter	AB	C	Ref.
R.A. (J2000)	03:24:24.73	03:24:23.89	Gaia DR2a
Dec. (J2000)	-15:39:13.8	-15:39:17.2	Gaia DR2
Parallax (mas)	19.531 ± 0.043	19.673 ± 0.038	Gaia DR2
PM (mas yr ⁻¹)	221.29, -100.65	218.05, -100.18	Gaia DR2
RV (km s ⁻¹)	29.98 ± 0.15	30.31 ± 0.56	Gaia DR2
V (mag)	7.51	12.70	SIMBAD
K (mag)	6.05	8.66	SIMBAD
Sp. type	G1/2V	M0?	SIMBAD

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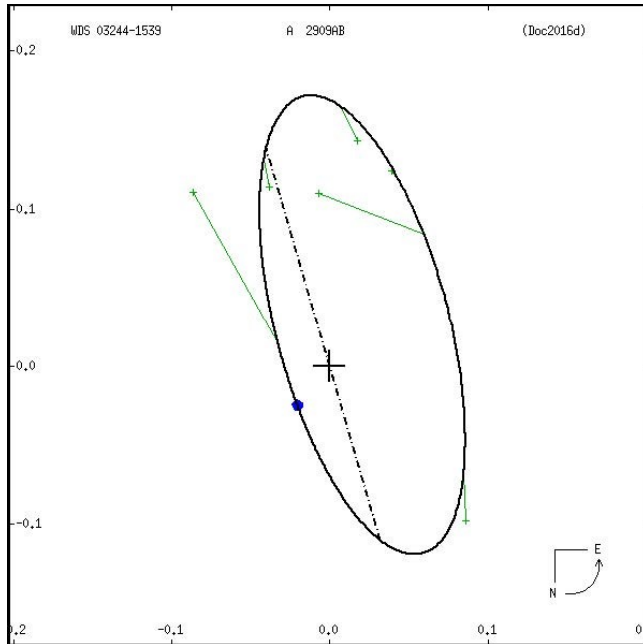


Figure 2. The orbit of A2909AB by Docobo et al. (2016) as represented in the Sixth Orbit Catalog: $P = 11.35$ yr, $e = 0.507$, $a = 0.172''$, and $i = 71.4^\circ$.

Gaia parallax, the orbit corresponds to the mass sum of $5.3 M_\odot$, while the mass sum estimated from the absolute magnitudes of A and B (as given by the WDS) is $2.05 M_\odot$. The orbit is suspicious, despite the grade 3 assigned to it in the Sixth Orbit Catalog (Hartkopf, Mason & Worley, 2001). Although the semimajor axis and period of AB do not quite match the expected mass sum, they are mutually consistent. A pair of solar-type stars of $0.1''$ separation at 50 pc distance should have the period of the order of 10 years. So, the non-resolutions at SOAR during 12 years are highly significant and mean that the star A2909AB is not a binary (incidentally, the wide pair AB,C is a binary).

Believed to be a close binary, this star has attracted attention of other observers. Notably, the survey by Nordström et al. (2004) reports 43 radial velocity (RV) measurements over a time span of 6676 days (18.3 yr). The mean RV is 29.40 km s^{-1} , the rms scatter is 0.3 km s^{-1} , and the probability that such a scatter is caused by measurement errors (in other words, that the RV is constant) is $P(\chi^2) = 0.83$. Gaia measured a similar RV (Table 1). On the other hand, a 10-year binary is expected to have an RV amplitude of $\sim 15 \text{ km s}^{-1}$ multiplied by the inclination factor $\sin i$. This factor is large ($i = 71^\circ$) according to Docobo et al. (2016). So, the constant RV strongly contradicts the claimed binarity of A2909AB. Apparently, this object is being monitored

in search of exoplanets using HARPS (Sousa et al., 2011). It has been targeted by several spectroscopic studies of abundance, and none of those mentions double lines.

The photometry and parallax listed in Table 1 place the stars AB and C on the main sequence in the color-magnitude diagram. If AB were a close pair of equal stars, it would be located at 0.75 mag above the main sequence.

4. Discussion

The object A2909AB is a single star occasionally resolved as a double, similarly to A3010. Those two ghosts have several common features. Both are nearby solar-type stars. They were resolved at separations of the order of $0.1''$ with $\Delta m = 0$ (equal components). The position angles appear random (erratic), and the orbits computed from the historic measurements contradict modern speckle non-resolutions. Evidently, these orbits are spurious.

If the occasional image doubling of these stars is (or was) real, what could cause it? Light can be deflected by refraction or by a gravitational field, splitting the image in two or more components. For example, we might envision that the star is surrounded by a thin gaseous disc with a strong vertical density gradient that refracts the rays. If such a disc is on the line of sight, we would see two refracted images of the central star on both sides of the disc. However, deviation of light by a refracting medium or by a gravitational field is usually accompanied by the wave-front curvature and by the corresponding change of the flux. Only a perfect prism deviates the light without affecting the flux, but a prism cannot double the image. Substantial photometric variability of the two ghost binaries discussed here would have been noticed (e.g. by Hipparcos). Therefore, the image doubling of ghosts by a hypothetical lens (either refractive or gravitational) located on the line of sight seems unlikely.

Gravitational waves stretch the image in one direction and compress it in another direction without changing the flux. The amplitude of a gravitational wave needed to split the image by $\sim 0.1''$ (10^{-6} radians) is many orders of magnitude larger than expected from natural sources of gravitational radiation, even if the wave is aligned with the line of sight, amplifying the effect. So, this exotic hypothesis is also unlikely.

If the doubling were caused by a hypothetical polarizing medium on the line of sight, there would be no flux variation, and the resulting pair would always have $\Delta m = 0$, as observed. Moreover, the gravity center of the blended image would not be displaced, and there would be no detectable astrometric effect. So, a “Wollaston” prism on the line of sight splitting the light

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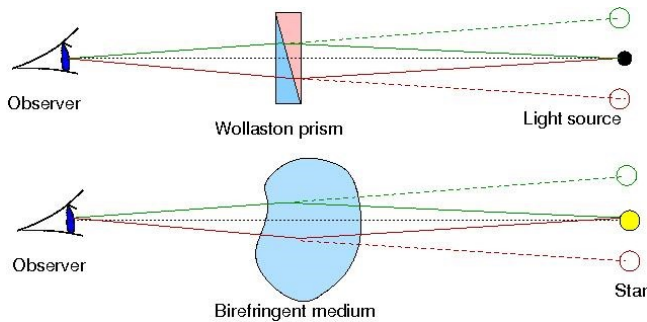


Figure 3. Doubling of the image of a light source caused by the polarizing Wollaston prism (top) and doubling of the image of a star by a hypothetical birefringent cloud (bottom). Green and red lines depict the light rays with different polarizations.

in two linear or circular polarizations could explain the doubling of ghosts. In this case, the two components would be strongly polarized, and this can be verified by speckle polarimetry (Safonov et al., 2019) or by a polarization-dependent displacement of the image photo-center.

Figure 3 illustrates image doubling produced in the laboratory by a Wollaston prism and a similar hypothetical doubling of stellar image that could be produced by a birefringent medium on the line of sight. In the latter case, the linear distance between the polarized images separated by $0.1''$ in angle would be ~ 5 AU if the star is at 50 pc distance. The size of the birefringent cloud should be of the same order or larger. Typical relative velocities of stars in the Galactic disc are $\sim 15 \text{ km s}^{-1}$ or $\sim 3 \text{ AU yr}^{-1}$. So, a chance alignment between the polarizing cloud and the star could be preserved on a time scale of the order of a year.

We prefer not to speculate on the nature of hypothetical “Wollastons” in the interstellar medium. Note, however, that interstellar scintillation of pulsars reveals the existence of elongated sheets of ionized interstellar gas, presumably shaped by magnetic fields, that deviate and split images of pulsars in the radio domain (Gwinn, 2019).

Despite the facts presented here, the phenomenon of ghosts remains elusive and still needs confirmation. Repeated doubling of a single star recorded by modern speckle interferometers would provide such a confirmation. We continue to revisit the known ghosts A3010 and A2909AB at SOAR in hope of detecting a new doubling. Obviously, ghosts (if they exist) are rare, and

the chances of catching a new doubling are small. If the doubling is detected, a polarization test should be made as soon as possible.

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Double Star System: WDS 01171-2314 (HWE3)

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Abstract: Data was collected from observing the double star system WDS 01171-2314 (HWE3). The current measurements taken show theta of 287.7° , and rho of $7.83''$. Compared with previous data from the Washington Double Star Catalog, the two stars in the system have not moved substantially in the 140 years they have been observed.

Introduction

The research objective was to measure the position angle (theta) and the separation (rho) of WDS 01171-2314 (HWE 3) and compare it to previously documented data to determine the star system's nature as either a gravitationally bound binary star, or an optical double star. Data from the first observation in 1875 and most recent in 2015, as indicated in the Washington Double Star Catalog (WDS), are very similar (Mason and Hartkopf, 2016). Additional data was retrieved from the GAIA database for inclusion in the study and showed the most recent observation in 2015.5, with a theta measured as 288° and rho $7.6''$.

Materials and Methods

The images were taken with an SBIG camera paired with a 0.4-meter telescope provided by the Los Cumbres Observatory (LCO) worldwide network. The LCO images have a resolution of $0.571''/\text{pixel}$. The telescope and camera used to take the images is located in Chile at an altitude of 2198 meters, Figure 1.

The filters and exposure times used were a Sloan red filter (RP) for four seconds, a Sloan green filter (GP) for four seconds, a Sloan infrared filter (IP) for six seconds, and a Bessel V filter (V) for four seconds. There were a total of 63 images taken, with 18 images for the red filter and 15 images each for the other three filters. The images were taken in 2018.845 (Besselian Epoch).

Each image was processed through the Our Solar Siblings (OSS) Pipeline (Fitzgerald, 2018), which cali-



Figure 1. LCO Telescope kb26.

brated all images and put the World Coordinate System (WCS) coordinates into each FITS header. The images were then measured using Mira Pro x64, which found the centroid of each star, then measured the position and separation angle.

Data and Results

Table 1 shows the mean, standard deviation, and standard deviation of position and separation angles measured for each filter. Table 2 shows the mean, standard deviation, and standard deviation of the position and separation angle data collection of all combined filter measurements.

Double Star System: WDS 01171-2314 (HWE3)*Table 1. Data sorted by filter type*

Filter	Number of Images	Theta (Mean)	Standard Deviation	Rho (Mean)	Standard Deviation
IP	15	$287.78^\circ \pm 0.020^\circ$	0.01	$7.83'' \pm 0.003''$	0.08''
GP	15	$287.58^\circ \pm 0.038^\circ$	0.02	$7.82'' \pm 0.004''$	0.15''
RP	18	$287.76^\circ \pm 0.023^\circ$	0.01	$7.83'' \pm 0.003''$	0.09''
V	15	$287.67^\circ \pm 0.037^\circ$	0.02	$7.83'' \pm 0.005''$	0.14''

Table 2. All data averaged together.

	Mean	Standard Deviation	Standard Deviation of the Mean
Theta	287.70°	$\pm 0.14^\circ$	$\pm 0.018^\circ$
Rho	$7.83''$	$\pm 0.02''$	$\pm 0.002''$

Discussion

A negligible change was observed in the theta and rho values between the historical trend and the current observation data. Figure 2 visually represents the historical data for HWE3 in a scatterplot, with the current observation added and labeled as 2018. Table 3 lists each historical data point with the accompanying date and the current observation written in italics.

Discrepancies were found between the GAIA and SIMBAD data for this star system. SIMBAD indicates the possibility that this system may be a triple-star system (SIMBAD WEB), Figure 3. The three possible stars are two from the Tycho catalog (TYC 6425-1209-1 & TYC 6425-2478-1) and one from the Henry Draper catalog (HD 7776). Taken collectively, this would appear to be triple star system with TYC 6425-1209-1 and HD 7776 being spaced approximately 0.03'' apart and

TYC 6425-2478-1 being the possible third star. However, the WDS reports this as a two-star system.

The RA and Dec measurements of TYC 6425-1209-1 and HD 7776 are two slightly different measurements of Right Ascension 01 17 05.622 Declination -23 14 18.87 and Right Ascension 0117 05.61862 and Declination -23 14 18.8357 respectively. The DSS image, via ALADIN, Figure 4, shows the area in question. In Figure 4, the North and East indications differ from what is traditionally displayed in Double Star papers. However, the orientation has been left in the original orientation per the DSS and GAIA images as provided by ALADIN. The resolution of Figure 4 does not permit clear identification of all stars in the region.

Using data in the GAIA, only two stars were apparent in the region identified by small squares from ALADIN, Figure 5. Though it is not possible to determine which database is more accurate, the discrepancies in RA and Dec position could be attributed to the difference in epoch and methodologies between the Henry Draper and Tycho catalog measurements and it is possible that HWE3 remains a two-star system, with the SIMBAD reported stars TYC 6425-1209-1 and HD 7776 possibly being the same star. The two stars shown in Figure 5 from GAIA have a theta and rho similar to the historical measurements outlined in this paper.

Using additional GAIA catalog data, both stars in the system have similar proper motion RA and Declination; any difference is trivial. The near identical radial velocity values found in Table 4 are expected of a physical pair. The parallax data from Table 4 was converted to Parsec and Light Year distances for both stars, Figure 6. The parallax data suggests that both stars are lo-

(Text continues on page 590)

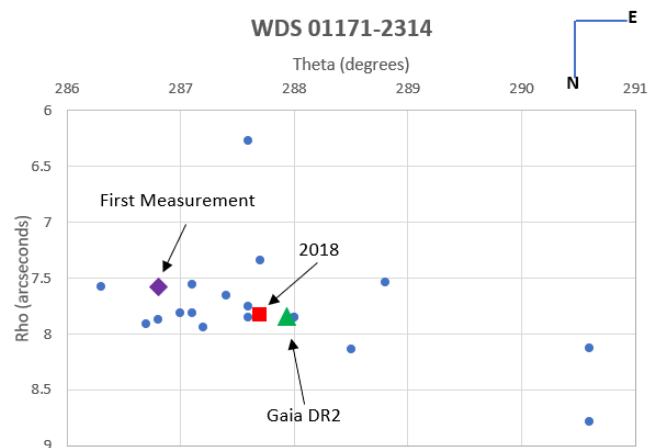


Figure 2. Current observation as compared to previous historical data (observations).

Double Star System: WDS 01171-2314 (HWE3)

Table 3. The 2015.5 data point is from the GAIA catalog, while all points before that are from the WDS catalog. The italicized numbers are the current observation.

Date	Theta	Rho		Date	Theta	Rho
1875.85	286.8	7.58		1922.96	287.4	7.66
1877.87	286.8	7.58		1931.9	287.6	7.75
1877.86	286.8	7.87		1962.9	288.5	8.14
1885.74	288.8	7.54		1991.25	288	7.856
1891.77	287.2	7.94		1991.55	287	7.818
1909.79	286.7	7.91		1991.795	288	7.851
1909.84	287.6	6.274		1998.63	287.1	7.81
1921.89	290.6	8.79		1999.556	287.6	7.851
1921.89	290.6	8.126		2010.5	287.1	7.56
1921.9	287.7	7.34		2015.5	287.93	7.84
1921.9	286.3	7.579		2018.	287.7	7.83

N ^o	Identifier	dist(asec)	Otype	ICRS (J2000) RA	ICRS (J2000) DEC
1	TYC 6425-1209-1	0.04	*	01 17 05.622	-23 14 18.87
2	HD 7776	0.07	**	01 17 05.61862	-23 14 18.8357
3	TYC 6425-2478-1	7.87	*	01 17 05.0763060216	-23 14 16.481978821

Figure 3. SIMBAD identified objects with in 10 arcseconds of the primary star.

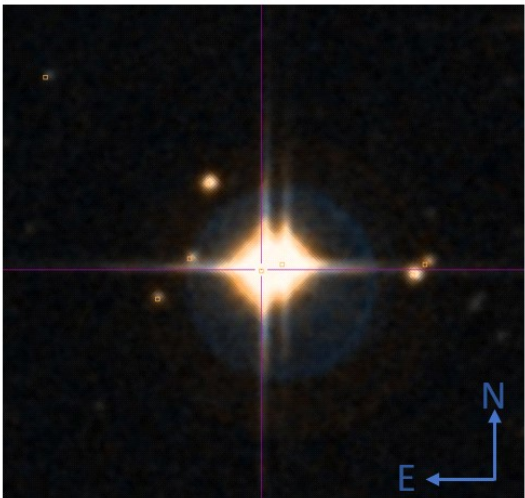


Figure 4. DSS image from ALADIN

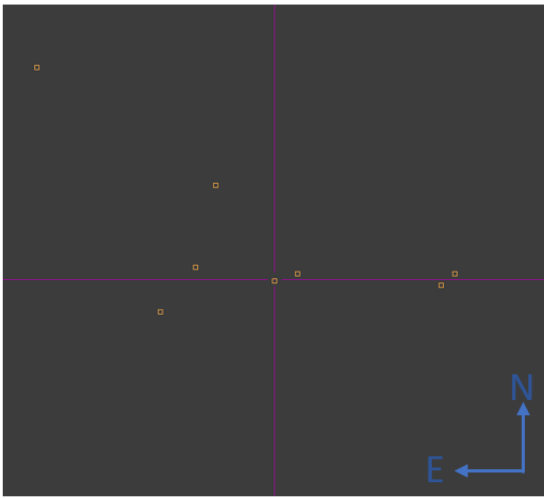


Figure 5. Gaia image from ALADIN

Double Star System: WDS 01171-2314 (HWE3)*Table 4. Gaia Proper Motion, Parallax, and Radial Velocity Data*

Star	Proper Motion RA	Proper Motion Dec	Radial Velocity	Parallax
Primary	18.05 ± 0.17	-0.7 ± 0.13	2.42 ± 0.73	5.5 ± 0.07
Secondary	17.79 ± 0.93	1.75 ± 0.90	0.86 ± 0.49	5.2 ± 0.42

(Continued from page 588)

cated close to each other in space; there is significant overlap when the margin of error is considered.

Conclusion

Astronomical measurements of position angle and separation in 2018.845 of the double star system HWE 3 were made using the KB26 telescope in the LCO network. Analysis of 63 images taken with four different filters revealed that the rho and theta data did not vary significantly from historical data in a noticeable pattern. There is significant overlap between the parallax data and the stars are, therefore, statistically identical. Collectively, the radial velocity, parallax, and proper motion data are typical of a physical pair. The data taken from observations and databases indicates a possible binary star system.

Acknowledgments

We would like to thank Pat Boyce and Grady Boyce for their support and for providing us with the materials and resources necessary. Special thanks to Jerry Hilburn for his continuous assistance throughout the course of this research as well as Grady Boyce for his aid in editing this paper. This research uses information found on the Washington Double Star Catalog made possible by the United States Naval Observatory. Investigators and mentors are part of BRIEF. This research also has used data from Stelle Doppie. This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France. LCO was the observatory used to produce images of the star system from which data was collected. Mira Pro x64 was used in analyzing and collecting the data from the images. Researches are associated with Westview High School and Mt. Everest Academy respectively and all mentioned are associated with Boyce-Astro.

This work has made use of data from the European Space Agency (ESA) mission Gaia (<https://www.cosmos.esa.int/gaia>), processed by the Gaia Data Processing and Analysis Consortium (DPAC, <https://www.cosmos.esa.int/web/gaia/dpac/consortium>). Funding for the DPAC has been provided by national institutions, in particular, the institutions participating in the Gaia Multilateral Agreement.

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Double Star Measurements of WDS 13367+2847 (GRV870AB)

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3. Boyce Research Initiative and Education Foundation (BRIEF)

Abstract: Using data from Global Astrometric Interferometer for Astrophysics (GAIA), Washington Double Star Catalog and Aladin 10, we gathered data about WDS 13367+2847 GRV870AB, C, further referred to as GRV870AB, C. This data includes magnitude, distance and proper motion. Our objective was to analyze whether star AB may be gravitationally bound to C. Images of GRV870AB, C were acquired using the remote telescope network Las Cumbres Observatory (LCO) using a 0.4-meter modified Meade telescope. From the images we calculated the mean position angle and separation of AC $118.70^\circ \pm 0.03^\circ$ and $22.49'' \pm 0.019''$ on 2019.289.

Introduction

This research, part of an Astronomy Research Seminar conducted by Boyce Research Initiatives and Education Foundation (BRIEF) and offered by San Diego Mesa College, explored the history of WDS13367+2847 GRV870AB, C, Figure 1, and took measurements to provide an updated Theta (position angle) and Rho (angular separation) measurement for this pair. Data was collected using GAIA, the Washington Double Stars Catalog (WDS), and Las Cumbres Observatory (LCO) remote telescopes. GAIA is a telescope launched by the European Space agency in 2013 with a mission to catalogue a billion stars and chart their position, distances, motion and changes in brightness over a five-year period. It is expected to be 10,000 times more accurate than Hipparcos (GAIA, 2016).

The first measurement of GRV870AB, C was taken in 1896 measuring theta of 117.3° and rho $22.57''$ (Mason, 2019). Measurements of theta at 118.7° and rho $22.53''$ were recorded in 2001. Proper Motion of GRV870AB, C is recorded as -24.43 for star AB and -21.64 for star C. One component of our star system, the AB pair, are two stars closely spaced together making it difficult to distinguish them apart from each other without the use of spectroscopy hence the designation

of AB. Based on the proper motion of the stars (GAIA, 2016) we decided to see if star C may be gravitationally bound to AB.

Materials and Methods

Images of GRV870AB, C were requested via the Las Cumbres Observatory (LCO). A 0.4-meter modified Meade telescope with a SBIG STX-6303 CCD camera, located at Mt. Haleakala, Hawaii, 10,000 feet above sea level, was used to acquire images of this pair. It provided a resolution of $1.14''/\text{pixel}$ and a field of view of $19' \times 29'$ arcminutes.

A total of 10 images were acquired with the following filter and exposure configurations: clear filter at 8, 10, and 12 second exposure times, and an SDSS g filter at 5 and 7 second exposure times. Because both the AB and C stars are G0 class stars, the clear filter was used. The peak wavelength emitted by G0 class stars is in the yellow range of visible light, so the band-pass of the g filter captures the most light for this system. The exposure times were calculated through the LCO Exposure Time Calculator, taking into account the magnitude of the stars, filter and telescope used, moon phase, air mass, and PkDN (peak number of counts) in the image.

The images were processed through the Our Solar

Double Star Measurements of WDS 13367+2847 (GRV870AB)



Figure 1. Image of GRV870AB,C

Siblings (OSS) Pipeline (Fitzgerald, 2018). The OSS Pipeline removed bad pixels, cosmic rays, any known camera defects and inserted the World Coordinate System (WCS). The separation distance and angle between the stars were determined using the application AstroImageJ (Collins, et al. 2017).

Results

To eliminate human error, two sets of independent

measurements were taken for the data set: Trial 1 and Trial 2. Using AstroImageJ the calculated position angle is 118.70° and separation is $22.50''$. These results and statistics are summarized in Tables 1 and 2.

A graph of the historical data in addition to our measurements of theta and rho, Table 3, provides an illustration of the historical measurements, Figure 2.

Table 1. Calculated Separation and Position Angle of 10 Images

Image Number	Trial 1 Position Angle (deg)	Trial 1 Separation (as)	Trial 2 Position Angle (deg)	Trial 2 Separation (as)
1	118.70°	$22.52''$	118.78°	$22.53''$
2	118.85°	$22.51''$	118.87°	$22.51''$
3	118.63°	$22.48''$	118.60°	$22.47''$
4	118.68°	$22.51''$	118.77°	$22.50''$
5	118.65°	$22.51''$	118.72°	$22.52''$
6	118.61°	$22.55''$	118.56°	$22.50''$
7	118.76°	$22.50''$	118.74°	$22.48''$
8	118.70°	$22.48''$	118.70°	$22.49''$
9	118.67°	$22.55''$	118.68°	$22.53''$
10	118.73°	$22.46''$	118.57°	$22.40''$
Trial Average	118.70°	$22.51''$	118.70°	$22.50''$
Standard Deviation	0.07°	$0.03''$	0.09°	$0.04''$
Standard Error of Mean	0.02°	$0.01''$	0.03°	$0.01''$

Table 2: Measurement Mean and Statistical Error for AB, C.

	Theta	Rho
Mean	118.70°	$22.50''$
Standard Deviation	0.08°	$0.05''$
Standard Error of Mean	0.03°	$0.01''$

Double Star Measurements of WDS 13367+2847 (GRV870AB)

Table 3: Table of Historical Data plus 2019.289 Measurements

Year	Theta	Rho	Observation
1896.31	117.3°	22.57"	WFC1998
1902.48	119.3°	22.58"	WFC1998
1999.32	118.7°	22.44"	TMA2003
2000	119.0°	22.50"	GRV2004
2001.468	118.7°	22.53"	UC_2013
2019.289	118.7°	22.50"	Our Data

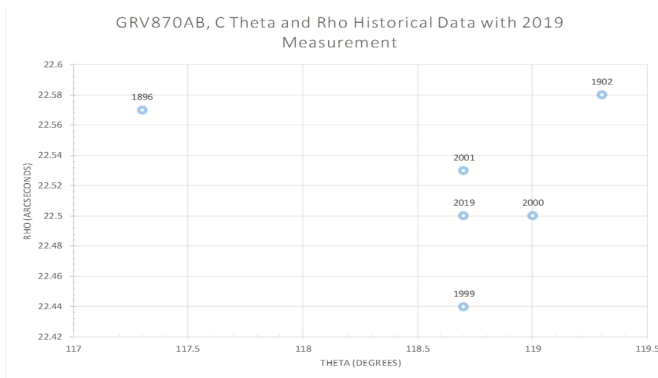


Figure 2: Historical Data plus 2019.289 Measurements of Theta and Rho. The X axis represents theta and the Y axis represents Rho. The year the observation was taken is shown above each dot.

Discussion

Stelle Doppie listed this system as a physical double and a triple system (Stelle Doppie Web). The possibility of the system being a triple star system is why we chose GRV870AB, C. There have been 5 observations of GRV870AB, C since 1896. In addition to our CCD measurements in this paper, we also addressed the radial velocity, proper motion and parallax from the GAIA data.

The radial velocity for AB is listed at -24.43 mas/yr and C was -21.64 mas/yr (Gaia, 2018). Proper motion data for star AB had an RA of 18.93 mas/yr and Dec of 8.5 mas/yr and proper motion for star C had an RA of 12.27 mas/yr and Dec of 11.82 mas/yr (Gaia, 2018).

Parallax, the distance to the star, for AB is 8.36 with a parallax error of ± 0.35 . Parallax of star C is 4.69 with a parallax error of ± 0.033 (GAIA, 2018). Converting these distances to parsecs, the AB distance is 120 pc, uncertainty (± 5 pc). C distance is 213 pc, uncertainty ($\pm 2, -1$ pc), Figure 3.

Comparing the historical measurements with data from this paper, the theta and rho measurements are consistent. When consulting GAIA data to complete the analysis of this system, the radial velocity and proper

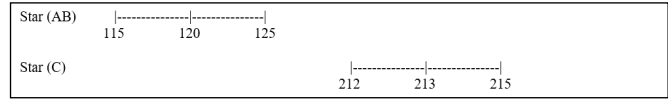


Figure 3. Graphical representation of parsecs with error bars.

motion show similar values yet show differences given a rough margin of error. The radial velocity of the AB star show that it is moving away from us at a faster rate than the C star. When looking at the proper motion of both stars, Gaia shows that the stars are moving around the celestial sphere at different rates, in which the AB star is changing its position faster. The difference in proper motion and radial velocity indicate that the AB star and the C star are not moving together as a system. This is indicative of an optical double. Parallax was the major factor in determining if the stars were gravitationally bound. Due to the large difference in parallax and probability that there is no overlap even with errors, the C star appears to not be gravitationally bound to the AB stars.

Conclusion

Although the stars have similar radial velocity and increasing proper motion it appears that the C star is not gravitationally bound to the AB star due to no overlap in the parallax. With this information we are suggesting this system may be a Y in accordance with the WDS Summary Catalog note flags (Washington Double Star Catalog, 2018). The Y note states: Statistically different parallax for the components indicates they are non-physical.

Acknowledgements

Professor Stephanie Colby and mentor Alexander Beltzer-Sweeney provided guidance for which we are grateful. Brian Mason contributed historical data about our system from the Washington Double Star Catalog of the United States Naval Observatory. We would like to thank all of the individuals and organizations who helped.

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Astronomical Association of Queensland 2017 Program: Blue Star Observatory Measurement of Nine Neglected Southern Multiple Stars

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Abstract: This paper presents partial results of a 2017 programme of photographic measurements of ten southern multiple stars. All results were obtained using an Atik 460EX mono CCD camera used in conjunction with an equatorially mounted 400mm F4.5 Newtonian reflector.

Introduction

These latest results are part of an ongoing program commenced in 2008 by the Double Star Section of the Astronomical Association of Queensland. The target stars were selected from the Washington Double Star Catalog (WDSC) and were observed in Queensland, Australia from a latitude of approximately 27° S.

The results are presented in Table 1. The mean 95% confidence intervals for the new measures were $\pm 0.718^\circ$ in PA and $\pm 0.108''$ in separation.

Method

Sets of images were obtained with the equipment

described above, the images were stacked using Atik DAWN software and then analysed using the astrometric double star program REDUC (Losse, 2008). Approximately ten stacked images of each target were taken per night for seven nights and the results averaged to obtain measures of separation and position angle with sufficient confidence.

Full details of the method are given in Napier-Munn and Jenkinson (2009). Some recent work on the errors inherent in the method is described in Napier-Munn and Jenkinson (2014). As proficiency has grown in the use of this equipment with the 400mm reflector, close doubles with considerable magnitude difference

Table 1. Measurements of Nine Southern Multiple Stars

System	Last listed measure			New measure			Comment
	PA °	Sep. "	Epoch	PA °	Sep. "	Epoch*	
DON119	275	4.5	1942	276.32	4.4	2017.117	Minimal change in 75 years
RSS152	7	9.5	1976	3.52	12.18	2017.109	Clear movement
DON238	15	6.7	1967	13.05	6.04	2017.109	Change in both axes
A1774	274	3.8	1952	270.52	3.81	2017.237	Clear movement
HJ840	93	5.3	1968	92.42	4.35	2017.237	Change in separation
B810	95	3.6	1930	62.47	3.74	2017.259	Considerable change in PA
HU470	251	3.6	1945	245.79	3.72	2017.270	Clear change in PA
RST5533	82	4.1	1951	342.79	4.43	2017.374	Considerable change in PA
RSS327	227	11.1	1976	221.53	11.39	2017.382	Definite change in PA

* Epochs of new measures given in Besselian years as the average of the observations making up the measure.

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between the components have been successfully measured.

Fellow AAQ members Culshaw, Hughes and Hughes provided invaluable assistance with image processing using Losse's REDUC software, and Janke with processing the original FITS image files into JPEG photographs.

Results

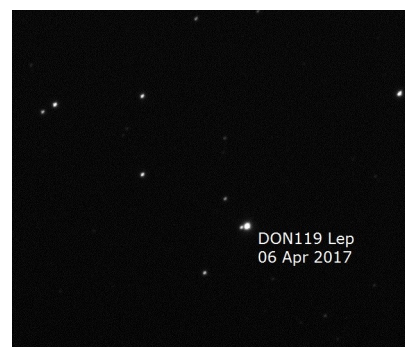
For all of the systems shown below, the WDSC information is first reproduced, showing the epoch 2000 position, magnitudes, separation, PA, and the last

recorded measurement. The new measurements are then given in tabular form, including the mean and standard deviation and 95% confidence limits. Any uncertainties between the images and the last recorded measurements are discussed. Finally a conclusion is given as to whether any movement of the component stars has occurred in PA or separation, based on the P-value for the t-test comparing the new mean values with the cataloged value ($P < 0.05$ is considered as evidence of change).

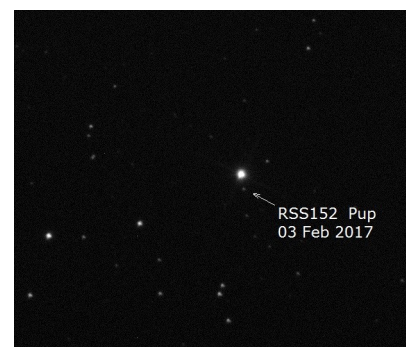
(Text continues on page 600)

DON119	RA. 06 07.1	DEC. -22 59	Last Measure 1942
Lepus	MAG. 9.78 & 13.6	PA. 275°	SEP. 4.5"
Date	No. images	PA°	Sep"
29 Jan 2017	10	276.33	4.419
06 Feb 2017	10	276.79	4.465
08 Feb 2017	10	276.42	4.380
10 Feb 2017	10	275.44	4.366
15 Feb 2017	10	276.28	4.491
17 Feb 2017	10	276.33	4.359
24 Feb 2017	10	276.67	4.318
Mean		276.323	4.400
Std dev		0.434	0.062
95% CI +/-		0.401	0.057
P(t) movement		0.000	0.000
COMMENTS			
Minimal movement in the last 75 years. Increase in PA consistent with increase shown in previous measures, separation may be closing again.			

Please note that all attached images are aligned with North to the bottom and East to the right

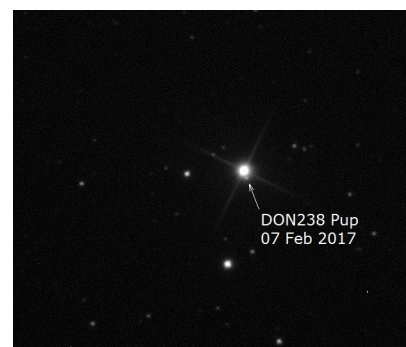


RSS152	RA. 08 18.3	DEC. -26 21	Last Measure 1976
Puppis	MAG. 7.58 & n/a	PA. 7°	SEP. 9.5"
Date	No. images	PA°	Sep"
03 Feb 2017	10	3.26	12.091
06 Feb 2017	10	3.52	12.223
07 Feb 2017	10	3.69	12.226
08 Feb 2017	10	3.34	12.218
10 Feb 2017	10	3.87	12.179
14 Feb 2017	10	3.41	12.129
15 Feb 2017	10	3.54	12.222
Mean		3.519	12.184
Standard deviation		0.210	0.054
95% CI +/-		0.194	0.050
P(t) movement		0.000	0.000
COMMENTS			
Clear movement in both position angle and separation.			



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DON238 Puppis	RA. 08 20.5 MAG. 6.13 & 12.9	DEC. -22 55 PA. 15°	Last Measure 1967 SEP. 6.7 "
Date	No. images	PA°	Sep"
03 Feb 2017	10	13.91	5.823
06 Feb 2017	10	12.70	6.181
07 Feb 2017	10	12.45	6.046
08 Feb 2017	10	14.28	6.072
10 Feb 2017	10	15.24	6.229
14 Feb 2017	10	11.77	6.380
15 Feb 2017	10	13.15	6.121
Mean		13.053	6.043
Std Dev		0.641	0.157
95% CI +/-		1.020	0.249
P(t) movement		0.009	0.004
COMMENTS Three night's data as highlighted not included in reduction due to poor quality seeing/images. Movement evident in both axes.			



A1774 Crater	RA. 11 03.2 MAG. 5.5 & 10.8	DEC. -11 18 PA. 274°	Last Measure 1952 SEP. 3.8"
Date	No. images	PA°	Sep"
17 March 2017	10	269.65	3.873
18 March 2017	10	271.13	3.739
25 March 2017	10	270.76	3.704
27 March 2017	10	269.51	3.762
04 April 2017	10	271.07	4.039
07 April 2017	10	271.94	3.908
09 April 2017	10	269.59	3.615
Mean		270.521	3.806
Standard deviation		0.948	0.143
95% CI +/-		0.877	0.132
P(t) movement		0.000	0.098
COMMENTS Clear movement evident in PA only.			

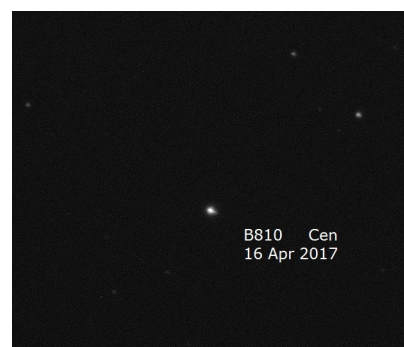


Astro. Assn. of Queensland 2017 Program: Blue Star Observatory Measurement of Nine Multiple ...

<i>HJ840</i>	RA. 11 24.9	DEC. -17 41	Last Measure 1968
<i>Crater</i>	MAG. 4.1 & 7.9	PA. 93°	SEP. 5.3"
Date	No. images	PA°	Sep"
17 March 2017	10	92.06	4.484
18 March 2017	10	91.83	4.335
25 March 2017	10	91.75	4.165
27 March 2017	10	92.92	4.37
04 April 2017	10	92.24	4.268
08 April 2017	10	94.07	4.3
09 April 2017	10	92.05	4.521
Mean		92.417	4.349
Std Dev		0.823	0.123
95% CI +/-		0.762	0.114
P(t) movement		0.000	0.000
COMMENTS			
Clear evidence of movement only apparent in separation.			



<i>B810</i>	RA. 13 22.0	DEC. -38 13	Last Measure 1930
<i>Centaurus</i>	MAG. 9.69 & 13.5	PA. 95°	SEP. 3.6"
Date	No. images	PA°	Sep"
18 March 2017	10	62.37	3.662
25 March 2017	10	61.69	3.766
07 April 2017	10	62.14	3.794
15 April 2017	10	60.72	3.719
16 April 2017	10	63.01	3.623
21 April 2017	10	63.56	3.81
23 April 2017	10	63.8	3.804
Mean		62.470	3.740
Std Dev		1.083	0.074
95% CI +/-		1.002	0.068
P(t) movement		0.000	0.000
COMMENTS			
Considerable movement has occurred in PA. No clear movement evident in separation.			



Astro. Assn. of Queensland 2017 Program: Blue Star Observatory Measurement of Nine Multiple ...

HU470	RA. 13 34.3	DEC. -11 32	Last Measure 1945
Virgo	MAG. 7.9 & 12.9	PA. 251°	SEP. 3.6"
Date	No. images	PA°	Sep"
25 March 2017	10	246.78	3.594
07 April 2017	10	245.72	3.787
08 April 2017	10	243.89	3.697
15 April 2017	10	245.79	3.613
16 April 2017	10	246.65	3.51
21 April 2017	10	245.44	4.173
24 April 2017	10	246.26	3.664
Mean		245.790	3.720
Std Dev		0.973	0.218
95% CI +/-		0.900	0.201
P(t) movement		0.000	0.000
COMMENTS Definite change in PA continues the reduction occurring since the first 1901 measure.			



RST5533	RA. 14 20.4	DEC. -30 02	Last Measure 1951
Hydra	MAG. 9.06 & 15.1	PA. 82°	SEP. 4.1"
Date	No. images	PA°	Sep"
01 May 2017	10	343.39	4.416
23 May 2017	10	342.19	4.466
24 May 2017	10	341.92	4.501
26 May 2017	10	342.75	4.381
27 May 2017	10	343.32	4.386
30 May 2017	10	342.04	4.39
02 June 2017	10	343.94	4.475
Mean		342.793	4.431
Std Dev		0.779	0.049
95% CI +/-		0.721	0.045
P(t) movement		0.000	0.000
COMMENTS Very large change in PA over 66 years.			



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<i>RSS327</i> <i>Centaurus</i>	RA. 14 21.6 MAG. 9.18 & n/a	DEC. -30 53 PA. 227°	Last Measure 1976 SEP. 11.1"
Date	No. images	PA°	Sep"
07 May 2017	10	222.53	11.409
23 May 2017	10	221.39	11.286
24 May 2017	10	221.12	11.443
26 May 2017	10	221.27	11.356
27 May 2017	10	221.89	11.39
30 May 2017	10	221.94	11.48
02 June 2017	10	220.59	11.331
Mean		221.533	11.385
Standard deviation		0.637	0.067
95% CI +/-		0.589	0.062
P(t) movement		0.000	0.000
COMMENTS Definite change in PA.			

*(Continued from page 596)***Acknowledgements**

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