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NEGLECTED NORTHERN HEMISPHERE BINARY STAR SYSTEMS WITH UPDATED SEPARATIONS AND POSITION ANGLES

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ABSTRACT

We observed 58 widely-separated ($\rho > 3''$) northern hemisphere neglected binary star systems listed in the Washington Double Star catalog. Our goal was to obtain current separations and position angles of binaries that had not been observed in years or decades, and compare them with historical data. For each system, we fit Gaussian models to each component to determine the celestial coordinates and the corresponding position angles and angular separations of the binary. We combined these data with proper motions for each component from the recently-published UCAC5 catalog to determine the likelihood that each system was a true binary. We found that 29 candidate binaries were likely *bona fide* binaries, while 17 systems had large proper motion differences between components and were therefore deemed unlikely to be binaries. The remaining 12 systems had no proper motion listed.

1. INTRODUCTION

A comprehensive list of binary systems is the Washington Double Star [hereafter WDS] catalog, which is maintained by the U.S. Naval Observatory (1). The catalog include a list of "neglected" binary systems, consisting of unconfirmed binaries as well as systems which have not been observed for many years.

These systems provide a fertile research area for observers with small dedicated telescopes, as their properties can only be deduced by combining careful synoptic measurements with historical observations. This, in turn, can be used to create an aggregate database spanning many years. As an example, consider two solar-mass stars in a visual binary system with an angular separation 3″ at a distance 100 pc. This system has an orbital period more than 1,000 yr, i.e. an annual position angle change less than 0.3°/yr. Therefore, well-spaced observations are required over several decades to adequately sample the slow changes in position angle and angular separation.

In this paper, we report on observations of 59 visual doubles with angular separations exceeding 3″ from the Northern Neglected WDS list. For all targets, we also retrieved proper motions from the recently-published UCAC5 proper motion catalog (2) based on GAIA data release 1. By combining our observation with proper motions for each component, we categorized the likelihood that each system is truly binary.

2. OBSERVATIONS

The observations were made using the Iowa Robotic Observatory (3) in southern Arizona. The IRO is a fully robotic telescope consisting of a 0.51 m f/6.8 Cassegrain reflector, a 2Kx2K back-thinned CCD imaging camera, and a 12-position filter wheel. We used a Sloan r′ filter with exposure times between 1–3 sec depending on the apparent magnitude of the target stars. The observations were made at epoch 2017 March 30. Both nights had good observing conditions with clear skies and FWHM seeing between 1.″8 – 2.″0. Prior to analysis, each image had both CCD calibration (bias subtraction, dark-subtraction, flat-fielding) and a WCS astrometric solution (4) applied automatically.

3. DATA ANALYSIS

We fit circular Gaussian model profiles to each component using a downhill-simplex algorithm (Python library Scipy.optimize). For example, Figure 1 shows the double 05210+3728AB with overlaid contours from the Gaussian fits to each component. Using the derived centroid coordinates, we calculated the resulting binary angular separation (ρ) and position angle (ϕ). We also calculated the magnitude difference between primary and secondary components using the model-fit Gaussian peak amplitudes (a_p, a_s) and the expression,

$$\Delta m = 2.51 \cdot \log \frac{a_s}{a_p} \quad (1)$$

Stars in systems with a separation less than ~6" were deemed too close to reliably fit Gaussian model components due to component brightness overlap. For these systems we determined component centroid coordinates visually using the image display program DS9. This method did not yield peak amplitude, so magnitude difference was not calculated.

The uncertainties in ρ and ϕ were calculated in the following manner. We estimated that model-fit centroid positions had a 1σ uncertainty ± 0.15 arcsec based on comparison of the fitted centroids with cataloged positions of field stars (e.g., Sloan Digital Sky Survey). Using standard error propagation analysis, the resulting uncertainties in the separation and position angle are,

$$\sigma_\rho = 2\sigma = 0.''3 \quad (2)$$

$$\sigma_\phi = \frac{\sigma_\rho}{\rho} \text{ radians.} \quad (3)$$

Most target binaries had angular separations between 3″–30″, so the resulting position angle uncertainty was in the range 0.6°– 6°.

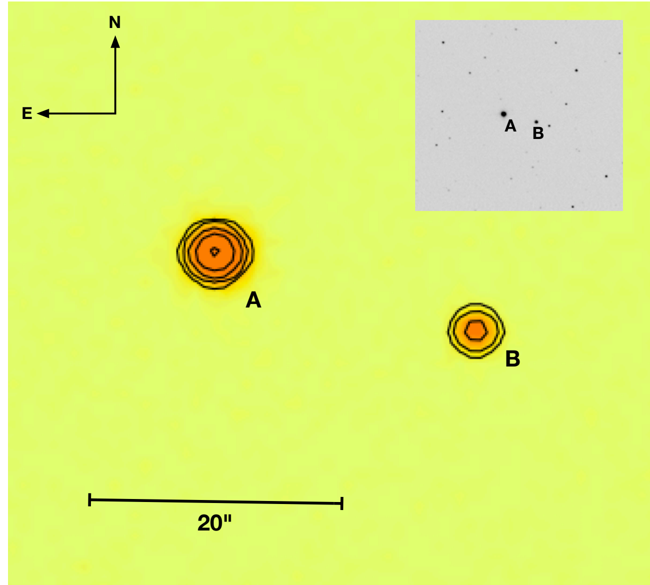

Figure 1. Image of binary system 05210+3728AB on March 2017 showing overlaid contours from Gaussian fits to primary (A) and secondary (B) components. Inset shows the location of 05210+3728 in 3’ x 3’ field.

4. RESULTS

We determined the angular separations, position angles, and Sloan r′ magnitude differences for 59 neglected binary systems at epoch 2017.24. These are listed in Tables 1–2 along with measured J2000 coordinates of each primary component and proper motions from the UCAC5 proper motion catalog (2). The latter were used to categorize each system as a *bona fide* binary with high or low confidence, as described below.

For any binary, there will be two velocity components contributing to each component's total proper motion on the sky: the center of mass proper motion and the contribution from the component's orbital velocity in the binary system. For the long-period binaries considered in this survey, orbital speeds are a few km/s or less, corresponding to a differential angular speed between components $\Delta\mu_{orb} \lesssim 10$ mas/yr for systems at a distance 100 pc, and correspondingly less at greater distance. Hence, if the proper motion difference in either right ascension or declination significantly exceeds this value, it is increasingly unlikely that the system is a true binary.

For tables 1 and 2, columns are organized as: WDS listed binary system name, right ascension and declination of primary components at epoch J2000, magnitude of the proper motion vector difference between primary and secondary stars, proper motion uncertainties of primary and secondary stars, observed angular separation, change in angular separation from 2017 to last cataloged separation, observed position angle, change in position angle from 2017 to last cataloged position angle, and difference in magnitude (secondary magnitude minus primary magnitude).

We assigned each binary a high confidence or low confidence label based on the proper motion difference between the primary and secondary stars. These are listed in Tables 1 and 2 respectively. To be considered a high confidence binary system, the proper motion difference between components in each coordinate must be less than three times the larger of the proper motion uncertainty in that coordinate or 10 mas (to account for possible orbital motion contribution).

Twelve candidate systems did not have proper motions listed for both the primary and secondary star. These systems are listed in Table 3, where their binary status is indeterminate due to the lack of knowledge on their proper motions.

This research used the Washington Double Star Catalog, maintained at the U.S. Naval Observatory, and the VizieR and SIMBAD databases, both maintained at CDS, Strasbourg, France. This research was supported by the National Science Foundation under grant No. 1517412.

REFERENCES

[1]Washington Double Star Catalog, United States

Naval Observatory. http://ad.usno.navy.mil/wds/wdstext.html

[2] Zacharias, N. Finch, C. and Frouard, J. 2017, UCAC5: New Proper Motions Using Gaia DR1, AJ, 53,166

[3]Iowa Robotic Observatory. http://astro.physics.uiowa.edu/iro

[4] Greisen, E. and Calabretta, M. 2002, Representations of world coordinates in FITS, A.A. 395,1075.

Table 1. High Confidence[a] Binary Systems

WDS Name	RA (J2000)	Dec (J2000)	$\Delta\mu$ (mas/yr)	σ_μ	ρ (")	$\Delta\rho$ (2017-WDS)	ϕ (deg)	$\Delta\phi$ (2017-WDS)	Δ m
03467+4241FOX 134	03:46:45.013	+42:39:27.45	3.16	18.41, 9.68	5.9 +/- 0.2	-0.2	107.7 +/- 2.8	+3.7	1.2
04260+4515ES 567BC	04:26:02.179	+45:13:59.98	3.08	11.51, 21.19	8.1 +/- 0.2	+0.0	128.1 +/- 3.0	-1.9	0.2
04477+3446HJ 349	04:47:40.621	+34:46:22.89	1.42	24.2, 30.85	10.4 +/- 0.3	+0.0	266.7 +/- 1.6	-0.3	-0.4
04484+4611HJ 2239	04:48:10.874	+46:11:19.81	0.85	34.46, 46.02	13.6 +/- 0.2	+0.5	163.7 +/- 2.8	+0.7	1.1
05177+3757SEI 156	05:17:42.932	+37:56:13.07	2.55	15.87, 13.57	24.8 +/- 0.3	-0.1	244.0 +/- 2.1	+2.0	0.1
05210+3728SEI 203AB	05:20:58.510	+37:28:30.81	9.43	27.42, <0.01	21.5 +/- 0.2	+0.0	251.2 +/- 1.3	+0.2	2.1
05231+3802SEI 225	05:23:08.984	+38:01:38.25	3.05	18.41, 6.69	26.2 +/- 0.3	+0.0	88.0 +/- 0.4	+0.0	-0.8
05275+3425TOB 35	05:27:29.322	+34:25:02.64	0.30	46.02, 50.00	21.2 +/- 0.2	+0.4	328.4 +/- 2.9	-0.4	0.7
05279+4441ES 1377	05:27:54.793	+44:41:08.24	3.92	34.46, 13.57	4.0 +/- 0.2	-0.4	185.0 +/- 5.7	-0.8	N/A
05385+3201J 901	05:38:32.826	+32:01:24.28	2.10	8.08, 46.02	2.8 +/- 0.3	-0.1	143.2 +/- 8.2	-5.6	N/A
05399+5145ES 893	05:39:56.724	+51:45:18.05	3.27	15.87, 42.08	7.2 +/- 0.2	+0.0	225.0 +/- 3.3	+0.0	0.5
05497+3146SEI 391AC	05:49:39.523	+31:46:29.74	6.58	0.02, 0.03	27.5 +/- 0.3	-1.4	140.3 +/- 2.6	+0.3	0.7
05498+3127SEI 392	05:49:48.887	+31:26:37.03	0.78	34.46, 38.21	8.7 +/- 0.3	+0.1	309.1 +/- 4.0	+2.1	0.8
05499+2259POU 789	05:49:53.621	+22:58:47.66	16.53	24.20, 21.19	12.7 +/- 0.3	+0.0	251.3 +/- 2.6	-0.7	1.6
05523+3442GYL 87	05:52:14.353	+34:41:20.96	1.53	46.02, 18.41	10.3 +/- 0.3	-0.6	327.2 +/- 4.4	+0.4	0.5
05525+3235SEI 424	05:52:30.662	+32:34:40.52	1.42	27.42, 24.20	13.1 +/- 0.2	-0.2	265.7 +/- 1.0	+0.7	0.7
05553+2023J 1914	05:55:15.816	+20:23:22.20	0.8	27.43, 50.00	7.8 +/- 0.2	+3.8	256.2 +/- 2.1	+6.2	0.7
05557+3127SEI 440	05:55:42.074	+31:27:01.17	2.10	46.02, 18.41	13.9 +/- 0.2	+0.2	333.0 +/- 2.6	-1.0	0.8
05559+3104SEI 442	05:55:48.964	+31:04:22.81	7.11	42.07, <0.01	25.1 +/- 0.2	-0.2	186.5 +/- 2.1	+1.5	1.2
05585+272723J 252	05:58:25.581	+27:22:01.36	2.05	15.87, 18.41	5.2 +/- 0.2	-0.3	318.5 +/- 3.8	-0.5	1.2
05589+3143SEI 450	05:58:52.536	+31:42:29.21	5.08	1.79, 4.46	28.8 +/- 0.2	-0.6	178.0 +/- 1.9	-1.8	-0.2
06138+3509GCB 16	06:14:07.230	+35:05:32.36	1.03	38.21, 30.86	6.4 +/- 0.2	-2.0	184.4 +/- 4.1	-0.6	0.1
06162+2051J 1054	06:16:10.209	+20:51:27.90	2.20	46.02, 8.08	3.3 +/- 0.3	+0.3	138.8 +/- 7.5	-0.2	N/A
06279+3715MLB 1028	06:27:58.609	+37:14:44.64	5.30	42.09, 13.57	7.9 +/- 0.2	+1.6	297.5 +/- 2.3	+7.8	3.2
06301+2756J 2428	06:30:03.892	+27:57:49.44	1.77	21.19, 24.20	4.0 +/- 0.2	+0.0	178.9 +/- 5.7	+28.9	N/A
06368+2335GCB 20	06:36:21.872	+23:38:18.56	0.22	46.02, 46.02	8.2 +/- 0.2	+0.2	229.2 +/- 3.0	+2.2	0.5
06442+3822J 665	06:44:05.904	+38:22:33.01	2.55	8.08, 24.20	7.6 +/- 0.3	-0.8	66.5 +/- 3.0	-1.4	2.8
08036+4739PKO 8	08:03:46.120	+47:39:05.06	0.54	46.02, 42.07	11.7 +/- 0.3	+3.9	249.8 +/- 2.8	-0.2	0.1
08334+3348MLB 838	08:33:25.805	+33:50:17.90	3.22	6.69, 42.07	4.8 +/- 0.3	+0.6	18.2 +/- 6.8	-0.8	0.0

[a] Systems whose differential component proper motion satisfies the high-confidence criteria described in section 4.

Table 3. Low Confidence[a] Binary Systems

WDS Name	RA (J2000)	Dec (J2000)	$\Delta\mu$ (mas/yr)	σ_μ	ρ ('')	$\Delta\rho$ (2017-WDS)	ϕ (deg)	$\Delta\phi$ (2017-WDS)	Δ m
03493+2424HL 30AB	03:49:16.805	+24:23:46.35	57.03	<0.01, <0.01	69.8 +/- 0.2	-2.4	13.4 +/- 1.2	+1.4	3.9
04020+6231SLE 43AD	04:01:58.322	+62:30:50.42	16.05	<0.01, <0.01	19.9 +/- 0.2	+0.8	277.9 +/- 1.5	-1.1	2.2
04076+3804ALC 1AE	04:07:34.354	+38:04:28.37	68.04	<0.01, <0.01	746.0 +/- 0.2	+26.0	99.6 +/- 0.1	N/A	0.0
04125+3538HJ 341	04:12:31.205	+35:43:59.23	12.25	24.20, <0.01	13.8 +/- 0.2	+1.0	333.4 +/- 2.6	+2.4	0.2
05179+3724SEI 162	05:17:54.782	+37:23:36.09	28.62	<0.01, 0.02	24.1 +/- 0.4	+2.9	223.5 +/- 3.6	-0.5	1.6
05161+3632SEI 132	05:16:06.174	+36:31:41.65	9.51	<0.01, <0.01	25.0 +/- 0.2	+0.4	113.6 +/- 2.8	-5.6	-0.1
05380+3643SEI 358	05:37:58.715	+36:42:34.70	9.97	6.68, <0.01	17.8 +/- 0.3	-0.4	196.8 +/- 3.6	+0.8	0.6
05463+3152SEI 384	05:46:16.199	+31:52:20.59	11.15	<0.01, <0.01	13.9 +/- 0.3	+0.2	175.4 +/- 4.1	-0.6	1.5
06050+2913MLB 750	06:04:58.089	+29:11:22.01	10.67	0.07, <0.01	6.6 +/- 0.2	+0.3	236.5 +/- 3.2	-0.5	0.9
06125+2025J 1926	06:12:27.013	+20:24:37.67	46.35	<0.01, <0.01	6.1 +/- 0.2	+5.0	0.2 +/- 5.8	+5.2	N/A
06204+2331J 1822	06:20:37.252	+23:28:19.31	23.90	<0.01, <0.01	7.0 +/- 0.2	+2.0	2.9 +/- 3.9	-1.1	0.5
06335+6712MLB 457	06:33:35.777	+67:11:38.78	22.61	<0.01, <0.01	4.5 +/- 0.3	-1.7	307.2 +/- 5.9	18.2	N/A
06383+2427HO 625AC	06:38:18.901	+24:27:01.71	42.47	1.07, 0.02	50.5 +/- 0.2	+0.4	352.2 +/- 1.4	-0.8	4.4
07208+3151SEI 478	07:20:51.463	+31:51:02	23.36	2.27, <0.01	4.2 +/- 0.2	-1.8	16.6 +/- 5.5	-8.2	N/A
09251+2933BU 1423AC	09:25:07.977	+29:32:49.02	47.79	<0.01, <0.01	155.2 +/- 0.2	+0.8	51.7 +/- 0.6	-0.3	2.7
09390+3017ARY 51	09:38:59.331	+30:16:31.56	37.89	<0.01, 5.48	118.7 +/- 0.2	-0.9	273.0 +/- 0.2	+0.0	0.7
11125+3549STT A108BD	11:12:44.285	+35:49:47.96	245.82	<0.01, <0.01	159.9 +/- 0.4	+7.0	247.8 +/- 0.7	+19.9	0.0

[a] Systems whose differential component proper motion does not satisfy the high-confidence criteria described in section 4.

Table 4. Systems without UCAC5 Proper Motions

WDS Name	RA (J2000)	Dec (J2000)	ρ (")	$\Delta\rho$ (2017-WDS)	ϕ (deg)	$\Delta\phi$ (2017-WDS)	Δ m
03267+4110J 889	03:26:46.903	+41:08:50.52	2.1 +/- 0.3	-0.8	61.0 +/- 9.2	-36.0	N/A
03495+5239ES 12DE	03:49:24.675	+52:40:19.45	2.4 +/- 0.3	-0.3	223.9 +/- 9.0	-6.1	N/A
04113+2630LDS5 514BC	04:11:13.457	+26:29:52.35	11.0 +/- 0.2	+0.0	305.2 +/- 2.3	+5.2	0.0
05119+3631SEI 93	05:11:49.163	+36:30:28.70	3.9 +/- 0.2	-0.7	146.7 +/- 5.5	+21.7	N/A
05225+6011LEO 11	05:22:32.232	+60:11:23.64	2.9 +/- 0.2	-0.5	215.6 +/- 6.4	+4.6	N/A
06212+2108S 513BE	06:21:10.309	+21:07:45.216	40.6 +/- 0.2	-0.5	327.8 +/- 1.5	+0.8	1.7
06214+3402MLB 1044	06:21:26.528	+34:01:55.550	7.4 +/- 0.2	+0.5	126.0 +/- 3.1	+1.0	1.3
06377+6129BUP 91AC	06:37:41.334	61:28:54.14	397.5 +/- 0.4	+17.6	92.3 +/- 0.2	-1.7	-0.2
07018+6617MLB 400	07:01:40.898	+66:16:54.20	2.1 +/- 0.3	+0.0	214.0 +/- 9.9	+24.0	N/A
07059+3603STF1013	07:05:51.903	+36:02:55.17	4.4 +/- 0.2	-0.3	56.6 +/- 4.6	+1.6	N/A
08010+3454MLB 932	08:01:01.534	+34:53:10.10	4.6 +/- 0.3	0.2	56.0 +/- 4.8	+4.0	0.7
10432+3849MLB 933	10:43:16.264	+38:48:40.83	3.5 +/- 0.2	-0.1	246.1 +/- 5.0	-1.9	N/A