Counter-Check of 4,937 WDS Objects for Being Physical Double Stars

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Abstract: The WDS catalog contains (as of August 2017) more than 20,000 V-coded objects which are considered to be physical pairs because of their common proper motion (CPM) or other attributes. For 4,937 of these objects both components were identified in the UCAC5 catalog and counter-checked with UCAC5 proper motion data using a CPM assessment scheme according to Knapp and Nanson 2017. A surprisingly large number of these pairs seem to be optical rather than physical. Additionally GAIA DR1 positions are given for all components, and precise separation and position angle based on GAIA DR1 coordinates were calculated for all of the 4,937 pair

1. Introduction

The WDS catalog contains (per the August 2017 release) more than 20,000 double stars listed with their V-code declaring them as possibly physical pairs, usually based on assumed common proper motion or other indicators. The most recently available precise proper motion data in the GAIA DR1 catalog allows for a very reliable counter-check of this assumption, but the TGAS subset of GAIA DR1 with only about 2,000,000 stars covers only a small number of the WDS stars. The next reliable source of precise proper motion data we consulted is the UCAC5, as it contains data for more than 100,000,000 stars with data based on re-reduction of the UCAC images which used the TGAS objects as positional references and compared these positions with those in the GAIA DR1. This gave us a huge increase in the number of objects available to check against the WDS V-code entries.

2. Selection and Identification of the Objects

Given the above, a program to scan the WDS for "V" type objects that were likely to be included in the UCAC5 was written. This program eliminated all pairs whose primary was brighter than 6.0mv (the halation spot on the image being large enough to throw off the scanning software that creates the UCAC5 catalog) or fainter than 16.0mv (the approximate limit of the UCAC5). It also eliminated pairs that were less than 4 arc seconds in separation or greater than 60 arc seconds in separation, as the former are likely to be within the primary's halation spot and the latter are more likely to be optical. Of the 20,000+ "V" pairs listed in the WDS, this program found 6,742 pairs that met these criteria.

A second program was written that takes the 6,742 "V" pairs and tries to find stars in the UCAC5 that correspond to both the primary and secondary of the WDS pair. Of the 6,742 pairs only 4,937 were found that had UCAC5 stars associated with them. The criteria used to select these were:

- The UCAC5 stars could only be brighter than the WDS star by one magnitude, or fainter by two magnitudes.
- The separation of the UCAC5 stars needed to be within 4" of that listed by the WDS's most recent measurement.
- The position angle of the UCAC5 stars needed to be within 4 degrees of that listed by the WDS's most recent measurement.

Similar to visual observations there is the question of possible false positives. We did a counter-check with two different approaches: First we selected the

objects with the largest difference in separation and position angle between WDS and GAIA DR1 as such differences are either the result of very different proper motions as reported by the WDS and UCAC5 or of a misidentification. Second, we ran a program that searched all 4,937 pairs with UCAC5 stars associated with them, looking for objects close to these pairs as potential sources for misidentifications. We then checked these suspect objects manually with the help of Aladin using 2MASS images with WDS and UCAC5 catalog overlays and found a few misidentifications of primaries and secondaries. However, we kept the data set, as the error rate was less than one in a thousand, and further refinement of our search programs would not yield significantly better results. The misidentifications that we found are listed in "Appendix A - Errata" and include the correct data for these objects.

These 4,937 pairs were then analyzed by a spreadsheet that implemented the CPM assessment (see Appendix B) and calculated separation and position angle from the GAIA DR1 positions provided with the UCAC5 data rows.

3. Results

290 objects were found to be listed in the UCAC5 catalog with an unexpected large proper motion error range for at least one component. To avoid questionable CPM ratings we decided to split the results into two subsets to isolate the objects with pm data considered suspect. The spreadsheet with the results is far too large to be given here in print so we list only the first 25 items in table 1 as an example. The full data set with all data for all objects, including content description can be downloaded as spreadsheet from http://www.jdso.org/.

The programs used to find V pairs in the WDS, and then couple those stars with ones in the UCAC5, and then check for misidentifications are posted here: https://sourceforge.net/projects/codefromwdsvsucac5/files/?source=navbar.

The following data are given in Table 1:

- WDS ID
- Name = Discoverer ID
- GAIA DR1 coordinates for the primary (observation epoch 2015)
- Separation and position angle calculated from the GAIA DR1 positions for primary and secondary
- Proper motion vector direction for both components calculated from UCAC5 proper motion data in degrees.
- Proper motion vector length for both components calculated from UCAC5 proper motion data in mas/yr
- CPM rating (see Appendix B)
- Notes with comments.

The full data set available for download also contains additional columns to provide full information on all counter-checked objects.

4. Summary

From 4,937 V-coded WDS objects counter-checked with UCAC5 proper motion data (using the CPM assessment scheme according to Appendix B):

- Only 68 qualified as perfect AAAA CPM candidates with (within the given error range) ident proper motion vector direction and length, a PM error size of less than 5% of the PM vector length and a relationship of angular separation to PM speed of less than 100 years. This means the pair is almost certainly physical.
- 1,880 qualified as solid CPM candidates with (within the given error range) ident proper motion vector direction and length but with minor issues regarding PM error size and relationship of angular separation to PM speed. These are almost certainly physical.
- 1,005 qualified as good CPM candidates with proper motion vector direction and length differences within twice the given error range and with only minor issues regarding their PM error size and relationship of their angular separation to PM speed. Some differences in PM vector length and direction might be caused by an orbit depending on the plane of the orbit with respect to the sky so this class of objects might contain doubles with orbit. Overall there is a good chance that these pairs are physical.
- 168 objects qualified as weak CPM candidates, as they have a rather small probability for being physical.
- 197 objects are probably optical as their proper motion vector is more than twice but less than triple the given error range, as well as showing some PM vector length differences
- 1,329 objects (nearly 30% of the total number) are almost certainly optical pairs. Over 600 of them are UC pairs demonstrating the remarkable change of proper motion data from UCAC4 to UCAC5 by rendering these pairs from "probably physical" based on UCAC4 proper motion data to "almost certainly optical" based on the UCAC5 proper motion data.
- Additionally we have 290 objects with somewhat suspect UCAC5 proper motion data to be considered separately (see Addendum).

We would have expected that all V-coded WDS

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Table 1. The first 25 objects from the data set

WDS ID	Name	RA A	DE A	GAIA Sep	GAIA PA	PMVD° A	PMVD° B	PMVL A	PMVL B	CPM Rat	Notes
00001-2432	UC 301	0.02117861	-24.52940000	47.024	283.37	231.49	232.05	92.66	89.92	ABAB	Good CPM candidate
00004+3549	CRB 23	0.09759917	35.81139000	37.243	154.53	84.38	84.40	67.42	67.62	AABB	Solid CPM candidate
00006+4539	UC 303	0.14172670	45.65775000	52.176	311.43	79.36	77.91	65.53	69.24	ABBB	Good CPM candidate
00013+0504	UC 304	0.32828920	5.07007700	15.342	53.63	247.39	244.64	67.38	67.95	BAAB	Good CPM candidate
00013+0742	DU 4AB	0.33342190	7.70133900	15.209	264.10	205.54	205.15	80.24	79.76	AAAB	Solid CPM candidate
00020+2347	TVB 2	0.50731720	23.78087000	28.116	292.27	76.57	74.94	27.55	25.79	ABBC	Good CPM candidate
00020+4530	J 864AC	0.50702940	45.52219000	18.012	8.37	20.56	255.00	1.71	10.04	DDDC	Almost certainly optical
00023+1609	BPM 1	0.58341170	16.14635000	30.686	185.11	168.27	104.44	5.41	20.86	DDDC	Almost certainly optical
00029-7436	BVD 30AB,C	0.71324250	-74.59810000	37.832	11.44	172.63	152.18	67.86	59.14	DDAB	Almost certainly optical
00042+3732	UC 310	1.04570400	37.53939000	30.980	14.80	76.06	88.31	72.23	64.43	DCAB	Almost certainly optical
00043-4304	UC 311	1.07507200	-43.07456000	8.686	141.95	54.01	55.37	74.03	74.26	AAAB	Solid CPM candidate
00047+4049	UC 312	1.18156600	40.81849000	39.448	157.18	97.99	101.85	47.46	54.05	BCAB	Weak CPM candidate
00049-1811	UC 313	1.23707800	-18.17912000	18.133	239.72	191.08	191.42	96.29	96.00	AAAB	Solid CPM candidate
00053-0523	UC 315	1.32045300	-5.37600800	19.679	257.19	203.84	208.22	66.80	65.14	BABB	Good CPM candidate
00053-1857	UC 316	1.31539700	-18.95130000	25.494	278.04	35.31	50.47	63.84	46.03	DDBB	Almost certainly optical
00063+6851	CBL 559	1.58039100	68.85215000	19.432	209.67	92.65	95.48	58.46	57.56	AAAB	Solid CPM candidate
00070-1837	UC 322	1.73973600	-18.61536000	44.707	63.35	211.58	211.42	71.60	73.47	AAAB	Solid CPM candidate
00081+2029	AZC 2	2.02307600	20.47806000	25.761	146.83	106.95	106.01	86.45	83.02	AAAB	Solid CPM candidate
00085-0419	UC 324BC	2.14046700	-4.29685400	53.485	117.77	103.12	102.15	62.12	64.14	AABB	Solid CPM candidate
00091-5649	UC 327	2.27667000	-56.80847000	44.487	181.99	102.04	102.31	67.59	70.83	ABAB	Good CPM candidate
00092+3201	UC 328	2.30533600	32.01432000	9.955	172.25	243.01	237.65	65.65	60.37	BBBB	Good CPM candidate
00093+2517	GIC 2AB	2.31640300	25.28135000	29.602	237.15	131.84	130.82	230.87	223.33	BCAB	Weak CPM candidate
00099+0827	STF 4	2.46544400	8.45311900	5.232	275.69	103.17	101.52	59.26	65.62	ACBA	Weak CPM candidate
00100-5028	CBL 561	2.50342600	-50.47068000	21.011	83.90	240.87	238.52	149.97	152.43	BAAB	Good CPM candidate
00105+4524	CBL 1	2.62025200	45.39443000	22.982	229.57	323.13	322.85	85.00	86.94	AAAB	Solid CPM candidate

objects show significantly large proper motion but 260 from the 1,526 objects rated as probably or most certainly optical are listed in the UCAC5 catalog for both components with proper motion values far too small to allow for an assessment as "common". As a threshold we used the root mean square over all e_pm values larger than 30% of the proper motion vector length of both components - this means that the given proper motion values are insignificant in comparison with the large proper motion error range. In some cases the UCAC5 proper motion errors are even larger than the proper motion values themselves.

This result shows the need for a critical CPM assessment of the remaining ~16,000 WDS objects not covered by our report. If our sample is representative, then there are about 5,000 V-coded objects that are probably optical pairs.

References

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Acknowledgements

The following tools and resources have been used

Appendix A - Errata:

Checking about 50 of the most suspect objects regarding identification with unusual large difference in separation or position angle compared with the WDS catalog we found the following errors in the data set:

Table 2. Errors found in the data set

WDS ID	Name	RA A	DE A	RA B	DE B	CPM Rat	Notes	Error
15079-4019	UC 2935	226.980500	-40.319590	226.960600	-40.320340	DDDC	Almost certainly optical	Wrong secondary
09024+1226	GWP 1131	135.599300	12.432740	135.605800	12.434150	DADB	Almost certainly optical	Wrong secondary
17197-8520	UC 3324	259.912700	-85.337790	259.832700	-85.339490	DDDB	Almost certainly optical	Wrong secondary
17329-0129	UC 3366AC	263.225800	-1.490887	263.224900	-1.504463	DDDC	Almost certainly optical	Wrong primary

Table 3. Correct data for objects listed in Table 1.

Name	RA	Dec	Sep "	PA °	M1(G)	M2(G)	pmRA1	pmDec1	e_pm1	pmRA2	pmDec2	e_pm2	Ap	Me	Date	CPM Rat	Source/Notes
UC 2935	226.9805089	-40.3195914	58.545	268.682	15.855	16.049	-35.80	-11.20	5.445	-19.20	-7.90	11.322	0.96	Hg	2015	BCCC	GAIA DR1. M1 and M2 GAIA DR1 Gmag. PM data from UCAC5 catalog
GWP 1131	135.5992506	12.4327389	26.345	80.871	12.432	15.705	14.70	-47.50	1.414	32.20	-49.50	30.689	0.96	Hg	2015	CCCB	GAIA DR1. M1 and M2 GAIA DR1 Gmag. PM data from UCAC5 catalog
UC 3324	259.9127372	-85.3377903	25.788	263.364	14.016	16.119	-31.00	22.60	1.838	9.90	9.60	10.615	0.96	Hg	2015	CCCC	GAIA DR1. M1 and M2 GAIA DR1 Gmag. PM data from UCAC5 catalog
UC 3366AC	263.2254975	-1.4901794	51.462	182.249	10.298	15.138	-62.30	-4.00	1.414	-2.70	-4.40	3.471	0.96	Hg	2015	CCCC	GAIA DR1. M1 and M2 GAIA DR1 Gmag. PM data from UCAC5 catalog

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The AB pair of UC3366 is J 453, obviously a good CPM candidate:

Table 4. Data for J 435

Name	RA	Dec	Sep "	PA °	M1 (G)	M2 (G)	pmRA1	pmDec1	e_pm1	pmRA2	pmDec2	e_pm2	Ap	Me	Date	CPM Rat	Source/Notes
J 453 AB	263.2254975	-1.4901794	2.789	155.933	10.298	10.761	-62.30	-4.00	1.414	-66.70	-5.80	3.536	0.96	Hg	2015	ABBA	GAIA DR1. M1 and M2 GAIA DR1 Gmag. PM data from UCAC5 catalog

It is remarkable that the errors found did not have a real impact on the CPM rating of the objects in question. A few more errors might still exist but we would not expect them to be more than one or two if any. On the other hand we found several UC objects from Hartkopf et al. 2013 as well as one BPM object from Gavras et al. 2010 with incorrect or at least unclear positions for the primary or secondary caused by very close objects covered by the data range between first and last observation:

Table 5. Data for correctly identified WDS objects with questionable data.

WDS ID	Name	RA A	DE A	RA B	DE B	CPM Rat	Notes	Error
07599-7511	UC 1632	119.9753	-75.18118	119.9733	-75.18758	DADB	Almost certainly optical	Correctly identified according to WDS, but most probably WDS error for primary - see difference first/last observation
14574-3908	UC 2879	224.3548	-39.13891	224.3479	-39,14464	DDDC	Almost certainly optical	Correctly identified according to WDS, but most probably WDS error for primary - see difference first/last observation
18375-4736	UC 3627	279.3780	-47.5943	279.3886	-47.60707	DDDC	Almost certainly optical	Correctly identified according to WDS, but most probably WDS error for primary - see difference first/last observation
15314-2908	UC 3020	232.8475	-29.14083	232.8366	-29.14693	DDCB	Almost certainly optical	Correctly identified according to WDS, but most probably WDS error for secondary - see difference first/last observation
18349-4746	UC 3617	278.7222	-47.7727	278,7324	-47.78019	DDDC	Almost certainly optical	Correctly identified according to WDS, but most probably WDS error for primary - see difference first/last observation
19400+1542	BPM1269	295.0003	15.70334	294,9916	15.69306	DDDC	Almost certainly optical	Correctly identified according to WDS, but most probably WDS error for secondary - see difference first/last observation

To avoid such unclear situations we suggest that the nearby objects be included in the WDS catalog as additional components of these objects, even if they are only optical.

As a side effect of our error search we found the primary of UC 3020 to be a common proper motion pair:

Table 6. Data for a newly detected CPM pair

Name	RA	Dec	Sep "	PA °	M1 (G)	M2 (G)	pmRA1	pmDec1	e_pm1	pmRA2	pmDec2	e_pm2	Ap	Me	Date	CPM Rat	Source/Notes
UC 3020 Aa/Ab	232.8474981	-29.1408275	3.093	267.445	12.062	13.928	-47.30	-45.70	1.345	-51.30	-45.30	3.607	0.96	Hg	2015.000	AABA	GAIA DR1. M1 and M2 GAIA DR1 Gmag. PM data from UCAC5 catalog
	232.8477345	-29.1406278	3.030	267.255									0.20	Eu	1999.270		UCAC5

Appendix B - Description of the CPM Rating Procedure

Four rating factors are used: Proper motion vector direction, proper motion vector length, size of the position error in relation to the proper motion vector length according to Knapp and Nanson, with an extension for relating separation to proper motion speed

- Proper motion vector direction ratings: “A” for identical direction within the error range (calculated by assuming the worst case of the position error pointing in the right angle to the PM vector), “B” for similar direction within the double error range, “C” for similar direction within the triple error range, and “D” for outside the triple error range.
- Proper motion vector length ratings: “A” for identical length within the error range (calculated by assuming the worst case of the position error pointing in the direction of the PM vector), “B” for similar length within the double error range, “C” for similar length within the triple error range, and “D” for errors outside of this.
- Error size ratings: “A” for an 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 an error size larger than 15%.
- Relation of separation to proper motion speed: "A" for less than 100 years, "B" for less than 1,000 years, "C" for less than 10,000 years and "D" for greater than 10.000 years.

To compensate for excessively large position errors resulting in an “A” rating despite high deviations proper motion direction and/or angle, an absolute upper limit is applied regardless of the calculated error size:

- Proper motion vector direction: Upper limit 2.86° difference for an “A”.
- Proper motion vector length: Upper limit 5% difference for an “A”.

Addendum Regarding UCAC5 Proper Motion Data

After finishing the first draft of this report we became aware of a reasonably large number of UCAC5 objects identified with WDS binaries having a surprisingly large proper motion error range making CPM assessment with UCAC5 proper motion data less reliable than assumed. While most UCAC5 objects are listed with e_pm values around 2mas/yr some are listed with a tenfold or even higher error size. These were initially considered as rare outliers but with more detailed checking it became clear that the number of such objects is larger than assumed. This is somewhat surprising as the UCAC5 data is based on re-reduction of UCAC image data with TGAS reference stars and the proper motion data is calculated by comparing UCAC5 and GAIA DR1 positions – this setup suggests a very high data quality. But as proper motion data calculated from comparison of 2MASS to GAIA DR1 positions is in many cases within an e_pm range of less than 6mas all UCAC5 objects with e_pm larger than that are to be viewed with caution.

As an example of this we checked a small sample of our data in Table 1 in detail.

Table 7: Counter-check UCAC5 based CPM rating for some of the objects with RMS e_pm larger than 12mas

					Rating with UCAC5		Rating with 2MASS to GAIA DR1	
Name	RA A	DE A	Sep	PA	CPM Rat	Notes	CPM Rat	Notes
UC 317	1.39717000	-47.5694100	10.564	176.88	DDCB	Almost certainly optical	CBBB	Probably optical
MRI 53	1.68339000	57.27257000	6.624	307.50	BACB	Good CPM candidate	AABB	Solid CPM candidate
UC 329	2.33485900	-41.5343300	31.526	326.12	DDCB	Almost certainly optical	CACB	Probably optical
UC 3968	292.969700	52.01293000	11.412	159.54	DBDB	Almost certainly optical	CCCC	Almost certainly optical
GRV1087	200.531300	67.81200000	28.268	8.30	BDCB	Almost certainly optical	AABC	Solid CPM candidate
GWP2029	202.026600	16.31330000	10.401	265.24	DDCB	Almost certainly optical	CBBB	Probably optical

This comparison shows that in most cases the difference in the CPM assessment might be minor but that there are also a few cases with very different results. For example we have changed an “Almost certainly optical” designation to “Solid CPM candidate”. These counter-checks are easily done manually for a few pairs, but this is impracticable for larger data sets. The only solution for this current work is to simply eliminate such suspect objects from the data set and postpone for these objects the CPM assessment for a subsequent paper probably based on GAIA DR2 proper motion data.