Recovery of “Very” Neglected WDS Objects in Gaia DR2

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Abstract: The USNO WDS catalog website lists also 3 sets of neglected objects selected by different criteria (mainly “Not observed in 20 years”) to point out double stars in need of new observations. To concentrate on “very” neglected double stars not observed in 60 years all objects with a last observation date before the year 1958 were selected directly from the WDS catalog and 3,149 such objects remained after elimination of all pairs with data not suitable for cross-matching with GAIA DR2. After a drill down process in several steps 1,473 pairs were successfully matched with GAIA DR2 objects – a recovery rate of about 47 percent. For the rest most not recovered objects are either bogus (or lost due to wrong J2000 positions) or simply not resolved in DR2 mostly with separations below 1 arcsecond.

1. Selection of the objects

Selecting all WDS objects with last observation year smaller than 2000 with CDS TAP-VizieR resulted per end of December 2018 in 36,459 neglected double stars with the X-coded bogus objects already eliminated. Several discoverer IDs are rather prominently present: Alone TDS/TDT (Tycho Double Stars) objects represent with a number of 12,661 about one third of the total number of neglected double stars, next comes RST (Rossiter) with 4,452 objects, then B (van den Bos) with 2,071 objects, A (Aitken) with 1,087 objects, I (Innes) with 1,063 objects, OCC (for doubles found by different discoverers during occultation observations) with 1,003 objects, BRT (Barton) with 918 objects, DON (Donner) with 872 objects, COU (Couteau) with 754 objects and so on.

In the next step all objects with separation or position angle "-1" for unknown were deleted due to missing data necessary for cross-matching as well as all objects with separation smaller than 0.4 arcseconds as this is the declared resolution limit for GAIA DR2 (Arenou et al. 2018) but also all objects with separation “999.9” indicating an unspecific separation larger than 1000 arcseconds. This reduced the number of neglected double stars suited for cross-matching with GAIA DR2 to 31,383 – a number still far too large for serious manual counter-checking. Besides I had already a look at TDS/TDT objects in a separate report (Knapp 2019) rendering any attempt in this direction redundant so I decided to concentrate on the 3,149 “very neglected” double stars with last observation year smaller than 1958. Interestingly 85% of these objects are with Dec values below zero located in the southern hemisphere suggesting a general neglect of double stars in the southern skies.

2. Recovery of selected objects in GAIA DR2

The next steps were straight forward:

- Cross-matching the list of 3,149 objects with GAIA DR2 for primary and secondary with 5" search radius using the CDS X-Match tool
- Eliminating all self-matches for objects with a separation less than 5 arcseconds
- Eliminating all matches with a delta in separation larger than 100% of the WDS separation and delta in position position angle larger than 40 degrees. These are rather generous thresholds for cross-matches but considering the huge time delta to the last recorded WDS observation still several correct matches might have been eliminated by this step
- Eliminating all pairs with magnitude delta differences (comparing GAIA DR2 Gmag deltas with WDS mag deltas) larger than 2.5 as well as all pairs with difference between WDS magnitude and GAIA DR2 Gmag for primary or secondary larger than 2.5mag. Considering the often questionable reliability of WDS magnitudes and the fact that in some cases the delta between Vmag and Gmag might be larger than 2.5 this might

again mean eliminating a few correct matches.

Next came the manual counter-check of all matched objects with delta separation >20% and delta position angle >20 degrees using AstroPlanner and Aladin with the consequence of deleting several obvious mismatches especially for components of multiples mostly based on magnitude issues. A surprisingly large part of these matches was found to be correct despite such large deltas in separation or position angle probably due to changes caused by proper motion but maybe also caused by poor quality of earlier measurements often over 100 years old.

Side results of the manual counter-checks:

- RST3185: J2000 measurement for RST3185AB seems to be in error - probably AC measurement
- RST2406: AB might be bogus
- ES 694 AB: TDT3959 Aa;Ab probably bogus
- ES 2350 BC: Probably bogus, B has same WDS position as A
- SEI 975: Probably bogus as there is no 11.7 secondary at the given location
- RST1515: TDS7211 Aa;Ab not resolved - bogus?
- RST1578 AC: Very different proper motion
- KUI 85: Curious object - no such bright stars at this position. Jump in separation from 0.2 to 3.1" from first to last observation despite rather slow proper motion seems curious
- I 1152/RMC 136/DAW 189/HJ 3796/: Of in total about 70 objects (members of the 30 Dor cluster in Large Magellanic Cloud) only 2 could be recovered due to the overly dense star field. Why such objects should be listed as double stars remains unclear as neither Plx nor PM suggest any physical relationship.

3. Results of Cross-Matching

After eliminating all obviously suspect matches 1,473 objects remain

- 364 objects of these come without proper motion and parallax data making assessment for common proper motion and potential gravitational relationship impossible
- 194 objects qualify as common proper motion pairs
- 80 objects qualify for potential gravitational relationship
- Only 26 objects qualify for both
- Several matched GAIA DR2 objects have "duplicated_source" issues or a number of "visibility_periods_used" of less than 9 – this might indicate data precision issues but in the given task using such data seems the better choice than just keep the WDS neglected pair status.

Table 1 lists a subset of the data for the first 20 of the recovered 1,473 WDS objects not observed longer than 60 years. The full table is abailable for download from the JDSO website as fixed format flat text file "WDS very neglected XX DR2".

4. Summary

With 47% a surprisingly large part of the more than 60 years not observed WDS objects could be recovered in GAIA DR2. In many cases this required a manual counter-check to overcome differences in separation and position angle due to the long time delta between observations larger than usually accepted for software based cross-matching.

The reasons for 53% negative cross-matching results are according to a random sample:

- No DR2 object for the secondary mostly in cases with a separation of less than 1 arcsecond like for example
  - DON1056
  - RST1183
  - RST2229
- although in some cases this might simply suggest a bogus like for example for B 631
- Deltas in parameters too large for a positive match at least with the in this report applied cut values as for example LDS2080 or RST1179 with a clear positive recovery with a pure manual procedure
- Missing objects in DR2 for the primary as for example for RST3341 (interestingly despite an existing object in DR1) or POU5868
- Obviously bogus or lost due to wrong J2000 positions as for example
  - WG 1
  - DOO 1
  - BRT1578
  - BRT 528
  - LDS2064
  - ES 1355
  - ARA 314
  - FEN 44
  - BRT 526
  - J 299
- Not obviously bogus but at least very doubtful like for example
  - BRT 527
  - FEN 43

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Table 1: Subset of the data for the first 20 of the recovered 1,473 WDS objects not observed longer than 60 years

WDS	Disc	Comp	PA	Sep	Gmag1	Gmag2	Plx1	Plx2	pmRA1	pmDE1	pmRA2	pmDE2	CPMR	CPMS	PlxR	PlxS
00010-4920	RST1178		294.511	2.01869	9.598	12.577	1.9870	1.8757	6.531	-5.899	6.914	-5.779	CCAB	8	DA	1
00025-5654	B 1022		127.414	2.96263	9.798	12.273	2.9743	2.8526	21.247	28.690	21.448	28.527	AAAA	100	DA	1
00068-4055	RST1179		106.157	1.32607	8.764	12.132	1.8570	0.1978	13.892	6.715	14.427	-1.910	DDBA	0	DD	1
00089-1107	RST3342		301.826	1.55661	9.465	13.094	4.0414	4.1751	33.405	6.798	32.745	5.135	BCAA	32	CA	20
00091+4051	BU 483	AB	34.045	2.06759	6.689	11.107	16.7115	16.5777	126.532	-171.143	119.707	-178.928	CBAA	16	BA	80
00108-3452	RST2236		98.298	1.97939	6.635	11.288	5.6522		85.667	-0.872						
00136-4340	DON 1		248.701	2.08249	10.175	13.199	5.3159	5.3392	-12.837	5.230	-11.399	2.939	DDAB	0	BA	80
00170-2803	RST1184		60.851	3.52453	9.380	13.389	5.4261	5.3560	-8.419	-47.453	-9.558	-46.697	BBAA	64	CA	20
00185-4606	RST 3		131.147	2.22547	11.396	12.705	5.7267	5.4746	18.232	14.927	17.518	13.799	BDAA	4	DA	1
00262+3815	A 1503		304.855	2.02759	9.413	11.923	2.7519	2.6771	-5.423	-6.493	-5.456	-6.668	ABAB	78	CA	20
00281-2512	B 5	AB	222.478	1.29337	9.281	11.982	9.9580		-42.269	-75.819						
00289-3931	RST1188		18.354	1.87420	10.407	13.008	3.5322	3.4424	10.690	2.932	10.756	2.923	AAAB	97	CA	20
00310-0850	RST4149		154.936	2.05516	9.386	13.080	5.8203	5.8466	57.852	36.186	63.046	37.264	BDAA	4	BA	80
00316-3721	JSP 6		206.381	1.63575	11.465	12.630	2.9213	3.0335	35.978	12.942	36.575	13.556	ABAA	80	DA	1
00341-3217	RST2247		340.923	1.06089	6.973	10.628	2.4756		15.212	3.291						
00397-2205	DON 9		172.725	1.63034	11.163	12.894	2.6687	2.7129	55.053	1.033	54.589	-0.121	BAAA	80	CA	20
00420-2457	RST2250	BC	313.024	0.77609	11.088	12.288	5.1102		11.703	-7.839						
00456-2055	HU 1204		267.370	1.45443	9.582	11.996	1.8576	-1.0790	20.517	-1.269	17.436	-24.176	DDBA	0	DD	1
00525-3138	JSP 14		216.171	3.24964	9.478	12.797	3.0822	3.1024	22.484	-4.651	20.859	-3.688	BDAB	4	CA	20
00529-5123	RST 22		17.959	1.51524	10.714	12.164	3.9347	3.9290	36.812	-16.526	36.620	-16.871	AAAA	100	BA	80

Description of the table content (all values per epoch 2015.5, values in parentheses only in download file):

WDS = WDS ID
Disc = Discoverer code
Comp = Components
PA = Position angle calculated from the GAIA DR2 coordinates
(e_PA = Error position angle)
Sep = Separation in arcseconds calculated from the GAIA DR2 coordinates
(e_Sep = Error separation)
Gmag1 = GAIA DR2 Gmag primary
(e_Gmag1 = Error Gmag1)
Gmag2 = GAIA DR2 Gmag secondary
(e_Gmag2 = Error Gmag2)
Plx1 = Parallax primary in mas
(e_Plx1 = Error Plx1)
Plx2 = Parallax secondary in mas
(e_Plx2 = Error Plx2)
pmRA1 = Proper motion RA primary in mas/yr
(e_pmRA1 = Error pmRA1)
pmDE1 = Proper motion DE primary in mas/yr
(e_pmDE1 = Error pmDE1)
pmRA2 = Proper motion RA secondary in mas/yr
(e_pmRA2 = Error pmRA2)
pmDE2 = Proper motion DE secondary in mas/yr
(e_pmDE2 = Error pmDE2)
CPMR = Common proper motion rating letter based
CPMS = Common proper motion estimated probability
(BCD_1_2 = Best case distance between primary and secondary in AU)
(RCD_1_2 = Realistic case distance between primary and secondary in AU)
(WCD_1_2 = Worst case distance between primary and secondary in AU)
PlxR = Rating for potential gravitational relationship
PlxS = Estimated probability for gravitational relationship

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Overall it seems that most not recovered objects are either bogus (or simply lost due to wrong J2000 positions) or not resolved in DR2 because of separations below 1 arcsecond.

5. References

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6. Acknowledgements

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- 2MASS images
- DSS2 images
- PS1 images
- PS1 catalog
- Aladin Sky Atlas v10.0
- GAIA DR2 and DR1 catalogs
- TAP-VizieR
- CDS X-Match
- 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 probability and a verbal assessment for being CPM

Description of the Plx rating procedure (according to Knapp 2018):

- Two rating factors are used: Distance between the components in AU and relationship Plx error to Plx value. The distance between the components is calculated from the inverted GAIA DR2 parallax data (if positive and Plx>3*e_Plx) and the angular separation using the law of cosine. Realistic case is based on the given Plx values and the best and worst case scenario uses the given e_Plx data on the Plx values to estimate a smallest and largest possible distance
- "A" for worst case distance, "B" for realistic case distance and "C" for best case distance less than 200,000 AU (means touching Oort clouds for two stars with Sun-like mass) and "D" for above
- "A" for Plx error less than 5% of Plx, "B" for less than 10%, "C" for less than 15% and "D" for above

The letter based scoring is then transformed into an estimated likelihood for being potentially gravitationally bound.

A Plx Score of

- less than 10 means a likelihood of or near zero
- less than 50 means a likelihood lower than 50%
- larger than 50 means a likelihood larger than 50%
- equal 100 means a likelihood of 100%

for a distance between the components smaller than 200,000 AU.

These likelihoods are based on the assumption that RA and DEC coordinates as well as parallaxes are normal distributed measurements with the given error range as standard deviation.