Cross-Match of WDS TDS/TDT Objects with Gaia DR2

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Abstract: The WDS catalog contains in total 14,169 Tycho Double Stars (based on Fabricius et al. 2002) with the designation TDS/TDT. So far (per August 2018) only 1,366 such objects got confirmed by at least a second observation. Out of these 1,366 confirmed TDS objects 1,079 were recovered as Gaia DR2 pairs. This statistic has been broken down to separation classes to check the performance of Gaia DR2 for resolving close doubles more in detail. Additionally 1,034 TDS objects with so far only one observation got confirmed by Gaia DR2 raising the percentage of confirmed TDS objects from less than 10 to ~17%. Finally the matched TDS objects were checked for being potentially binaries by means of common parallax.

1. Introduction

The claim of unprecedented precision and sky coverage of the Gaia DR2 catalog raises some hope to finally get most precise measurements for most if not all objects in the WDS catalog. A closer look at the documentation papers coming with Gaia DR2 dims this expectations significantly – Gaia DR2 resolves doubles "only" down to 0.4" separation and the hit rate in the sub-arcsecond range is less than perfect. The first impulse to try Gaia DR2 with the full WDS catalog quickly loses its appeal for this reason – having a look at a specific group of WDS objects seems better suited to check not only the performance of Gaia DR2 in detail but to gain also valuable new data for this object group. One of the groups of WDS objects of special interest are the Tycho Double Stars with a status of questionable data quality due to the currently low confirmation rate of less than 10%. Several attempts were recently made to either get confirmations for Tycho Double Stars with so far only one observation or to declare them for good reasons as bogus objects (for example Knapp and Gould 2016) – but the tools available to do this were until now rather limited.

Using the CDS TAP-VizieR tool, a total of 14,169 TDS/TDT objects were selected from the WDS catalog. Using the CDS X-match tool, these objects were then cross-matched for the primary with DR2 with a search radius of 5" around the given WDS J2000 position. Due to the density of DR2 objects this yielded 19,306 objects. With the given Gaia DR2 J2000 positions and the WDS data for separation and position angle the J2000 position for the secondary was calculated with the caveat that Gaia DR2 provides for a good part of the components of the TDS objects no proper motion values and thus the calculated positions were a mix of J2000 and J2015.5 coordinates. These calculated positions were again matched with Gaia DR2, but this time with 2" search radius for the secondaries giving 32,719 objects including the unavoidable self-matches for the primaries.

As next step a drill down process was started after calculating separation and position angle for the found pairs (observation epoch J2015.5):

- Eliminating the self-matches of the primaries by recognizing a separation of zero.
- Eliminating all pairs with a difference between calculated and WDS given position angle larger than 15°.
- Eliminating all pairs with a difference between calculated and WDS given separation larger than 50%. This threshold at first looks far too generous but we are talking here of mostly very small separations and for example a given WDS separation of 0.4 and a found Gaia DR2 separation of 0.6 would result in a 50% separation delta yet looks pretty much like a good match, especially if other parameters like po-

sition angle and magnitudes are close to the WDS data. Another aspect requesting some tolerance is the fact that the positions used for calculating the Gaia DR2 separation are J2015.5 with accumulated proper motion since 1991 (the Tycho Double Star observation epoch)

- Sorting the objects by discoverer ID and checking for multiple matches made clear which objects had to be checked in detail to keep the best matches with the given WDS parameters not only for position angle and separation but also for the magnitudes
- Finally, even the best matches by position angle and separation could only be false positives if the Gaia DR2 magnitudes in the G band were far beyond the given WDS magnitudes, so these objects had also to be deleted

The end result was 2,113 remaining TDS to Gaia DR2 matches considered to be valid.

2. Results

The details of this cross-match and drill down process are as follows:

- 320 TDS objects are (in the WDS "precise *last* only" list) given with a separation smaller than 0.4" – no match is to be expected for this class of objects as this is the declared resolution limit of Gaia DR2 (Arenou et al. 2018)
- 8,562 TDS objects are listed with 0.4 to 1 arcsecond separation with 282 of them confirmed with more than 1 observation. 102 such objects were recovered as Gaia DR2 pairs which means a hit rate of 36%. In total 435 objects in this class were resolved in Gaia DR2 which means about 300 new confirmations but also that only about 5% of the TDS pairs in this range got a hit. Taking the recovery rate for the confirmed objects as expectation for the rest of so far unconfirmed objects in this range we can estimate the number of TDS bogus objects in this class to ~7,350
- 3,029 TDS objects are listed in WDS with a separation between 1 and 2 arcseconds with 448 of them confirmed with more than 1 observation. 424 such objects were recovered as Gaia DR2 pairs means a hit rate of 95%. In total 1,002 objects in this class were resolved in Gaia DR2 which means about 580 new confirmations. I we take the 95% ratio as expectation for this class of objects then we can expect ~2,000 bogus TDS objects here
- 1,860 TDS objects are listed in WDS with a separation between 2 and 3 arcseconds with 288 of them confirmed by more than 1 observation. 266 such objects were recovered as Gaia DR2 pairs means a hit rate of 92%. In total 380 objects in this class were resolved in Gaia DR2 which means 114 new confirmations. I we take the 92% ratio as expectation for this class of objects then we can expect ~1,450 bogus TDS objects here
- 398 TDS objects are listed in WDS with a separation of larger than 3 arcseconds with 307 of them confirmed by more than 1 observation. 287 such objects were recovered as Gaia DR2 pairs means a hit rate of 93%. In total 289 objects in this class were resolved in Gaia DR2 which means a meagre 2 new confirmations – not such a surprise as at this separation range resolution is no longer a challenge even for amateur telescopes. I we take the 93% ratio as expectation for this class of objects then we can expect ~90 bogus TDS objects here meaning that all TDS objects in this class so far not confirmed can be considered bogus.

In Table 1 the first 20 rows of the list of the cross-matched TDS objects are given with a subset of the data. The full list with all columns can be downloaded from the JDSO website as "TDS XX DR2".

3. Check for binaries

Finally the found matches were checked for being potentially binaries by calculating the distance between the components of the pairs using the parallax data provided by Gaia DR2 which was the case for at least a part of the objects. After eliminating all objects with missing or negative parallax values or Plx values smaller than 3 times the given parallax error range 1,556 pairs remained available for assessment according to Knapp 2018 (see Appendix A). 12 pairs qualified for being most probably physical and additionally 90 pairs as probably physical – in total 6-7% of the pairs with usable Plx data given. 691 pairs are to be considered probably opticals with maybe the one or other common proper motion pair thrown in and the rest is to be considered as most certainly optical.

In Table 2, the first 20 rows of the list of the cross-matched TDS objects are given with a subset of the data. The full list with all columns can be downloaded from the JDSO website as "TDS XX DR2 Plx".

4. New pairs found?

As a side result several hundred Gaia DR2 pairs were found during the matching process as close objects to TDS pairs but with magnitudes beyond the TDS range. This number shrank significantly by eliminating all objects with negative parallax or parallax value

(Text continues on page 182)

Table 1: Results cross-match WDS TDS/TDT objects with Gaia DR2

WDS	Disc	Comp	nObs	RA 2015.5	Dec 2015.5	Sep	PA	Gmag1	Gmag2	Plx1	Plx2	pmRA1	pmDec1	pmRA2	pmDec2
00008+5016	TDS1246		1	0.204124063	50.27390741	0.53891	200.429	10.811	11.922	2.6093		-5.523	0.943		
00014+5704	TDS 1		1	0.355449541	57.06503669	0.88576	318.866	10.688	10.857	-0.5807	2.02	-1.323	-3.028	4.086	-1.224
00018+6014	TDS1254		1	0.457120112	60.23094451	1.02536	234.225	11.335	12.177	0.5792	0.2025	-2.851	-2.418	-5.54	2.083
00021+5556	TDS1258		2	0.527363777	55.92517011	0.72625	246.635	10.697	10.63	-1.2994		3.564	4.694		
00025+6100	TDS 2		1	0.617138072	61.00312872	0.97111	192.678	10.292	11.068	3.0605		8.748	-3.32		
00029-7436	TDS 3	AB	2	0.713255314	-74.5981027	1.50470	46.728	10.302	10.993	8.1791	8.101	25.921	-49.665	30.235	-47.379
00030+5908	TDS1271		1	0.760941931	59.13327805	0.61548	258.023	10.708	10.602						
00043+3705	TDS1281		2	1.064647766	37.08627092	1.51446	335.864	11.947	11.979	2.0191	2.0484	2.866	-9.023	3.556	-9.47
00043+4848	TDS1280		2	1.068741862	48.79952405	2.13214	257.414	11.584	11.836	2.7233	2.6964	15.394	-4.495	13.775	-5.941
00061+5457	TDS1289		2	1.523163239	54.94259951	1.03586	127.454	11.15	11.765	3.7343	0.3263	-10.787	-7.729	-15.791	-12.274
00063+1847	TDS1291		2	1.586563521	18.78148558	2.95055	81.790	12.363	12.906	1.3827	1.441	-1.288	-6.612	-1.631	-6.817
00066+4503	TDS1297		1	1.637575406	45.04769915	1.97373	19.312	11.663	12.634	1.3876	1.1494	-1.723	-5.95	-0.806	-5.77
00069+5243	TDS 4		1	1.716718911	52.71552131	0.79756	181.797	10.981	11.5	1.0047		-2.611	-2.299		
00085+7830	TDS1308		2	2.128163782	78.50614953	1.43658	26.070	11.015	11.509	3.4644	3.0977	-36.247	-9.479	-35.773	-7.819
00094-3321	TDS1322		10	2.33933148	-33.3552472	9.46619	277.574	10.663	10.61	7.0201	7.1058	167.998	-20.353	167.66	-21.768
00094+6122	TDS1321		1	2.352078206	61.36798051	0.60694	82.276	10.298	10.943						
00096+0426	TDS1323		2	2.398324295	4.436205279	1.79846	226.240	10.929	11.618	5.029		5.038	-33.504		
00112+5034	TDS 5		1	2.803504545	50.56212194	1.20025	135.396	11.12	12.3	1.6263	-10.6015	9.55	-0.725	7.872	1.24
00132+4723	TDS1345		4	3.295231061	47.38523046	5.78043	293.423	11.241	12.653	4.0557	4.0237	19.121	-13.365	18.738	-14.021
00134+0226	TDS 7		2	3.354035428	2.43837279	1.67327	36.692	11.109	11.878	2.3663	2.7208	6.859	-15.382	6.441	-16.237

Description of Table 1 contents.

- WDS = WDS ID
- Disc = Discoverer code
- Comp = Components
- nObs = Number of observations according to WDS per August 2018
- RA 2015.5 = RA observation epoch 2015.5 in degrees
- Dec 2015.5 = Dec observation epoch 2015.5 in degrees
- Sep = Separation in arcseconds
- e_Sep = Error separation in arcseconds
- PA = Position angle in degrees
- e_PA = Error position angle in degrees
- Gmag1 = Gmag1
- Gmag2 = Gmag2
- Plx1 = Parallax 1 in mas
- Plx2 = Parallax 2 in mas
- pmRA1 = Proper motion RA 1 in mas
- pmDec1 = Proper motion Dec 1 in mas
- pmRA2 = Proper motion RA 2 in mas
- pmDec2 = Proper motion Dec 2 in mas

Table 1: Results of assessment for being physical based on parallax and separation

WDS	Disc	Comp	Plx A	e_Plx A	Plx B	e_Plx B	Sep	Best Case Distance	Realistic Case Distance	Worst Case Distance	Plx Rat	Plx Score	Notes
00029-7436	TDS 3	AB	8.1791	0.0272	8.1010	0.0495	1.505	4,350.213	243,131.512	483,260.215	CA	20	
00043+3705	TDS1281		2.0191	0.0359	2.0484	0.0390	1.514	736.979	1,461,266.144	5,191,941.281	CA	20	
00043+4848	TDS1280		2.7233	0.0516	2.6964	0.0491	2.132	776.611	755,626.104	3,582,897.878	CA	20	
00063+1847	TDS1291		1.3827	0.0510	1.4410	0.0467	2.951	2,058.036	6,035,466.986	16,241,909.293	CA	20	
00066+4503	TDS1297		1.3876	0.0397	1.1494	0.0506	1.974	18,860,947.128	30,806,369.153	43,205,168.097	DA	1	S
00085+7830	TDS1308		3.4644	0.0491	3.0977	0.0930	1.437	4,251,372.562	7,048,192.657	9,941,233.388	DA	1	S
00094-3321	TDS1322		7.0201	0.0511	7.1058	0.0480	9.466	1,338.724	354,374.033	764,591.767	CA	20	
00132+4723	TDS1345		4.0557	0.0511	4.0237	0.0391	5.780	1,422.799	404,478.575	1,540,342.685	CA	20	
00134+0226	TDS 7		2.3663	0.0489	2.7208	0.2078	1.673	3,323,743.621	11,357,534.354	18,576,184.963	DB	1	S
00150+5243	TDS1357		1.7108	0.0942	0.8687	0.1254	1.168	79,898,927.378	116,876,943.540	163,228,022.744	DB	1	S
00167+1334	TDS1377		1.7359	0.1115	2.4203	0.1031	1.402	22,637,204.545	33,600,855.776	45,239,193.481	DB	1	S
00181+5255	TDS 10		1.2119	0.1085	1.5169	0.0832	1.259	12,345,263.149	34,222,390.630	58,029,428.940	DB	1	S
00181+0043	TDS1387		1.6816	0.0422	1.6421	0.0509	1.606	948.817	2,950,591.321	9,971,629.211	CA	20	
00195-8505	TDS1401		1.6940	0.5624	2.6516	0.5583	0.744	329.753	43,974,100.295	118,020,659.619	CD	13	
00197+5258	TDS1402		1.0004	0.0387	0.9744	0.0383	2.022	1,997.155	5,501,696.909	21,841,973.612	CA	20	
00211+6443	TDS 13		3.3619	0.0257	3.3718	0.0331	2.553	753.609	180,146.855	1,247,482.952	BA	80	T
00220+4529	TDS1422		4.2056	0.1305	4.3234	0.3311	1.246	287.255	1,336,368.284	6,300,883.180	CB	19	
00230+2735	TDS 16		1.5344	0.0589	1.1189	0.1340	1.400	24,837,265.446	49,920,095.335	79,971,225.878	DB	1	S
00233+5756	TDS 17		1.3967	0.0837	0.8947	0.1246	1.354	45,265,929.000	82,862,377.165	128,513,826.946	DB	1	S
00244+4342	TDS1444		1.5997	0.0489	1.6000	0.1095	1.119	678.862	24,186.816	12,347,705.748	BA	80	T

Description of the table content:

WDS = WDS ID
Disc = WDS discoverer code
Comp = Components (AB if blank)
Plx A = Parallax for primary
e_Plx A = Error parallax for primary
Plx B = Parallax for secondary
e_Plx B = Error parallax for secondary
Sep = Separation in arcseconds
Best Case Distance = Best case distance A to B in AU
Realistic Case Distance = Realistic case distance A to B in AU
Worst Case Distance = Worst case distance A to B in AU
Plx Rat = Letter based rating for potential gravitational relationship
Plx Score = Estimated probability for potential gravitational relationship
Notes= Suggested WDS code either "T" for physical or "S" for optical, else blank

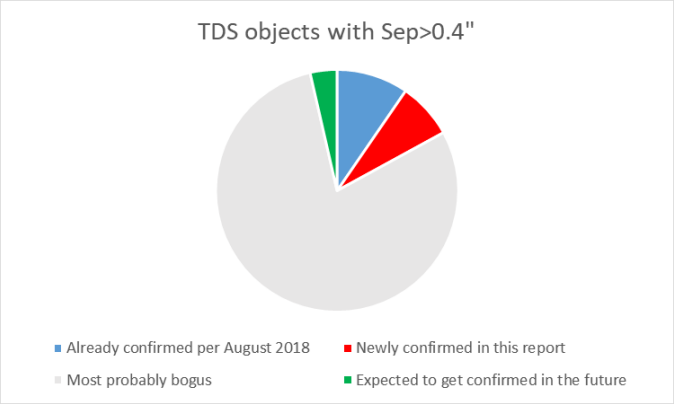

Figure 1. Status of Tycho Double Stars

(Continued from page 179)

smaller than 3 times the given parallax error range. But also for the rest the given Plx values were insignificant so none of the found pairs qualified as potentially binary.

5. Summary

To summarize the results above, we get 13,849 TDS objects with a separation larger than 0.4" (See Figure 1) with 1,325 of them with two or more observations. 1,079 such objects were recovered in Gaia DR2 which means (not counting the objects with separation below 0.4") an overall hit rate of 81%. In total 2,113 TDS objects got resolved in Gaia DR2 which means more than 1,000 new confirmations. And overall we have to expect that ~11,000 TDS objects are most certainly bogus – which means close to 80%.

Taking a look at the Gaia DR2 recovery performance we find that pairs below 0.4" separation are generally not covered. Pairs between 0.4 and 1.0" separation have a hit rate of ~36% and for objects with separation larger than 1" we find a hit rate of 93 to 94%. These values might be not perfect (especially for pairs with a separation larger than 2" one would expect close to 100%) but make evident that Gaia DR2 is certainly a valuable source for counter-checking of close double stars not only for new precise measurements but also for assessing the possibility of gravitational relationship.

6. Acknowledgements

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

- Washington Double Star Catalog
- Gaia DR2 catalog
- Aladin Sky Atlas
- CDS TAP-VizieR TAP
- CDS X-match

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Appendix A

Description of the Plx rating procedure

- The distance vector of the two components of a pair is calculated with the naive approach 1/Plx +/- error range and the distance between the components is then calculated using the law of cosines with the two resulting vectors and the given angular separation
- "A" for worst case distance (Plx with errors applied for largest possible result), "B" for realistic case distance (using given Plx without error) and "C" for best case distance (using Plx with errors applied for smallest possible result) 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 probability for being potentially gravitationally bound