A Catalog of High Proper Motion Stars in the Southern Sky (HPMS3 Catalog)

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Abstract: The LSPM catalog (Lepine and Shara 2005) covers the high (>150mas/yr) proper motion stars in the northern sky. This report presents in tribute to the work of Lepine and Shara the second half of such objects – high (>150mas/yr) proper motion stars in the southern sky selected from the Gaia DR2 catalog, in total over 90,000 such objects. Several thousand objects come in pairs up to 60 arc seconds separation. A part of these pairs are already listed in the WDS catalog and given with the corresponding WDS ID, the rest are newly discovered pairs most of them with common proper motion. Several hundred CPM pairs have parallax data similar enough to be considered as potentially gravitationally bound so the other CPM pairs are most probably random pairs travelling in the same direction with the same speed. The CPM pairs potentially bound by gravitation are listed in a separate table as newly discovered binaries and other catalogs were checked to give an observation history. A new class of pairs are those with potential gravitational relationship but proper motion different enough to be considered not quite common up to quite different – this might be a serious hint that fast orbits might overlap proper motion to the degree of rendering the criteria common proper motion as irrelevant for the assessment as binary double star if there are good reasons to suspect an orbit.

Preamble: The second data release of the still preliminary Gaia catalog comes similar to DR1 with a multitude of caveats listed in the different documentation papers published parallel to the data release (https://www.cosmos.esa.int/web/gaia/dr2-papers). Along with the amazingly small error range resulting from the huge amount of measurement results, this provides a mixed message of unprecedented data precision with a general uneasiness regarding data reliability beyond any error range. Therefore we tried our best to keep our results as far as possible on solid ground by eliminating objects with potentially questionable data. That said, we appreciate the wealth of Gaia DR2 data very much indeed.

Introduction

The LSPM catalog contains 61,977 high proper motion stars detected mainly by comparing POSS I (average epoch 1950) to POSS II (average epoch 1990) images using software developed specifically for locating such objects (Lépine and Shara 2005) but also by using other sources as for example Tycho II and 2MASS. This setup limited the research area to the northern sky. The authors of this catalog also identified 1,159 common proper motion pairs to be included in this data set but only about 170 such pairs were considered new discoveries and listed in the WDS catalog with the discoverer code LEP. Yet our own research showed that the LSPM catalog contains about 3,500 pairs of objects closer than 25 arcseconds with a high probability that such pairs are very fast common proper motion pairs.

SIMBAD contains 37,607 and UCAC5 lists 31,543 objects in the southern sky with proper motion >150mas/yr – as there is no reason to assume that the southern sky contains fewer high proper motion objects than the northern sky we expected that there is a rather large number of so far not known high proper motion objects to be found in Gaia DR2. The availability of about 1,300,000,000 Gaia DR2 objects with proper motion data made it rather easy to select the 90,455 objects with a proper motion vector larger than 150mas/yr and declination smaller than zero. This selection is made in the knowledge that very fast moving stars with >600mas/yr are not fully covered with Gaia DR2 – about 20% of such objects might be missing (Luri et al. 2018) and that by selecting high proper motion objects we take the risk of a higher probability of spurious data compared with a purely random selection (Arenou et al. 2018).

High proper motion stars in the southern sky

In Table 1 we list a subset of the data for the first 10 objects. The full data set with 90,455 objects is available for download on the JDSO website as "HPMS3". A random sample of HPMS3 objects was visually counter-checked by just looking at the Aladin DSS colored images providing in many cases evidence for high proper motion due to being composites of images taken at different points of time and different colors, see for example Figure 1.

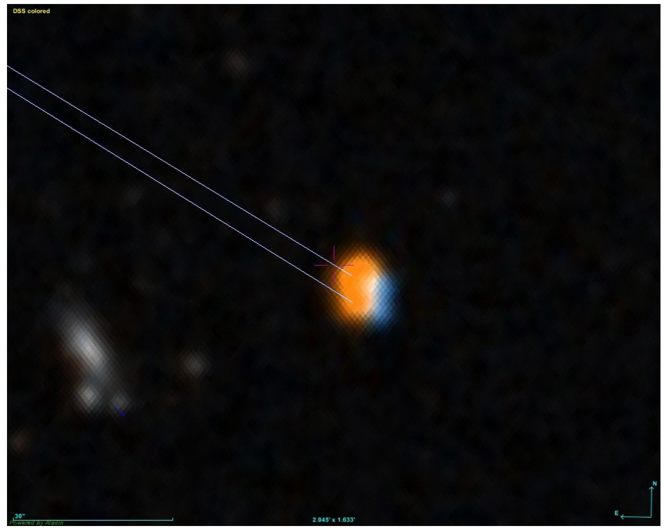

Figure 1. Evidence of high proper motion in DSS image for HPMS3 objects 203 and 204 (white lines indicate Gaia DR2 proper motion vectors)

All HPMS3 objects were cross-matched with 2MASS, UCAC4, PS1 and Gaia DR1 to give additional references. 74,616 corresponding 2MASS objects and 39,087 corresponding UCAC4 objects were found within a 2" radius of the J2000 Gaia DR2 positions. 68,417 Gaia DR1 corresponding objects were found within 0.4" from the DR2 epoch 2015 positions covering the Gaia DR1 objects without proper motion data given. Despite this rigid cut value corresponding with the resolution limit of Gaia DR2 several matches are to be considered arbitrary as Gaia DR1 contains a large number of spurious objects with separations smaller than 0.4" so in such cases a choice had to be made usually based on quality parameters especially such as the given position errors. Despite these efforts several suspect Gaia DR1 objects remained in the data set to be recognized for example by unexpected large deltas between DR1 and DR2 Gmags – for the first 20 such objects we had a closer look (see Appendix C). 6.517 additional Gaia DR1 objects were found within 1" from the epoch 2000 positions covering the TGAS objects with proper motion data given – in total this gives 74,934 cross-matched DR1 objects. The cross-match with PS1 using the Gaia DR2 2015.5 positions with 1" search radius resulted in 67,856 objects with 47,830 remaining after eliminating the multiple matches caused by the abundant PS1 spurious sources for high proper motion objects. In total a few thousand HPMS3 objects remained without confirmation by other catalogs due to the much higher resolution in Gaia DR2 and for this reason we got here in some cases also identical objects matched due to non-resolution in the other catalogs.

Manually counter-checking a part of the unconfirmed objects with other catalogs, we found no serious issues with them besides being often very faint to the point of non-resolution in the DSS images. For obvious reasons, we were not able to verify at least a part of the very close HPMS3 objects, but we decided to keep these objects in our data set taking the risk of error contamination by Gaia DR2 spurious stars. But this risk seems in Gaia DR2 much smaller than in Gaia DR1 as the data processing for DR2 is considered to be significantly improved compared with DR1 (Gaia Collaboration: Brown et al. 2018) and objects below 0.4" separation are treated as duplicated sources as the chance that such a pair might be a resolved double star was considered as very small (Arenou et al. 2018). Another issue are the objects with negative Plx values (according to the Gaia documentation correct results in the sense of correctly executed measurement procedure even if obviously in error) – such objects including these with a positive Plx value but smaller than 3 times the Plx error are considered as potentially suspect as the proper motion data might at least in some such cases be incorrect as there is (according to Luri et al. 2018) a non-zero

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Table 1. High proper motion stars in the southern sky (HPMS3) catalog

hpms3	gaia dr2 source_id	ra	dec	pmra	pmdec	pmvd	pmvl	vmag
1	2305847067958584832	0.09154153	-41.5643772	-61.673	-215.984	195.936	224.617	16.129
2	2305857027987132928	0.11776003	-41.4254417	503.879	-31.364	93.562	504.854	16.179
3	2305871596516150656	0.08668279	-41.2983045	134.491	-112.265	129.853	175.189	9.772
4	2305871600811057280	0.08068845	-41.2966365	134.649	-113.366	130.095	176.018	19.238
5	2305937056113463296	359.396218	-40.9940889	20.848	-204.658	174.183	205.717	15.354
6	2305945096292235648	359.585306	-40.8047801	-32.804	-162.522	191.411	165.800	16.082
7	2305945538674043392	359.500445	-40.8294248	-33.01	-162.222	191.502	165.546	17.905
8	2305956984761692288	0.03015094	-40.6662214	-42.1	-194.405	192.219	198.911	16.366
9	2305965883933917568	0.15497041	-40.4884915	176.276	-56.865	107.879	185.221	14.702
10	2305989489073956608	0.5922841	-40.81064	128.392	-216.409	149.320	251.629	14.749

Description of the table content per object (the content of the full data set gives additional error data, 2MASS and UCAC4 IDs, Plx data etc.):

- hpms3 gives the object ID with a running number
- gaia dr2 source_id gives the Gaia DR2 object ID
- ra and dec give the Gaia DR2 RA/Dec coordinates for epoch 2015.5 in degrees
- pmra and pmdec give the proper motion data for RA and Dec in mas/yr
- pmvd and pmvl give the proper motion vector direction in degrees and proper motion vector length in mas/yr
- vmag gives the estimated Vmag derived from Gaia DR2 GBR-mag

correlation between proper motion and Plx data. Another indicator for potentially suspect data is the Gaia DR2 duplicity flag – either an unresolved double star or a spurious star might be a reason for this. Finally there is the recommendation in Arenou et al. 2018 to check the number of observations (visibility_periods_used) putting a questions mark on all objects with less than 9.

This gives in total ~22% with potentially contaminated data, especially the 5% with negative parallax values might be listed with suspect proper motion values. Checking the issue with negative parallaxes with random object samples we found that about 25% of all given Gaia DR2 parallaxes are negative while in our high proper motion selection this percentage is much lower. The explanation for this unexpected result is probably the fact that high proper motion objects are in average much closer to our Sun system than the average Gaia object with an according to Luri et al. 2018 much better statistical behavior than objects with larger distances which show an asymmetrical and rather complex error distribution – so high proper motion objects are in this regard a positive selection even when we have to consider a co-variance between parallax and proper motion as caveat.

The estimation of the visual magnitude based on Gaia DR2 G/B/R-mags uses a prototype formula (estimated Vmag = 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 same data set from our Vmag paper (Knapp and Nanson 2018) 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 several cases Gaia DR2 provided no B- and R-mag data so we used here the formula for Vmag estimation from Knapp and Nanson 2018 using J/H/K-mags from matched 2MASS objects. In the rare cases with neither B- and R-mag nor J/H/K-mag data available we estimated Vmag from Gmag plus an average difference Vmag to Gmag of 0.318 according to our data sample.

Compared with SIMBAD and UCAC5 the number of objects is about threefold with some overlap of objects around 150mas/yr due to slightly different proper motion values means making the cut in SIMBAD or UCAC5 but not in Gaia DR2 or vice versa. A cross-match of SIMBAD objects with proper motion >600mas/yr with the HPMS3 catalog based on the J2000 positions and a search radius of 5 arc seconds reveals 195 missing objects out of 1,579 such objects – this is about 12.35% which is slightly less than the 17% mentioned in Arenou et al. 2018.

The number of HPMS3 objects with proper motion >600mas/yr is 2,411 indicating that about 300 to 400 very high proper motion objects might be missing in the

HPMS3 catalog giving room for future maintenance. The SIMBAD cross-match results indicate that a good part of these missing high proper motion objects are already included in existing star catalogs but we made no attempts to include these in the HPMS3 catalog to keep our discovery method consistent.

3. HPMS3 pairs

As visually close pairs with high proper motion are according to our experience often common proper motion pairs we selected from the HPMS3 catalog all objects with a neighbour within 60 arcseconds to verify this assumption – 4,412 such pairs are to be found in the HPMS3 catalog.

3.1 HPMS3 pairs cross-matched with WDS

In the next step we cross-matched this list with the WDS catalog with a search radius of 15 arc seconds to identify the objects already WDS listed. For most objects this cross-matching was straight forward but in several cases multiple matches or mis-matches occurred for different reasons:

- A;BC or pairs of similar pattern were resolved as AB and AC
- Components A or B were resolved into Aa;Ab or Ba;Bb (the latter cases causes some troubles of identification because the cross-match is based on the primaries but we did our best to identify also the Ba;Bb or even Ca;Cb etc. cases)
- WDS multiples were matched to only one HPMS3 pair because the other components are not high proper motion stars
- The matched WDS object had only one component identical with the HPMS3 pair while the high proper motion secondary was another star
- Odd cases with different WDS objects for the same pair.

Such cases had to be cleared by manual counter-checks. During these manual counter-checks we became aware that the 15" search radius was not such a good choice as some WDS pairs come with a position difference to Gaia DR2 larger than 15" and that several WDS objects with separation larger than 15" are listed with reversed components. Additionally a few WDS objects with wrong PA and Sep data led to erroneous negative results in the second cross-matching step looking for the secondary. All these missing WDS matches were manually cleared.

Finally 1,623 of the HPMS3 pairs were found to be identical with existing WDS objects for which we give the found Gaia DR2 based data with our assessment for being physical pairs as recent 2015.5 observations. Several identified pairs are listed with a sub arc second separation indicating that Gaia DR2 seems reliable also for close pairs even if the coverage of such close pairs is rather limited in Gaia DR2 (Arenou at al. 2018). In a few cases the listed components are in reversed order compared with WDS due to slightly different magnitude values.

The common proper motion assessment is based on the scheme presented in Knapp 2018 (see Appendix A) with a modification allowing for the slight differences in direction and speed in case of an orbit depending on the plane of the orbit from our point of view: The allowed difference in direction was set to a plausible value of 1° and the allowed difference in speed to 1% of the average vector length. These values might be somewhat arbitrary, but were selected to cover most cases of pairs with seemingly obvious orbits.

In Table 2 we list a subset of the data for the first 10 HPMS3 pairs found to be existing WDS pairs, the full data set is available for download on the JDSO website as "HPMS3_pairs_WDS_matches".

3.2 HPMS3 pairs with negative parallax

Bailer-Jones (2015) shows that estimating stellar distance is even with a given parallax not trivial and that the naïve approach of reporting 1/Plx +/- error is unreliable and fails for obvious reasons for negative parallax values. About 7% of the HPMS3 objects are listed in Gaia DR2 with a negative parallax or with Plx values smaller than 3 times the given error range – this ratio is probably representative for Gaia DR2 objects with high proper motion while the overall Gaia DR2 ratio for objects with negative parallax is as already indicated much higher. A specific ADQL (Astronomical Data Query Language) query for such objects using the Gaia Archive resulted in amazing 80.85%. While the very existence of negative parallaxes is explained as unavoidable side effect of data sampling and processing in Luri et al. 2018 we can only consider the data of such objects as not usable for our purpose and as we do not use the given parallax data for any sample based conclusion but only for single object assessment it is therefore no problem to simply ignore such objects against the recommendation in Luri et al. 2018.

From the remaining HPMS3 pairs without a WDS match 160 pairs are listed with a negative parallax or a Plx value smaller than 3 times the Plx error for at least one component – as already mentioned such a situation indicates a serious issue with data reliability not only for the Plx values but for all other data including especially also proper motion values. In consequence these objects were simply excluded from the next steps of

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Table 2: WDS pairs in the HPMS3 catalog

HPMS3 ID	WDS	Disc	Notes	RA A	DE A	Sep	PA	Mag A	Mag B	pmRA A	pmRA B	pmDE A	pmDE B	Plx A	Plx B	CPM Score	Plx Score	True Binary
00003+00004	00003-4118	SKF1140		0.086682791	-41.29830453	17.289	290.325	9.772	19.238	134.491	134.649	-112.265	-113.366	8.8058	8.7678	100	80	80
00062+00063	23571-3838	UC 5051		359.271552	-38.62617133	41.204	269.620	13.822	16.628	52.345	51.416	-166.781	-166.012	16.7258	17.0874	97	20	19
00073+00072	23538-3729	LDS 825		358.4623977	-37.48660162	13.217	192.195	11.173	14.33	386.43	389.873	-14.147	-15.958	18.1389	18.1097	100	100	100
00122+00123	00177-3428	LDS3148		4.432803099	-34.48390988	28.806	0.412	12.47	16.064	-163.455	-124.568	-160.509	-248.169	12.8019	3.9785	0	1	0
00162+00161	00094-3321	TDS1322	AB swap	2.336210894	-33.35490059	9.466	97.574	11	11.053	167.66	167.998	-21.768	-20.353	7.1058	7.0201	100	20	20
00190+00191	23538-3622	LDS5134		358.4303741	-36.34808237	14.346	54.851	16.871	17.696	185.731	183.356	-152.857	-150.487	17.8894	18.0088	80	80	64
00202+00201	23491-3542	LDS5125		357.2867156	-35.69233549	24.915	245.999	15.35	17.217	181.225	181.574	-78.346	-78.446	7.5143	7.777	97	1	1
00209+00210	23430-3546	LDS5113		355.7274743	-35.76148366	25.346	308.972	15.637	16.062	206.899	205.492	-71.846	-70.296	16.3816	16.477	97	100	97
00246+00247	23575-3414	LDS5141	AB swap	359.3749881	-34.21980433	5.120	68.362	17.303	17.441	-111.454	-111.011	-159.559	-160.291	8.0988	7.9908	100	20	20
00249+00250	23579-3408	WIS 397		359.4740452	-34.12820448	24.857	49.712	13.072	18.631	152.891	155.195	-388.047	-382.353	30.9118	30.344	80	100	80

Description of Table 2 contents per WDS pair:

- HPMS3 ID gives the HPMS3 object ID for both components
- WDS gives the WDS ID
- Disc gives the WDS discoverer code
- RA and Dec give the Gaia DR2 RA/DE coordinate of the primary for epoch 2015.5
- Sep gives the separation in arc seconds
- PA gives the position angle in degrees
- Mag A and B give the estimated Vmags in most cases derived from Gaia DR2 green, blue and red magnitudes
- pmRA and pmDE give the proper motion data for RA and Dec for both components in mas/yr
- Plx A and B give the parallax value for both components in mas
- CPM Score gives the estimated probability for common proper motion according to the used CPM assessment scheme (see Appendix A)
- Plx score gives the estimated probability for assumed gravitational relationship according to the used assessment scheme (see Appendix A)

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evaluation. To provide complete information this data subset is available for download on the JDSO website as "HPMS3_pairs_negPlx".

3.3 HPMS3 probably optical pairs

As we have no intention to determine the "true" distance of stars but only the probability for two stars of being close enough for potential gravitational relationship we stick in our procedure for potential gravitational assessment (Appendix A) with the "naïve" parallax inversion combined with the given angular separation and the given error range to consider a best/realistic/worst case scenario for the distance between the components of a pair. The assessment of potential gravitational relationship is then done based on another simplification assuming that all considered objects are of average Sun-like mass and that therefore the limiting distance is similar to the Oort cloud of our Sun system. Based on this assessment scheme about 450 HPMS3 pairs are only optical and are reported here just for purpose of completeness but not as double stars to be included in the WDS catalog. In Table 3 below the first 10 such pairs are listed with selected columns. To provide complete information the full data subset is available for download on the JDSO website as "HPMS3_optical_pairs".

3.4 HPMS3 random common traveler pairs

About 1,250 HPMS3 pairs are traveling with common proper motion but have parallax values which while seemingly rather similar indicate combined with the angular separation a difference in distance making gravitational relationship probably impossible. We report these objects only to give complete information but not as double stars to be included in the WDS catalog. In Table 4 we list a subset of the data for the first 10 such pairs, the full data set is available for download on the JDSO website as "HPMS3_random_common_traveler_pairs".

3.5 HPMS3 seemingly random encounter pairs

About 250 HPMS3 pairs are according to the given parallax values close enough to potentially interact by gravitation but move with clearly different proper motion speed and direction so these objects could be considered as encounters by chance. On the other side we got the impression that fast orbits could very well lead to significant different proper motion values depending on the properties of a possible orbit to the degree that proper motion direction might even be opposite (possible scenario: two stars of similar mass orbit each on its own ellipse path with a common center of gravity, Figure 2.).

Also different proper motion vector length can at least to some degree be explained by the effects of an orbit – possible scenario: Orbit with a plane in direction of the view from our sun system. And proper motion speed far less than to be expected from the change in separation and position angle due to an orbit might be explained with opposite directions of proper motion and orbit path at a given point of time. To verify these considerations we had a look at the objects listed with code "O" for orbit in the WDS catalog (see Appendix B). From the random but representative sample we checked less than 10% made the cut to be considered as physicals according to the used assessment scheme (see Appendix A). For the rest the given Gaia DR2 proper motion values did not allow for assessing them as CPM pairs while a good third of the pairs have parallaxes rendering them as clearly optical (most interestingly all of them but one also with a negative CPM assessment). And more than half the pairs with orbits are according to their parallaxes and their angular separation close enough for gravitational relationship suggesting strongly the possibility of an orbit despite the lack of common proper motion – for this reason we conclude that if potential gravitational relationship is given common proper motion is no longer a requirement to being considered as physical. As side effect from an additional counter-check of the 6th orbit catalog suggested position angles and separations for 2016 against the data from the Gaia DR2 positions we got the impression that a good part of the given orbits are suspect and an overall impression in this regard is that the basic idea of an orbit as a secondary orbiting on an ellipse path around the primary at the focus of the ellipse is only suitable for pairs with a secondary small enough to cope with the role of a satellite.

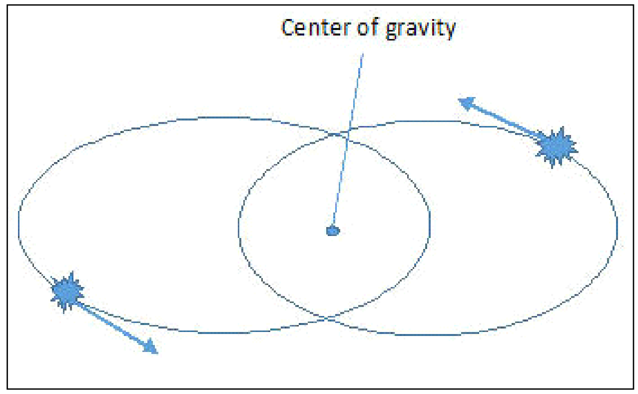

Figure 2. Orbit with opposite movement of the components

In consequence changing the cut parameters for the "HPMS3 seemingly random encounter pairs" by a factor 10 – means allowing 10° difference in PM direction

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Table 3: Optical pairs in the HPMS3 catalog

HPMS3 ID	RA A	DE A	Sep	PA	Mag A	Mag B	pmRA A	pmRA B	pmDE A	pmDE B	Plx A	Plx B	CPM Score	Plx Score	True Binary
00038+00039	0.935224382	-38.5757594	28.610	282.287	17.053	20.048	132.474	115.407	-191.7	-191.03	16.3478	3.5644	0	1	0
00099+00098	2.923904671	-36.1161998	58.676	83.107	15.033	19.295	216.06	-94.628	-82.14	-123.2	17.1597	10.2876	0	1	0
00100+00098	2.924117843	-36.1167388	58.328	81.141	17.441	19.295	217.241	-94.628	-80.307	-123.2	16.8948	10.2876	0	1	0
00226+00225	357.299505	-34.9243453	1.227	334.979	13.733	19.269	97.549	92.822	-154.5	-162.39	13.2195	13.4267	8	20	2
00240+00241	0.197129961	-35.1688352	40.468	28.792	12.314	18.472	352.241	-88.311	-114.27	-130.64	25.6723	3.1245	0	1	0
00346+00345	6.328957553	-32.2386839	0.965	338.597	15.233	19.955	154.082	150.508	70.206	65.685	9.3106	9.6261	5	20	1
00642+00643	355.3440102	-33.4982437	13.712	345.002	17.583	20.476	-13.686	-9.912	-183.13	-179.36	7.1176	8.7518	32	1	0
00682+00683	354.5698959	-31.9059854	12.165	110.400	15.549	19.448	-94.362	85.511	-129.55	-146.95	11.5282	5.1969	0	1	0
00751+00752	354.6548352	-29.932437	14.921	307.171	13.68	23.182	177.421	175.328	17.994	27.14	18.3401	21.1455	1	1	0
00872+00871	356.5977838	-26.9013456	3.153	252.934	9.679	15.456	-132.22	-135.78	-73.398	-74.358	11.9973	11.3779	40	1	0

Description of the table content per WDS pair:

- HPMS3 ID gives the HPMS3 object ID for both components
- RA and Dec give the Gaia DR2 RA/DE coordinate of the primary for epoch 2015.5
- Sep gives the separation in arc seconds
- PA gives the position angle in degrees
- Mag A and B give the estimated Vmags in most cases derived from Gaia DR2 green, blue and red magnitudes
- pmRA and pmDE give the proper motion data for RA and Dec for both components in mas/yr
- Plx A and B give the parallax value for both components in mas
- CPM Score gives the estimated probability for common proper motion according to the used CPM assessment scheme
- Plx score gives the estimated probability for assumed gravitational relationship according to the used assessment scheme
- True binary gives the combined probability of common proper motion and gravitational relationship

Some objects are connected with existing WDS objects as additional components or as splits of components so far not resolved – in these cases the reference to the existing WDS objects is given.

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Table 4: Random common traveler pairs in the HPMS3 catalog

HPMS3 ID	RA A	DE A	Sep	PA	Mag A	Mag B	pmRA A	pmDE A	pmRA B	pmDE B	Plx A	Plx B	CPM Score	Plx Score	True Binary
00015+00014	0.907707841	-40.17958656	1.004	299.175	18.391	18.49	203.119	200.977	-116.979	-121.688	18.224	19.148	80	1	1
00016+00014	0.908882221	-40.17873525	4.848	237.914	12.659	18.49	204.775	200.977	-119.199	-121.688	18.739	19.148	100	20	20
00016+00015	0.908882221	-40.17873525	4.453	226.506	12.659	18.391	204.775	203.119	-119.199	-116.979	18.739	18.224	80	20	16
00034+00033	2.289757182	-38.2899016	24.945	101.701	9.726	19.722	165.72	166.972	-63.351	-64.12	9.337	8.832	97	20	19
00075+00076	0.313019398	-38.07013532	3.240	113.306	17.902	18.575	145.98	146.546	-51.452	-52.056	5.945	5.813	100	20	20
00307+00308	359.7614712	-30.36763023	1.303	64.313	14.915	21.374	237.595	236.521	-56.754	-57.472	15.135	15.954	100	1	1
00379+00380	5.037019142	-31.66280021	1.797	168.769	15.891	22.078	143.892	143.922	-77.002	-76.504	2.336	2.135	100	16	16
00442+00441	6.113438755	-29.98541366	4.775	96.606	16.757	20.928	165.834	166.626	-268.733	-264.116	6.621	5.942	80	19	15
00488+00489	2.39543309	-31.40260578	22.272	288.800	13.879	21.365	-149.477	-148.713	23.997	23.689	11.917	12.672	97	1	1
00502+00501	2.687064928	-30.40714766	2.774	164.525	17.73	19.246	208.557	211.166	-48.525	-48.351	10.107	9.866	80	20	16

Description of the table content per HPMS3 pair with common proper motion but with parallax data indicating probably lacking gravitational relationship:

- HPMS3 ID give the HPMS3 object ID for both components
- RA and Dec give the Gaia DR2 RA/DE coordinate of the primary for epoch 2015.5
- Sep gives the separation in arc seconds
- PA gives the position angle in degrees
- M1 and M2 give the estimated Vmags in most cases derived from Gaia DR2 green, blue and red magnitudes
- pmRA and pmDE give the proper motion data for RA and Dec for both components in mas/yr
- Plx A and B give the parallax value for both components in mas
- CPM Score gives the estimated probability for common proper motion according to the used CPM assessment scheme
- Plx score gives the estimated probability for assumed gravitational relationship according to the used assessment scheme
- True binary gives the combined probability of common proper motion and gravitational relationship

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Table 5: Seemingly random encounter pairs in the HPMS3 catalog

HPMS3 ID	RA A	DE A	Sep	PA	Mag A	Mag B	pmRA A	pmRA B	pmDE A	pmDE B	Plx A	Plx B	CPM Score	Plx Score	True Binary
02278+02279	10.20149397	-13.26963616	1.448	275.233	12.873	14.293	173.798	177.124	-37.526	-22.302	28.639	28.803	1	100	1
02331+02332	11.1455977	-11.81187803	4.300	345.446	14.705	17.519	88.913	97.602	-164.586	-164.486	27.012	27.104	8	100	8
03357+03356	348.5622504	-14.61277706	4.900	111.760	12.268	13.647	46.047	50.54	149.677	144.626	27.999	27.967	8	100	8
04274+04275	356.0791833	-7.797372595	1.613	100.010	15.719	18.128	151.971	163.65	-19.256	-17.334	23.468	23.320	4	100	4
04496+04495	356.546014	-5.32617544	1.535	68.503	16.005	18.088	145.183	150.461	-110.667	-113.939	26.737	26.677	5	100	5
04600+04599	22.82877782	-17.68515618	2.714	168.018	9.236	14.677	172.606	174.155	54.509	43.855	10.453	10.554	1	80	1
06773+06774	336.3452163	-16.67821288	43.821	333.959	20.62	20.977	85.357	83.084	-135.398	-131.364	10.104	10.153	39	64	25
07347+07346	329.0811845	-10.33914264	1.358	164.252	14.573	16.743	-307.182	-284.268	-272.339	-258.88	50.538	50.780	5	100	5
08261+08262	326.3399266	-7.490587515	5.853	356.045	11.078	17.047	-83.718	-86.896	-132.873	-136.36	20.494	20.207	40	80	32
08378+08377	321.5290075	-4.524444054	9.284	132.407	17.118	17.35	171.827	169.863	-32.769	-20.907	24.013	24.433	0	80	0

Description of the table content per HPMS3 pair with parallax data indicating probably gravitational relationship but with lacking common proper motion:

- HPMS3 ID give the HPMS3 object ID for both components
- RA and Dec give the Gaia DR2 RA/DE coordinate of the primary for epoch 2015.5
- Sep gives the separation in arc seconds
- PA gives the position angle in degrees
- M1 and M2 give the estimated Vmags in most cases derived from Gaia DR2 green, blue and red magnitudes
- pmRA and pmDE give the proper motion data for RA and Dec for both components in mas/yr
- Plx A and B give the parallax value for both components in mas
- CPM Score gives the estimated probability for common proper motion according to the used CPM assessment scheme
- Plx score gives the estimated probability for assumed gravitational relationship according to the used assessment scheme
- True binary gives the combined probability of common proper motion and gravitational relationship – despite these negative results we consider these pairs as probably physica

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Some objects are connected with existing WDS objects as additional components or as splits of components so far not resolved – in these cases the reference to the existing WDS objects is given.

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and 10% difference in PM speed for an "A" rating – resulted in a perfect "AAAA" rating for about 95% of the objects with only 3 remaining complete outliers but this large cut parameters render the common proper motion criteria as of little value for assessing physical pairs. We decided here to keep the CPM assessment scheme as it is and to simply keep these pairs in the list of probably physical pairs with the comment "PM data probably influenced by orbit" in the notes column.

To give an example we list in Table 5 a subset of the data for the first 10 despite a negative CPM assessment as probably physical pairs. The full data set is available for download on the JDSO website as "HPMS3_seemingly_random_encounter_pairs"

3.6 HPMS3 pairs probably physical

The standard assessment scheme provides by means of common proper motion and potential gravitational relationship (often referred to as common parallax but includes also the factor angular separation) about 720 most probably physical HPMS3 pairs, plus the above mentioned seemingly random encounter pairs gives in total about 940 probably physical pairs. In Table 6 we list a subset of the data for the first 10 probably physical pairs. The full data set is available for download on the JDSO website as "HPMS3_probably_physical_pairs":

3.7 Observation history

To provide for each object an observation history we cross-matched the objects in Table 6 with the following catalogs: 2MASS, UCAC4, USNO-B1, PS1 and Gaia DR1. Several pairs especially with very faint secondaries remained without a corresponding match in another catalog suggesting a counter-check with a future Gaia data release. Cross-matching of stars with high proper motion is a bit difficult due to the fast change of star position over time (especially when using the CDS X-match tool working differently with catalogs with or without proper motion data given) but as we deal with double stars we have the additional criterion of matching separation and position angle making elimination of false matches a bit easier. Even when assuming a fast orbit a difference of separation larger than 10% or position angle larger than 10° seems to indicate rather a mis-match so we eliminated those at the price of losing some correct matches with larger position errors in older catalogs and for Gaia DR1 we reduced these cut values to 2.5% respective 2.5°. We did also a manual counter-check of a sample of still suspect looking matches and eliminated a few more pairs with resolution issues in the older catalogs mostly for triples and we also eliminated all pairs with a separation of less than 2" from the cross-match results with 2MASS, UCAC4 and USNO-B1 due to suspected resolution issues. Despite these steps a few mis-matches might still exist in the final observation history list as specific situations are simply undecidable especially in the PS1 catalog which has many ghost stars – in such cases we decided to keep the best matching combination. The Vmag estimations given for the 2MASS records are based on the formula of Caldwell et al. 1993. In Table 7 we give the observation history for the first 10 records as example. The complete list with the observation history is available for download on the JDSO website as "HPMS3_probably_physical_pairs_observation_history".

4. Summary

This report selects not only the high proper motion stars in the southern sky from Gaia DR2 but checks also for so far unknown double stars with common proper motion and stellar distance small enough to allow for gravitational relationship. Such activities are still of interest as Gaia offers so far no own catalogue for binary and multiple stars – such a catalog is to expect with Gaia DR3 announced for late 2020 and will at least for some time put an end to the traditional search for new double stars.

A most interesting side result of this research is the new perspective when considering common proper motion as pre-requisite for a double star to be considered as potentially binary – this is obviously no longer a useful concept as the proper motion of a system is overlapped by the movement of the components in a potential orbit depending on the properties of the assumed orbit. On the other side – optical close high proper motion stars have a good probability for being close enough for gravitational relationship. Furthermore the very concept of proper motion of a star as the position change between two points of time in terms of changes in RA and Dec in mas/yr seems obsolete as proper motion defined in this way is in many cases changing over different time frames and for this reason cannot longer be described by static values but only for a given time frame.

5. Follow Up

The significant difference in the number of high proper motion stars in the southern sky compared with the LSPM-North catalog suggests a Gaia DR2 counter-check for the number of high proper motion stars in the northern sky. Another topic for a follow up with future Gaia releases are the HPMS3 objects with currently negative parallaxes. Another interesting issue will be the validation of the proposition that proper motion values should change in between the different Gaia data

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Table 6: Probably physical pairs in the HPMS3 catalog

HPMS3 ID	WDS	Disc	Comp	Notes	RA A	DE A	Sep	PA	Mag A	Mag B	pmRA A	pmRA B	pmDE A	pmDE B	Plx A	Plx B	CPM Score	Plx Score	True Binary
00099+00100		KPP n+1			2.923904671	-36.11619984	2.037	162.281	15.033	17.441	216.06	217.241	-82.14	-80.307	17.160	16.895	100	80	80
00113+00114		NSN n+1			3.111962812	-35.38265237	1.017	50.695	17.278	18.477	140.799	140.067	62.198	59.619	7.227	7.244	80	80	64
00126+00125		KPP n+2			1.688700515	-36.56007028	2.245	208.929	15.161	15.62	264.548	262.188	18.871	20.986	22.858	22.772	100	100	100
00204+00203		NSN n+2			358.0517905	-35.22570951	4.889	181.096	15.395	16.108	208.803	211.432	127.609	131.716	30.834	30.826	80	100	80
00362+00361		KPP n+3			3.608898743	-33.2254134	3.956	285.537	12.178	12.233	160.843	160.064	53.321	54.23	10.697	10.701	100	100	100
00389+00390	00226-3111	NSN n+3	Ba;Bb	LDS 14	5.642439033	-31.17389442	1.352	42.176	14.461	15.757	256.511	254.899	-79.051	-82.966	12.705	12.819	100	80	80
00563+00562		KPP n+4			5.230195333	-27.77173861	6.877	110.660	14.595	20.604	208.958	206.642	-41.537	-41.911	7.587	7.566	80	80	64
00568+00569		NSN n+4			7.577858677	-27.67717199	4.133	48.239	16.045	19.18	50.477	51.269	-178.793	-179.782	11.407	11.333	100	80	80
00894+00895		KPP n+5			353.8663082	-27.48919136	1.287	135.195	17.194	18.302	94.075	97.29	-151.187	-151.033	25.684	26.050	100	100	100
01227+01228		NSN n+5			12.14621115	-28.57027134	2.250	94.856	17.91	20.433	96.924	98.571	-244.869	-243.822	17.664	17.545	100	80	80

Description of the table content per CPM pair with parallax data and in most cases proper motion similar enough to be considered probably physical:

- HPMS3 ID = HPMS3 object ID for both components
- WDS = WDS reference in case of a connection with an existing WDS object
- Disc = discoverer code KPP+/NSN+ running number
- Comp = components (AB if blank)
- RA and Dec = Gaia DR2 RA/DE coordinates of the primary for epoch 2015.5
- Sep = separation in arc seconds
- PA = position angle in degrees
- M1 and M2 = estimated Vmags in most cases derived from Gaia DR2 green, blue and red magnitudes
- pmRA and pmDE = proper motion data for RA and Dec for both components in mas/yr
- Plx A and B = parallax value for both components in mas
- CPM Score = estimated probability for common proper motion according to the used CPM assessment scheme
- Plx score = estimated probability for assumed gravitational relationship according to the used assessment scheme
- True binary = combined probability of common proper motion and potential gravitational relationship suggesting a physical pair (this value is to taken with caution in cases of an assumed orbit overlapping proper motion)

Some objects are connected with existing WDS objects as additional components or as splits of components so far not resolved – in these cases the reference to the existing WDS objects is given.

Only few pairs are given with a distance to the Sun system significantly larger than 100 with none over 500 parsec – according to Luri et al. 2018 this should be a good base for rather reliable parallax data with a symmetrical error distribution.

Table 7: Probably physical pairs in the HPMS3 catalog - observation history

HPMS3 ID	Disc	Comp	RA	DE	Sep	PA	M1	M2	pmRA1	pmDE1	e_pm1	pmRA2	pmDE2	e_pm2	Date	Notes
00126+00125	KPP n+2		1.68865438	-36.5600729	2.245	208.883	13.65	14.19							2015.000	Gaia DR1. M1 and M2 are Gmags
00204+00203	NSN n+2		358.050613	-35.2263303	4.887	181.745	15.08					-83.50	117.60	11.64	1995.555	UCAC4. M1 and M2 are Vmags
00204+00203	NSN n+2		358.050687	-35.226238	4.959	181.529	13.57	14.12							2000.746	2MASS. M1 and M2 are Vmags estimated from J/K-mags
00204+00203	NSN n+2		358.0517549	-35.2257271	4.891	181.113	13.95	14.52							2015.000	Gaia DR1. M1 and M2 are Gmags
00362+00361	KPP n+3		3.6080065	-33.2256687	3.885	287.047	11.35					82.40	70.00	1.56	1992.200	UCAC4. M1 and M2 are Vmags
00362+00361	KPP n+3		3.607974	-33.225689	3.881	284.997	12.02	12.04							1998.939	2MASS. M1 and M2 are Vmags estimated from J/K-mags
00362+00361	KPP n+3		3.60887202	-33.2254207	3.955	285.532									2014.769	Pan-STARRS release 1 (PS1) Survey. M1 and M2 are PS1 gmags
00362+00361	KPP n+3		3.608872019	-33.2254207	3.955	285.532	11.58	11.63							2015.000	Gaia DR1. M1 and M2 are Gmags
00563+00562	KPP n+4		5.229049	-27.771528	6.855	110.089	13.91	17.83							1998.677	2MASS. M1 and M2 are Vmags estimated from J/K-mags
00563+00562	KPP n+4		5.23015354	-27.7717275	6.862	110.805	15.24	21.30							2012.569	Pan-STARRS release 1 (PS1) Survey. M1 and M2 are PS1 gmags

Description of the table content:

1. HPMS3 ID = HPMS3 ID for both components
2. Disc = Discoverer code KPP/NSN
3. Comp = Components (AB if blank)
4. RA = RA primary
5. DE = Dec primary
6. Sep = Separation in arcseconds
7. PA = Position angle in degrees
8. M1 = Mag primary. Content depending on available catalog data
9. M2 = Mag secondary. Content depending on available catalog data
10. pmRA1 = Proper motion RA primary in mas/yr
11. pmDE1 = Proper motion Dec primary in mas/yr
12. e_pm1 = Error proper motion primary
13. pmRA2 = Proper motion RA secondary in mas/yr
14. pmDE2 = Proper motion Dec secondary in mas/yr
15. e_pm2 = Error proper motion secondary
16. Date = Averaged observation date
17. Notes = Reference to catalog used and comments

Some objects are connected with existing WDS objects as additional components or as splits of components so far not resolved – in these cases the reference to the existing WDS objects is given.

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releases due to the different time frames at least for binaries with a fast orbit. To some degree such changes already occur between DR1 and DR2 but the cause of this effect can currently not be conclusively related to an assumed orbit. Another potential follow up would be a more extensive counter-check of WDS code "O" for components being close enough for an orbit – but best with a future Gaia data release as the coverage of subarcsecond pairs is rather limited in DR2.

6. Acknowledgements

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

- Washington Double Star catalog
- Gaia Archive
- Gaia DR2 catalog
- Gaia DR1 catalog
- 2MASS catalog
- UCAC4 catalog
- PS1 catalog
- USNO-B1 catalog
- LSPM catalog
- 2MASS and DSS images
- Aladin Sky Atlas v9 and 10
- SIMBAD, VizieR, TAP Vizier, X-Match
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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):
- "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 probability for being potentially gravitationally bound.

Both probabilities are then combined into an estimated probability for being a physical pair = binary.

Appendix B

Common proper motion and gravitational relationship assessment of WDS pairs with given orbit

We matched these about 2,000 pairs "O" coded WDS pairs with Gaia DR2 taking the most recent WDS parameters as given and got for this reason only about 200 corresponding pairs mostly with as to expect observations in the very last years. Yet this number of objects can still be considered a representative sample of pairs assumed to be physical. Applying our physicals assessment scheme used for the newly discovered physical pairs we got here less than 10% of the pairs considered to be physicals while for the rest "probably not physical" was assumed due to proper motion values significantly not common. On the other side 64% of the objects showed common parallaxes allowing in combination with the given angular separations potentially for gravitational relationship. We take this as confirmation that common proper motion might be a good indicator for physicals with slow orbits but that fast orbits can have a significant impact on proper motion values rendering the criteria "common proper motion" of limited value for assessing potential physical double stars at least under specific conditions. On the other side these results might also indicate that about 1/3 of the given orbits are given for with the now available date obviously optical pairs. The impression that a good part of the given orbits is not quite up to the task is also confirmed by the simple fact that in many cases position angle and separation due to the given orbit for 2016 is quite different from the Gaia DR2 data epoch 2015.5.

We tried also to verify the idea of fast orbits causing proper motion changes by calculating proper motion from Gaia DR1 to Gaia DR2 position (observation time span thus ½ year) and comparing these with the Gaia DR2 proper motion values for a time span of 1.75 years – but while several objects showed very well significant differences we could not find a pattern that these were indeed caused by an orbit but rather by other so far unknown reasons.

Table 8 with the discussed WDS code "O" sample is given on the following pages.

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Table 8. Assessment of WDS code "O" pairs for being physical pairs

WDS ID	Disc	Orbit	Orbit PA 2016	Orbit Sep 2016	WDS PA	WDS Sep	RA 2015.5	DE 2015.5	PA	Sep	Plx A	Plx B	PMVD° A	PMVD° B	PMVL A	PMVL B	CPM Score	Plx Score
00048+3810	BU 862	Cou1986b	28.3	0.842	28	0.9	1.195360563	38.17340036	27.11	0.88	11.2651	12.6173	158.95	148.64	66.54	66.00	1	1
00057+4549	STT 547AF	Kiy2001	254.3	326.823	254	327.9	1.426413637	45.8113965	253.78	328.40	86.8735	86.9567	100.36	99.86	903.35	883.79	39	100
00063+5826	STF3062	Sod1999	357.9	1.553	359	1.5	1.567845253	58.43685661	357.09	1.55	47.8005	46.2077	81.23	82.47	240.70	289.24	4	100
00093+7943	STF 2	Hei1997	15.2	0.909	17	0.9	2.336575829	79.71440331	16.42	0.90	8.3923	9.3157	109.47	104.46	114.71	108.27	0	19
00094-2759	BU 391AB	Zir2010	258.3	1.313	258	1.5	2.338124575	-27.98796258	258.51	1.34	14.5122	13.9054	96.73	99.56	70.07	73.79	1	20
00152+2722	J 868	Nov2007b	229.6	6.122	231	6.2	3.79151233	27.39631739	231.09	6.17	1.8935	3.5488	100.74	246.36	14.90	31.24	0	1
00162+7657	STF 13	Msn2017c	48.9	0.955	48	1	4.058457408	76.95073572	48.98	0.98	6.0789	4.7291	100.35	87.85	16.50	16.93	0	1
00184+4401	GRB 34AB	PkO2014c	66	34.31	64	34.3	4.612667737	44.02472958	65.45	34.38	280.6902	280.7866	81.89	83.30	2920.72	2882.99	64	100
00209+3259	AC 1	Zir2015a	288.8	1.84	290	1.8	5.225541768	32.9777294	289.00	1.86	13.021	13.0853	174.88	175.96	64.44	63.30	64	80
00210+6740	HJ 1018	Sod1999	87.8	1.766	86	1.7	5.238298295	67.66779317	87.78	1.69	31.7672	31.7806	19.10	17.15	78.78	77.76	64	100
00214+6700	STT 6AB	Ole2001	152.7	0.645	153	0.7	5.3427669	67.00542484	153.80	0.69	5.6045	1.8657	74.00	96.74	29.89	27.38	0	1
00360+2959	STF 42AB	Kis2009	20.4	6.312	21	6.3	9.010766204	29.99124993	21.00	6.28	18.5581	19.0305	155.56	156.06	448.28	440.34	80	20
00504+5038	BU 232AB	Sca2008a	255.1	0.856	255	0.9	12.60419815	50.63036538	254.29	0.90	11.8925	11.4428	253.67	265.27	37.89	38.94	0	1
00521+1036	STF 67	Hrt2011a	349.4	2.285	349	2.3	13.03187175	10.60076484	349.36	2.30	8.9372	8.9917	118.80	120.91	49.68	48.48	8	80
01030+4723	STT 21	Hei1966	175.7	1.15	175	1.3	15.75700258	47.3760958	175.07	1.29	9.2182	9.1208	99.80	105.09	89.04	90.90	0	20
01032+2006	LDS 873	FMR2012a	56.9	2.467	62	2	15.8120591	20.09807574	56.38	2.49	62.627	62.1	85.67	87.74	674.17	678.08	20	100
01158-6853	I 27CD	Sod1999	334	1.1	345	1.2	18.75856448	-68.81857854	335.27	1.06	47.6621	47.8003	75.18	74.11	372.88	443.15	4	100
01198-0031	STF 113A;BC	Zir2015a	20.7	1.638	21	1.6	19.9512694	-0.50907632	20.86	1.62	7.9412	7.5834	144.39	140.23	14.48	22.54	0	1
01262-6751	DON 17	Hrt2010a	289.4	1.371	290	1.4	21.54082128	-67.84279727	289.78	1.34	16.8716	17.1904	120.04	118.97	134.80	120.83	4	20
01337-1213	HWE 4	Doc2017i	330.6	0.87	331	0.9	23.42664903	-12.21291858	330.91	0.87	13.0793	14.6181	237.31	236.74	10.14	16.68	5	1
01398-5612	DUN 5	Sca2015c	186.8	11.61	186	11.5	24.95125178	-56.19325344	186.78	11.41	122.0552	122.1333	86.66	88.02	262.83	309.29	4	100
01467+3310	STF 158AB	Hrt2011a	272.9	2.023	272	2.2	26.68342736	33.16245259	270.50	2.22	9.6544	9.5512	220.67	232.85	35.54	34.22	0	20
01532+1526	BU 260	Cve2006e	261	1.09	261	1.1	28.30927402	15.43352903	260.46	1.13	9.9716	10.6373	304.91	326.00	31.91	27.30	0	1
02198-3527	HJ 3494	Hrt2010a	242.3	2.285	244	2.3	34.94905306	-35.44531649	242.34	2.32	28.6784	28.6758	293.89	280.89	97.14	92.01	0	100
02442+4914	STF 296AB	KSC2017	304.8	20.337	305	21.1	41.05215124	49.22806439	305.10	20.92	89.6955	89.2871	105.05	100.86	345.63	323.15	0	100
02475+1922	STF 305AB	Msn2014b	307.1	3.604	308	3.6	41.86479147	19.37114081	307.23	3.64	30.1041	30.2438	143.58	144.78	196.78	199.71	64	100
02563+7253	STF 312AB	Cve2006e	46.1	1.771	49	1.8	44.04814474	72.88591072	46.60	1.78	16.3305	16.4416	136.37	147.71	61.98	75.41	0	100
03127+7133	STT 50AB	Sca2012b	144.4	0.902	146	1	48.1631772	71.55582304	146.49	1.04	19.4922	19.7293	48.56	47.47	17.23	30.74	5	80
03140+0044	STF 367	Kiy2017	130.9	1.253	130	1.2	48.51233447	0.739291361	130.80	1.25	14.9758	13.7913	101.81	96.57	73.64	81.42	0	1
03162+5810	MLB 115AB	Zir2008	1.8	4.978	2	5	49.0612588	58.16597305	2.12	5.04	73.7645	73.7407	126.14	127.48	550.29	523.13	4	100
03196+6714	HU 1056	Zir2015a	80.1	1.067	81	1	49.89644774	67.23746237	79.59	1.08	14.0849	12.8472	248.98	253.02	52.43	57.31	0	1
03342+4837	BU 787AB	Cve2011c	293.8	4.747	293	5.2	53.55416486	48.61735982	292.72	5.57	5.8057	1.62	140.01	285.06	34.89	4.96	0	1
03344+2428	STF 412AB	Sca2002a	351.4	0.753	352	0.8	53.61100231	24.46428435	351.85	0.76	5.3701	9.6776	160.02	161.96	29.91	28.56	5	1
03362+4220	A 1535	Hrt2008	345.2	0.718	346	0.7	54.04026332	42.33878574	345.46	0.73	16.629	20.2908	135.54	134.25	198.60	208.19	4	1
03368+0035	STF 422	Hop1964b	273.4	6.704	274	7.1	54.19690463	0.587064302	273.07	6.74	33.7528	33.7882	191.49	193.98	165.08	142.34	1	100
04041+3931	STF 483	USN2006b	53.2	1.556	53	1.6	61.03038773	39.50930539	53.76	1.57	29.3245	29.2434	123.16	116.12	175.90	174.14	1	100
04076+3804	STT 531AB	Hei1986b	351.3	2.517	353	2.9	61.89411794	38.07358052	354.00	2.78	47.2101	47.1305	141.56	139.50	284.55	220.25	1	100
04227+1503	STT 82AB	WSI2004a	330.8	1.204	328	1.2	65.68456778	15.0560363	329.46	1.23	20.9394	20.8342	96.97	106.21	114.96	104.44	0	100
04301+1538	STF 554	Baz1980a	15.1	1.579	16	1.5	67.53631161	15.63773911	15.54	1.51	21.1198	20.9343	101.49	107.04	111.15	107.27	0	100
04403-5857	HJ 3683	USN2006b	89.6	3.742	89	3.7	70.07420849	-58.94316474	89.59	3.78	32.262	32.3624	9.61	16.01	176.20	182.46	0	100
04422+3731	STF 577	RAO2015	329.8	0.688	332	0.6	70.55643911	37.51495236	331.42	0.72	18.608	17.1595	79.38	91.61	46.80	39.24	0	1
04496-5353	I 342	Cve2008a	133.7	3.248	134	3.1	72.40537633	-53.88051988	133.28	3.23	33.8358	33.949	30.19	33.26	267.20	273.20	0	100
04590-1623	BU 314AB	Sod1999	316.9	0.754	318	0.8	74.75508892	-16.37541628	318.84	0.81	23.4248	27.4022	316.81	319.38	196.52	183.07	1	1
05003+3924	STT 92AB	Cve2006e	282.5	4.161	284	4.1	75.07635651	39.3946941	283.52	4.16	17.6339	17.8231	260.57	310.44	11.23	21.71	0	80
05013+5015	STF 619	Kis2009	159.9	4.092	161	4.1	75.33322154	50.25687432	159.44	4.23	4.3061	4.5958	145.63	181.87	35.59	41.01	0	1
05059-1355	A 3009	Tok2014a	274	1.178	274	1.2	76.48050357	-13.91352234	274.41	1.19	20.4953	19.7983	57.19	45.74	96.19	116.04	0	1
05167+4600	ST3HL	Hei1974a	171.0	3.706	174	3.5	79.3499731	45.83785539	173.26	3.47	75.0151	75.0888	168.33	172.61	437.96	420.97	0	100
05247+6323	STF 677AB	Hrt2008	112.5	1.145	114	1.1	81.18320412	63.38619701	114.96	1.11	20.1113	20.5416	242.45	248.95	136.42	113.52	0	20
05270-6837	I 276	Zir2013d	158.9	1.465	161	1.4	81.74905433	-68.62261379	159.15	1.43	12.2715	12.4328	211.44	194.30	20.83	20.48	1	20
05308+0557	STF 728	USN1999b	44.4	1.326	43	1.2	82.69608703	5.947978907	44.25	1.28	9.2261	9.0883	166.46	159.03	42.91	33.32	1	19
05322+7049	A 1034	Cve2008a	137.9	0.987	138	0.9	83.05970035	70.81494135	135.82	0.98	15.9635	14.1112	183.41	177.68	57.01	57.26	1	1

Table 8 continues on the next page.

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Table 8 (continued). Assessment of WDS code "O" pairs for being physical pairs

WDS ID	Disc	Orbit	Orbit PA 2016	Orbit Sep 2016	WDS PA	WDS Sep	RA 2015.5	DE 2015.5	PA	Sep	Plx A	Plx B	PMVD° A	PMVD° B	PMVL A	PMVL B	CPM Score	Plx Score
05336-5104	HU 1566	Erc1985a	49.1	1.645	50	1.8	83.40071019	-51.06557095	49.16	1.77	22.1201	22.1805	10.28	357.76	25.66	42.24	0	100
05371+2655	STF 749AB	Sca2007a	319.9	1.172	319	1.1	84.28715884	26.92412628	319.59	1.18	2.0809	5.6502	146.07	149.46	28.55	26.10	4	1
05535+3720	BU 1053	Zir2014a	359.7	1.881	0	1.7	88.36905137	37.33941106	359.57	1.90	15.0035	15.092	331.25	335.65	95.45	99.46	0	100
06048-4828	DUN 23	Tok2014a	127.8	2.579	128	2.6	91.19383988	-48.45839608	127.36	2.60	32.5101	32.4694	257.35	251.60	103.63	123.71	0	100
06262+1845	BU 1191AB	Hle1994	316.3	3.084	313	2.4	96.54212918	18.75622979	322.62	2.08	67.7317	67.9483	220.74	202.95	200.75	216.13	0	100
06344+1445	STF 932	Hop1960a	300.7	1.624	305	1.6	98.59004505	14.75222161	305.18	1.65	11.3337	11.5837	47.45	89.72	12.76	8.94	0	20
06425+6612	MLR 318	Pal2005b	308.7	1.703	309	1.7	100.6219114	66.19764085	309.04	1.70	13.7354	13.8391	209.50	213.63	34.16	33.33	0	80
06462+5927	STF 948AB	WSI2006b	66.5	1.901	65	2	101.5587229	59.44163273	67.22	1.91	13.3962	13.3229	243.41	281.29	20.26	19.93	1	80
06482+5542	STF 958AB	Kis2009	256.6	4.458	75	4.5	102.0516651	55.70373665	76.42	4.52	23.2885	23.33	151.12	153.32	121.13	117.91	8	100
06487+0737	A 2731AB	Pru2012	66.5	1.393	67	1.3	102.1637954	7.620715552	66.52	1.35	17.147	17.3162	189.32	188.06	380.54	382.73	80	80
06545-2734	B 706	Tok2014a	293.1	0.728	292	0.7	103.6372045	-27.5594275	293.36	0.72	14.0243	13.1312	261.33	285.64	27.55	22.35	0	1
06546+1311	STF 982AB	Msn2014b	142.9	7.311	143	7.3	103.6612963	13.17747146	143.02	7.39	33.9184	33.3308	141.63	130.85	110.75	117.97	0	80
06555+3010	STF 981	Kiy2017	119.4	0.963	119	0.9	103.8699909	30.16075509	119.71	0.93	23.8678	23.7566	137.23	135.88	350.20	313.57	4	80
07106+1543	J 703	Cve2008d	112.9	9.939	294	10.4	107.6579427	15.72060571	293.40	10.58	2.7841	12.1025	246.74	278.81	13.19	94.65	0	1
07294-1500	STF1104AB	Tok2014a	38.3	1.802	38	1.8	112.340274	-14.99964439	36.65	1.80	27.2831	27.4282	219.14	214.15	293.38	302.13	0	100
07319+3613	BEU 11Aa;Ab	Hei1993e	8.7	0.127	194	1.5	112.9891329	36.21841116	190.11	1.56	83.336	81.8459	225.37	224.67	350.61	349.93	100	100
07401+0514	STF1126AB	Zir2015a	176.8	0.835	177	1	115.0291369	5.231098796	175.09	0.86	4.9554	2.3276	180.49	190.82	17.76	16.85	0	1
08031-0625	A 1581	FMR2012b	299.2	1.497	300	1.4	120.7771859	-6.414180046	300.37	1.44	14.7718	14.4815	306.21	309.99	71.38	78.26	0	20
08061-0047	A 1971	Tok2015c	2.1	0.958	5	0.9	121.5151033	-0.776816729	1.92	0.95	15.1495	14.8293	122.69	124.74	113.25	108.51	1	20
08122+1739	STF1196AB	KSC2017	65.8	5.928	65	5.9	123.0536499	17.64729765	69.40	5.56	40.9598	42.1256	154.07	171.07	134.42	141.14	0	80
08132-1354	HU 115	Sod1999	117.2	1.104	117	1.1	123.2841936	-13.91886493	116.85	1.08	38.937	48.0282	208.64	203.66	498.37	532.57	0	1
08165+7930	STF1169AB	Kis2009	16.9	20.503	15	20.7	124.1281985	79.50069229	14.76	20.76	13.9234	13.9291	218.20	216.14	84.22	82.11	8	100
08221-4059	HJ 4087AB	USN2002	252.6	1.449	253	1.5	125.5341293	-40.99128179	253.34	1.44	11.975	11.9793	2.81	14.85	42.49	31.74	0	100
08243+4457	STF1217	Kis2009	242.3	28.636	242	29.1	126.0648491	44.94894394	242.14	29.13	27.1072	27.0223	199.57	198.89	189.12	186.89	78	100
08391-5557	HU 1443AB	Tok2015c	12.2	0.961	17	0.9	129.7667675	-55.94240342	17.81	0.89	6.5153	0.9024	288.54	285.38	18.36	26.92	4	1
08507+0752	VDK 3	WSI2006b	186.3	1.003	168	1.4	132.6760436	7.864454758	180.64	1.20	56.189	56.1155	238.61	277.84	50.86	106.69	0	100
09144+5241	STF1321AB	Chg1972	98.2	16.852	98	17.2	138.5839158	52.68415916	97.73	17.08	157.8796	157.8851	249.79	247.24	1647.52	1706.01	1	100
09273+0614	STF1355	Lin2011b	354.9	1.795	354	1.8	141.8188495	6.232204291	354.43	1.80	18.5979	18.7804	231.02	227.54	228.07	227.30	1	80
09414+3857	STF1374AB	Lin2013a	310.8	2.814	310	2.8	145.3417842	38.94964536	310.58	2.83	19.2207	18.5919	151.13	146.68	149.03	148.55	1	1
09487-2625	I 205AB	Zir2013d	282.3	1.855	282	1.8	147.1777462	-26.41428887	281.87	1.82	24.1282	24.1359	282.99	272.37	161.64	169.61	0	100
10110+7508	KUI 47	Hei1994a	125.3	1.865	121	2	152.7475345	75.14251035	121.95	1.95	47.4964	47.4612	40.10	42.61	343.97	335.29	8	100
10163+1744	STT 215	Zae1984	178.3	1.563	178	1.5	154.066817	17.74035736	176.22	1.49	9.3298	9.1086	284.64	266.33	8.77	3.25	0	20
10217-0946	BU 25	Zir2012b	130	1.562	130	1.5	155.4311281	-9.7741337	130.15	1.55	16.2473	15.8804	161.07	160.43	55.40	44.51	5	20
10227+1521	STT 216	Sca2009c	230.7	2.245	231	2.3	155.6813226	15.34401751	231.31	2.29	34.4535	34.193	251.38	246.26	282.07	290.99	0	100
10361-2641	BU 411	Tok2014a	304.5	1.336	304	1.3	159.0187743	-26.67581247	304.85	1.33	22.9595	23.0301	181.98	184.67	77.01	85.36	1	100
10387+0544	STF1457	RAO2015	333.6	1.841	335	1.8	159.6797839	5.734023722	334.15	1.83	13.8431	13.4414	299.33	328.93	7.91	12.30	0	1
11000-0328	STF1500	Hrt2013a	299.8	1.328	300	1.3	165.008825	-3.471135811	299.73	1.33	17.9895	18.186	56.13	62.51	75.25	75.64	1	80
11035+5432	A 1590	Baz1985b	331.5	1.507	328	1.5	165.8653981	54.52611665	328.42	1.47	23.495	23.4119	303.31	299.25	152.36	156.20	0	100
11105-3732	REP 21	Kll2017	206.6	1.555	207	1.6	167.6156734	-37.53105493	206.90	1.54	27.3058	26.774	261.45	255.48	116.52	109.49	0	80
11214-2027	STN 22	Zir2010	355.2	3.657	345	4.3	170.3619138	-20.45422812	354.11	3.84	76.4165	76.3549	116.99	120.43	203.38	255.50	0	100
11239+1032	STF1536AB	Sod1999	95.1	2.127	96	2.2	170.9817094	10.52915879	96.06	2.13	42.3548	41.4956	118.38	106.63	169.81	185.02	0	100
11247-6139	BSO 5	Sca2002c	248.3	7.542	248	7.5	171.163517	-61.64723394	247.92	7.59	82.5253	85.5929	278.87	279.04	531.26	563.82	5	100
11317+1422	STF1547AB	Hrt2013b	331.9	15.358	332	15.5	172.9358013	14.36368525	331.36	15.50	42.2619	42.2965	240.08	240.13	381.07	363.98	5	100
11368-1221	BU 456	Pru2012	161.5	1.162	163	1.2	174.2077782	-12.35082054	162.50	1.19	19.63	19.4249	162.08	170.27	45.96	56.07	0	100
11374+4728	KU 39	WSI2006b	152.2	0.845	129	1.1	174.3531492	47.46243741	140.97	1.19	29.798	29.209	98.20	116.69	115.42	86.55	0	80
12158-2321	BU 920	FMR2012g	307.3	1.901	307	1.9	183.9446142	-23.3540912	306.59	1.93	13.0932	13.2162	178.60	181.42	43.65	31.00	1	80
12160+0538	STF1621	Sod1999	45.4	1.678	46	1.8	183.9915475	5.639878227	45.63	1.67	28.6535	28.7151	259.27	259.38	340.52	309.19	5	100
12244+2535	STF1639AB	Ole2000b	323	1.832	326	1.7	186.1116356	25.58235532	323.62	1.84	11.6398	11.6948	220.88	247.41	14.38	16.75	0	80
12301-1324	BU 28AB	Msn2017a	346.6	2.145	347	2.1	187.5187173	-13.39339141	346.43	2.12	41.0536	41.3346	260.04	260.47	270.09	245.25	5	100
12306+0943	STF1647	Hop1970	251.8	1.24	250	1.3	187.6409765	9.715485247	248.57	1.29	10.3031	9.3567	140.37	136.21	77.25	73.00	0	1
13063+2044	HU 739	Hrt2014b	199	1.605	202	1.4	196.5638957	20.72965678	198.89	1.56	50.9035	50.7329	329.45	324.76	109.81	74.39	0	100

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Table 8 (continued). Assessment of WDS code "O" pairs for being physical pairs

WDS ID	Disc	Orbit	Orbit PA 2016	Orbit Sep 2016	WDS PA	WDS Sep	RA 2015.5	DE 2015.5	PA	Sep	Plx A	Plx B	PMVD° A	PMVD° B	PMVL A	PMVL B	CPM Score	Plx Score
13120+3205	STT 261	Kis2012	338.4	2.589	339	2.6	198.0086687	32.08523542	338.61	2.62	13.6916	13.7597	104.63	92.81	26.52	21.80	0	100
13169+1701	BU 800AB	Hle1994	104.9	7.751	105	7.8	199.2155793	17.01603844	104.64	7.66	91.0325	91.1065	112.59	112.11	688.89	701.42	80	100
13235+2914	HO 260	Zir2013a	87.5	1.642	89	1.6	200.8842654	29.23855213	88.28	1.65	55.1248	55.338	297.77	297.52	531.46	515.43	5	100
13343-0019	STF1757AB	Hei1988d	139.8	1.733	142	1.6	203.5668872	-0.313686879	139.83	1.73	37.1073	37.0096	275.79	274.02	199.04	236.54	4	100
13461+0507	STF1781AB	Alz2007	195.4	0.99	195	1	206.5277544	5.115473833	194.39	1.01	15.8023	15.6265	251.29	249.97	98.55	118.09	4	80
13550-0804	STF1788AB	Hop1970	99.9	3.591	102	3.7	208.7417565	-8.058988905	100.49	3.72	28.958	28.9488	259.06	255.22	176.39	174.99	1	100
13577+5200	A 1614	RAO2015	299.8	1.395	300	1.4	209.419636	51.99356311	299.97	1.44	18.8099	18.948	90.76	92.47	238.25	231.40	32	100
14135+5147	STF1821AB	Kiy2006	235.3	13.789	236	13.7	213.3712962	51.78992608	235.56	13.65	20.3067	21.198	98.65	131.73	61.66	59.08	0	20
14165+2007	STF1825	Kiy2017	153	4.43	153	4.4	214.1362262	20.12143797	153.41	4.38	30.0609	30.1035	234.79	235.20	165.38	152.58	5	100
14336+3535	STF1858AB	Zir2015a	37.8	3.028	39	3	218.4002903	35.58599482	37.97	3.05	25.3724	25.3706	288.41	288.48	203.71	202.53	100	100
14410+5757	STF1872AB	Kiy2010	50	7.57	51	7.6	220.2546615	57.95709655	49.37	7.56	17.8573	17.8652	139.96	140.04	212.82	222.34	5	100
14463+0939	STF1879AB	Msn1999a	82.8	1.72	83	1.7	221.565257	9.645597784	82.61	1.74	22.6388	22.7512	163.83	163.80	276.72	270.66	40	100
14464-0723	STF1876AB	USN2002	113	1.244	115	1.2	221.5893555	-7.379663038	113.59	1.29	12.9546	12.8204	307.10	304.47	182.74	183.92	20	80
14493-1409	BU 106AB	Zir2015a	6.2	1.947	4	2	222.329092	-14.14908754	6.65	1.93	13.2136	13.2585	257.44	254.86	66.11	60.73	1	80
14511-3706	I 529	Dom1978	40.6	1.156	38	1.2	222.7633274	-37.09749862	36.19	1.22	12.9211	13.5385	223.37	228.80	92.36	82.83	0	1
14542-6625	HJ 4707	Msn1999a	268.6	1.199	271	1.2	223.5425994	-66.42083174	270.32	1.18	25.3952	25.2822	237.74	237.67	323.50	348.53	5	100
15245+3723	STF1938Ba;Bb	Kiy2014	3.8	2.249	3	2.3	231.1278599	37.34768764	3.88	2.27	27.1525	27.2324	302.97	300.50	165.85	176.87	1	100
15405+1840	A 2076	Zir2014a	185.5	0.731	188	0.7	235.1184536	18.67174985	184.92	0.73	8.4005	8.4518	304.07	312.96	25.48	26.78	0	80
15413+5959	STF1969	RAO2015	28.9	1.059	30	1.1	235.3164604	59.98880209	29.42	1.06	15.4581	16.0523	306.02	308.97	274.51	279.11	16	1
15559-0210	STF1985	Hop1973b	354.5	6.286	346	5.9	238.977038	-2.164673826	354.20	6.04	26.063	26.1413	236.16	232.53	110.10	94.79	0	100
16044-1122	STF1998AC	Zir2008	43.6	7.538	45	7.6	241.091987	-11.37334656	41.64	7.99	35.3094	35.8219	246.12	260.90	81.30	76.00	0	100
16147+3352	STF2032AB	Rag2009	238.3	7.201	239	7.3	243.668832	33.85823856	238.45	7.22	44.1346	44.1475	252.05	254.88	282.05	301.56	1	100
16253-4909	COO 197AB	Ary2015b	92.8	2.33	91	2.4	246.3226435	-49.14828103	92.69	2.35	19.6639	19.7003	225.35	238.83	134.44	97.26	0	100
16289+1825	STF2052AB	Pru2017	118.9	2.392	118	2.3	247.2178394	18.41570615	119.10	2.39	51.749	51.787	317.70	319.77	518.17	501.91	1	100
16518+2840	STF2107AB	Sca2003c	105.4	1.392	105	1.4	252.9587318	28.66655786	104.65	1.44	15.6886	15.5264	359.70	352.71	37.58	26.53	0	80
16579+4722	A 1874AB	Kis2009b	63.5	5.015	62	5.1	254.4706516	47.36785581	63.00	5.09	55.7086	55.7754	331.82	332.64	308.77	301.71	40	100
17033+5935	STF2128	Kis2009	45.5	12.13	43	12.2	255.8247293	59.58638807	42.93	12.19	40.0442	40.063	304.01	304.45	428.74	441.81	5	100
17053+5428	STF2130AB	Pru2012	1.9	2.516	359	2.6	256.333431	54.47034242	2.61	2.52	36.7992	36.8008	322.61	313.94	93.27	136.66	0	100
17062-3838	SEE 318	Zul1987	357.1	0.915	357	1.4	256.5496434	-38.62561007	353.95	1.08	9.4281	9.6273	188.77	185.76	76.34	70.74	0	20
17102+5430	STF2138AB	PkO2014c	133.2	22.102	133	22.1	257.5443886	54.4939005	133.11	22.14	47.0533	47.0737	143.48	140.12	137.61	134.56	0	100
17141-0824	BAR 7	Cve2008a	52.9	1.637	50	1.5	258.5331874	-8.403537761	46.98	1.48	33.7958	34.6216	305.61	308.17	122.91	154.24	1	80
17191-4638	BSO 13AB	Sca2013d	257.8	10.478	258	10.8	259.7724461	-46.6357732	257.86	10.38	113.8158	120.1791	84.07	81.45	1035.19	962.92	1	100
17248+3044	BU 1250	Mnt2004b	119.6	1.888	118	1.9	261.2067799	30.74010427	118.57	2.01	2.3733	2.2556	4.46	168.09	9.18	4.68	0	1
17304-0104	STF2173AB	Hei1994a	144.1	0.686	143	0.7	262.5984522	-1.063482522	143.65	0.72	58.501	60.7132	210.04	223.76	240.90	199.97	0	80
17386+5546	STF2199	Pop1995d	52.4	1.933	54	2.1	264.6594828	55.75955769	55.19	2.07	8.442	8.7367	158.06	79.20	13.35	3.58	0	20
17394-1546	HU 181	Hrt2001a	43.3	1.019	41	1	264.8508686	-15.7617996	41.65	1.01	11.5155	10.0538	214.18	212.10	71.10	67.17	4	1
17403+6341	STF2218	Zir2015a	309	1.44	310	1.5	265.0754359	63.67599873	309.77	1.48	14.6473	14.5489	1.66	1.26	146.83	134.29	5	100
17419+7209	STF2241AB	Kis2009	16.8	29.581	14	30.1	265.4848335	72.14769941	16.50	30.08	46.6809	43.9875	163.75	173.02	281.31	277.92	1	1
17420+1557	BU 1251AB	Baz1991a	99	1.397	111	1.4	265.4942897	15.95286887	102.91	1.47	28.5416	31.1582	358.86	5.58	101.32	130.38	0	1
17530-0755	STF3128AB	Hrt2010a	49.7	1.274	51	1.2	268.2440861	-7.920620694	49.65	1.26	15.3759	14.4994	193.85	192.84	261.91	254.64	32	20
18068-4325	HJ 5014	Ary2001a	359.5	1.734	3	1.8	271.7079519	-43.42567812	1.69	1.78	22.4417	22.3498	174.07	180.50	106.31	101.05	0	80
18070+3034	AC 15AB	Jao2016	327.6	1.379	317	1.2	271.756127	30.56233942	324.91	1.32	63.5358	53.9769	298.35	322.22	113.10	125.69	0	1
18112-1951	BU 132AB	Hrt2011d	187	1.401	188	1.4	272.8115662	-19.84206937	187.68	1.41	9.0478	9.0861	193.47	183.98	28.40	31.35	0	80
18126+3836	BU 1091	Zir2012b	318.8	0.759	321	0.7	273.1528749	38.59740625	318.94	0.75	7.1501	6.0814	234.00	229.37	31.99	30.99	4	16
18126-7340	HDO 284AB	Lin2016b	270.7	2.133	271	2.1	273.1406152	-73.67353094	270.51	2.12	23.774	23.7859	199.72	194.39	270.15	249.87	0	100
18146+0011	STF2294	Sca2015b	93.2	1.326	93	1.4	273.6403005	0.175680517	93.29	1.36	11.9204	12.0247	148.90	142.80	35.93	38.50	0	80
18239+5848	STF2323AB	Nov2006e	348.1	3.745	347	3.8	275.9772185	58.80100846	348.17	3.76	17.115	17.2743	329.28	325.89	74.04	73.96	1	80
18253+4846	HU 66BC	Nov2008b	25.7	0.89	27	0.8	276.3258965	48.76163597	26.34	0.81	7.6115	4.9902	87.71	65.03	12.42	16.91	0	1
18359+1659	STT 358AB	Hei1995	145.9	1.502	148	1.6	278.9719598	16.97537472	148.20	1.66	28.9474	29.2593	147.78	138.95	86.95	86.00	1	100
18443+3940	STF2382AB	WSI2004b	345.6	2.337	346	2.3	281.0848439	39.67039718	346.06	2.29	17.9665	20.408	7.04	2.11	75.86	49.58	0	1
18570+3254	BU 648AB	Mut2010e	241.1	1.29	243	1.3	284.2576611	32.90073932	242.31	1.27	66.5742	67.7815	128.77	137.68	212.18	257.21	0	100

Table 8 concludes on the next page.

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Table 8 (conclusion). Assessment of WDS code "O" pairs for being physical pairs

WDS ID	Disc	Orbit	Orbit PA 2016	Orbit Sep 2016	WDS PA	WDS Sep	RA 2015.5	DE 2015.5	PA	Sep	Plx A	Plx B	PMVD° A	PMVD° B	PMVL A	PMVL B	CPM Score	Plx Score
19043-2132	HN 126	Hei1998	184.4	1.25	186	1.4	286.0848157	-21.53163164	184.81	1.28	19.4385	19.4045	123.72	121.32	73.46	85.64	1	100
19064-3704	HJ 5084	Hei1986b	344.9	1.418	338	1.4	286.6054158	-37.06488086	347.15	1.39	57.8583	58.6956	150.84	170.89	313.11	288.83	0	100
19121+4951	STF2486AB	Hle1994	204	7.224	205	7.1	288.0195333	49.85842285	204.33	7.20	39.5574	39.6041	341.27	343.56	655.92	657.02	20	100
19143+1904	STF2484	Hop1973b	239.7	2.261	242	2.1	288.5654125	19.06390082	240.36	2.10	15.9674	15.8409	132.87	120.28	38.95	37.32	0	100
19190+4138	KOI3158A;BC	Dup2016b	253.1	1.839	253	1.8	289.7528323	41.63188403	252.76	1.84	27.4137	32.6519	171.48	170.87	639.25	652.61	40	1
19266+2719	STF2525AB	Pru2017	289.4	2.172	290	2.3	291.6412141	27.32306301	289.42	2.19	16.3459	16.2984	48.70	46.14	136.22	129.59	1	100
19282-1209	SCJ 22	Msn2017c	287.8	1.094	291	1.1	292.0515431	-12.14526838	288.12	1.08	26.2966	26.8395	149.40	144.94	113.38	81.25	0	80
19316+1747	STF2536	Sca2001e	124.9	1.712	119	1.8	292.9074657	17.78239941	118.76	1.80	19.121	19.1344	185.46	186.52	120.70	134.25	4	100
19418+5032	STFA 46AB	Mrc1999	133.1	39.751	134	39.8	295.4529704	50.52437636	133.15	39.75	47.2771	47.2754	223.01	219.68	217.40	211.12	0	100
19458+2710	KUI 95AB	Sod1999	56.1	2.508	60	2.1	296.4392033	27.12007672	60.13	2.25	94.0139	93.9479	182.18	180.05	1225.82	1219.77	20	100
19464+3344	STF2576FG	Sod1999	156.5	3.03	158	3	296.3897403	33.60009718	156.95	3.05	47.6923	47.616	178.89	175.41	442.92	452.98	0	100
19496-5525	I 658	Doc2017i	132.4	1.217	132	1.2	297.4053253	-55.42428339	132.37	1.20	13.2542	13.2678	251.90	301.70	16.56	2.02	0	80
20012-3835	HDO 294	Dom1978	34.7	1.346	35	1.3	300.3031312	-38.58718924	32.16	1.24	12.2378	11.866	165.70	159.48	69.40	67.94	0	20
20014+1045	STF2613AB	Hop1973b	352	4.147	356	3.5	300.3616246	10.74876003	354.80	3.58	12.647	12.9723	65.53	75.23	88.33	89.04	1	1
20210+1028	J 838	Ole2002b	118.6	6.195	119	6.8	305.2527479	10.47252766	119.00	6.75	0.9171	2.0803	328.17	147.95	9.55	48.54	0	1
20213+0250	HLD 158	Msn2017c	42.3	1.187	42	1.2	305.3228978	2.839282081	42.10	1.18	19.4385	18.3952	111.25	97.79	67.09	69.13	0	1
20269-3724	R 321	Hei1988d	123.5	1.575	128	1.7	306.7192615	-37.40340329	124.97	1.57	25.6094	25.5163	244.98	245.84	276.15	261.98	5	100
20312+0513	AG 257	Zas2009	74.2	1.618	75	1.7	307.8074254	5.220250737	74.66	1.66	22.1593	22.2935	47.30	47.70	416.71	407.64	40	100
20329+1142	J 1AB	Ole2003d	55.1	2.11	57	2.1	308.219443	11.74349807	56.46	2.09	16.9206	16.9097	250.52	245.82	58.84	54.29	0	100
20450+1244	BU 64AB	USN2007a	355.6	0.649	354	0.7	311.2509485	12.72671827	354.83	0.66	8.8894	14.1302	225.50	246.95	7.07	16.41	0	1
20452-3120	LDS 720BC	Hrt2014b	146.2	2.125	148	2.2	310.4642932	-32.43697892	146.36	2.14	101.1982	101.717	149.25	135.54	483.53	424.17	0	100
20462+1554	STF2725AB	Msn2014b	11.6	6.142	12	6.2	311.5558561	15.90759797	11.50	6.17	25.316	26.6012	54.60	54.13	110.88	123.21	5	1
20514-0538	STF2729AB	Mdz2017	29.5	0.786	31	0.8	312.8577068	-5.626612466	29.35	0.79	15.2146	17.21	85.59	94.27	96.23	91.73	0	1
20548+3242	STT 418	Zir2013a	283.5	0.952	283	1	313.7081752	32.70665698	283.95	0.97	15.8234	16.3078	52.01	56.40	86.85	87.58	1	20
21072-1355	STF2752AB	Hrt2013c	184.2	3.532	180	4.4	316.7949536	-13.92314274	184.50	3.67	57.4341	57.5631	97.49	93.04	386.53	357.78	0	100
21200+5259	STF2789AB	Kis2009	113.8	6.895	113	6.9	319.9952307	52.97919219	114.24	6.85	12.1033	12.1232	8.99	6.50	61.12	57.27	1	100
21208+3227	STT 437AB	Hrt2011a	18.7	2.435	19	2.5	320.208849	32.45202628	19.40	2.45	14.0435	14.0463	127.64	124.89	73.47	66.26	1	100
21223+5734	A 764AB	Hei1995	24.7	0.988	19	1.3	320.5860521	57.56536026	18.59	1.26	11.9052	11.8654	68.50	69.58	82.62	93.14	4	80
21289+1105	STF2799AB	Hrt2011a	258.4	1.875	259	2	322.2204854	11.0849365	259.70	1.89	10.2079	10.2442	73.76	79.65	79.49	74.65	0	80
21582+8252	STF2873AB	PkO2006	65.8	13.741	66	13.8	329.5491053	82.86934379	66.04	13.86	24.8664	24.9757	238.42	254.92	141.03	142.16	1	100
22038+6438	STF2863AB	Zel1965	273.2	8.409	274	8	330.9498026	64.62835515	274.68	8.05	32.1697	32.1173	67.26	67.91	241.11	218.02	5	100
22202+2931	BU 1216	Lin2012a	277.2	0.883	276	1	335.0536316	29.51889926	276.43	0.93	9.0919	13.3973	76.48	72.78	84.46	66.78	1	1
22234+3228	WOR 11	Cve2011c	251.6	1.305	255	1.1	335.8726117	32.45833845	252.27	1.27	65.8608	65.4804	135.84	123.74	350.83	306.46	0	100
22288-0001	STF2909AB	Tok2016f	159.8	2.189	161	2.3	337.2086486	-0.019822258	163.89	2.30	34.507	34.4525	79.64	83.54	183.83	225.73	0	100
22478-0414	STF2944AB	Zir2007	304.5	1.829	306	1.9	341.958146	-4.23039185	304.29	1.87	30.1131	29.912	214.46	212.47	380.13	356.14	4	100
22514+6142	STF2950AB	Zir2015a	274.1	1.169	278	1.1	342.8451488	61.69692628	275.42	1.19	13.9565	13.5503	65.52	74.00	104.23	111.53	0	20
23009+3522	HU 991	Sca2017d	302.3	0.93	303	0.9	345.232771	35.36571851	302.69	0.95	16.599	29.393	121.15	112.57	102.39	57.72	0	1
23228+2034	STF3007AB	Tok2016d	94.5	5.828	92	5.9	350.704252	20.55889854	91.42	5.86	25.7457	25.9351	91.98	93.29	315.43	318.13	80	100
23317+1956	WIR 1AB	Hei1984a	78.6	5.494	78	5.4	352.9700384	19.93700114	78.04	5.38	159.7098	160.0598	95.90	87.90	580.68	553.85	0	100
23431+1150	A 1242	Lin2004c	339.3	0.984	339	1	355.7758129	11.83445029	339.19	1.05	11.025	11.0069	91.78	88.13	98.30	102.82	0	80
23487+6453	STT 507AB	Zul1977b	318.3	0.709	323	0.7	357.1628804	64.87639481	321.79	0.73	2.2565	9.835	109.69	105.96	15.19	23.32	4	1
23595+3343	STF3050AB	Hrt2011a	340.1	2.392	341	2.5	359.8717248	33.72338231	339.55	2.41	33.7083	33.9238	209.64	211.13	126.27	91.86	4	100

Description of the table contents:
- WDS ID: WDS ID
- Disc: Discoverer code
- Orbit: Orbit reference
- Orbit PA2016: Position angle for 2016 according to the given orbit
- Orbit Sep2016: Separation for 2016 according to the given orbit in arcseconds
- WDS PA: Position angle as given in the WDS catalog
- WDS Sep: Separation as given in the WDS catalog in arcseconds
- RA 2015.5: RA from Gaia DR2
- DE 2015.5: Dec from Gaia DR2
- PA: Position angle from Gaia DR2
- Sep: Separation from Gaia DR2 in arcseconds
- Plx A: Parallax for primary from Gaia DR2 in mas
- Plx B: Parallax for secondary from Gaia DR2 in mas
- PMVD A: Proper motion vector direction for primary from Gaia DR2
- PMVD B: Proper motion vector direction for secondary from Gaia DR2
- PMVL A: Proper motion vector length for primary from Gaia DR2 in mas/yr
- PMVL B: Proper motion vector length for secondary from Gaia DR2 in mas/yr
- CPM Score: Common proper motion score according to the used assessment scheme
- Plx Score: Gravitational relationship score according to the used assessment scheme

Appendix C

Suspect cross-matches between Gaia DR1 and DR2

Despite the rigid cross-match procedure we found in a preliminary version of the HPMS3 catalog (based only on epoch 2015 position comparison) a large number of suspect DR2 to DR1 matches showing unexpected large differences in Gmag values without an easy explanation why this should be the case. For the first 20 of such objects sorted by the size of the Gmag delta we did a manual counter-check. These are presented in Table 9.

Table 9. Suspect cross-matches between Gaia DR1 and DR2

angDist	HPMS3	Gaia DR2 source_id	RA 2015	DE 2015	Gaia DR1 source_id	Gmag DR2	Gmag DR1	dGmag	Notes
0.243608	49422	5280389615847484416	100.620594526	-67.12386149	5280389615844340096	14.004	18.467	4.463	No explanation for large Gmag delta to be found. Mag values from other catalogs rather confirm the DR2 Gmag value even if 14Gmag seems a bit on the faint side
0.055567	25173	4068720891437386624	266.489178394	-23.93295893	4068720994692669056	20.105	16.722	3.383	DR2 object not resolved in DR1. Mis-match with DR1 object nearby with ~0.06” separation in 2015. Nearby DR1 object resolved also in DR2 with corresponding Gmag value
0.203711	75320	6354062136252405632	348.731682424	-77.58006892	6354062136251017216	15.457	12.913	2.544	Close pair of components with different proper motion resolved in DR1 as well in DR2. No explanation for the Gmag delta of one component to be found, second one matches well
0.213727	24427	4063005286564273152	272.273130286	-27.32084607	4063005286564551424	19.632	17.365	2.267	DR2 object not resolved in DR1. Mis-match with DR1 object nearby with ~0.2” separation in 2015. Nearby DR1 object resolved also in DR2 with corresponding Gmag value
0.139356	89086	6854760902403562496	308.747695518	-23.87695460	6854760902403562496	20.443	18.217	2.226	Close pair with different proper motion resolved in DR1 as well in DR2. No explanation for the Gmag delta of one component to be found, second one matches well
0.040208	36187	4738761769866648832	37.787509747	-56.90661391	4738761769865402496	18.548	16.517	2.031	Close pair with identical proper motion resolved in DR1 as well in DR2. No explanation for a such large Gmag delta to be found
0.039475	16413	3577937731592103168	184.978061570	-10.64095174	3577937731592103168	20.621	18.776	1.845	ID DR1 and DR2 identical suggesting a correct match. No explanation for large Gmag delta to be found
0.004378	56910	5666955604699546240	149.686395674	-22.39706605	5666955604699546240	19.480	17.796	1.684	ID DR1 and DR2 identical suggesting a correct match. No explanation for large Gmag delta to be found
0.263273	10636	3017264076480825856	83.686475843	-5.56167221	3017264076477847680	14.684	16.138	1.455	No explanation for a such large Gmag delta to be found
0.000739	31585	4336376553171536384	254.523096010	-8.75387540	4336376553171536384	19.929	18.531	1.398	ID DR1 and DR2 identical suggesting a correct match. No explanation for large Gmag delta to be found
0.365761	61585	5864930404351742208	202.620685240	-63.82925640	5864930404309465600	20.518	19.148	1.370	DR2 object not resolved in DR1. Mis-match with DR1 object nearby with ~0.38” separation in 2015. Nearby DR1 object resolved also in DR2 with corresponding Gmag value
0.004080	6484	2531243756196895232	17.433769815	-3.65914326	2531243751904397440	14.609	13.286	1.323	No explanation for large Gmag delta to be found
0.002451	19084	3688712561723372672	194.645216968	-0.99704366	3688712561723372672	18.811	17.569	1.242	No explanation for large Gmag delta to be found
0.343403	15227	3534344084121700480	170.928114427	-25.10796166	3534344088415932544	10.378	11.593	1.215	Mis-match with DR1 probably spurious object nearby with ~0.35” separation and missed correct match with TGAS object due to significant proper motion data not taken into account

Table 9 concludes on next page.

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Table 9 (conclusion). Suspect cross-matches between Gaia DR1 and DR2

angDist	HPMS3	Gaia DR2 source_id	RA 2015	DE 2015	Gaia DR1 source_id	Gmag DR2	Gmag DR1	dGmag	Notes
0.003189	52775	5430285520662769152	139.576751199	-39.08402238	5430285520662769152	15.855	14.665	1.190	ID DR1 and DR2 identical suggesting a correct match. No explanation for large Gmag delta to be found
0.189000	21412	4040205164803540096	267.322297415	-36.51662798	4040205160472730880	20.122	18.971	1.151	No explanation for large Gmag delta to be found
0.140643	63683	5931042492300343168	249.187466807	-52.74279316	5931042492259440640	19.674	18.564	1.110	No explanation for large Gmag delta to be found
0.005611	54408	5512070906388269568	112.307280946	-43.30064363	5512070902092668928	2.486	3.565	1.079	No explanation for large Gmag delta to be found but the brightness of the star
0.080814	61524	5863988706959497856	202.149605893	-65.31468271	5863988706885354496	20.212	19.145	1.067	No explanation for large Gmag delta to be found
0.024003	64053	5941597047938535680	246.570784647	-48.16795707	5941597047938535680	14.764	13.698	1.066	ID DR1 and DR2 identical suggesting a correct match. No explanation for large Gmag delta to be found

Description of the table content:

- angDist = Distance between DR1 and DR2 positions J2015 in arcseconds
- HPMS3 = HPMS3 ID
- Gaia DR2 source_id = Gaia DR2 source id
- RA 2015 = RA J2015 calculated from DR2 position minus proper motion for 1/2 year
- DE 2015 = Same for DE
- Gaia DR1 source_id = Gaia DR1 source ID
- Gmag DR2 = Gmag Gaia DR2
- Gmag DR1 = Same for Gaia DR1
- dGmag = Absolute difference between Gmag DR2 and Gmag DR1
- Notes = Comment

For some cases of large Gmag delta between Gaia DR1 and DR2 we found explanations by unexpected mis-matches caused mostly by non-resolution in DR1 with other objects by chance nearby within the cross-match used search radius of 0.4 arcseconds. Yet for most cases no explanation could be found – even in cases with identical ID in DR1 as well in DR2 suggesting a certainly correct match.

With this counter-check we found a few DR2 to DR1 mis-matches in the HPMS3 catalog giving us the opportunity to eliminate them and making us aware that a few more still exist but the number of such mis-matches should in relation to the total number be negligibly small. The mis-match for HPMS3 object 15227 made us aware that a correct match with TGAS objects required a comparison based on positions of epoch 2000 due to the internal logic of the CDS X-Match tool – this was done then as additional step raising the number of Gaia DR1 hits by nearly 10%