A Catalog of High Proper Motion Stars in the Northern Sky (HPMSNS Catalog)

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Abstract: As follow up to our report on high proper motion stars in the southern sky (Knapp and Nanson 2019 - HPMS3 catalog) we present here our attempt to counter-check and extend the LSPM north catalog (Lepine and Shara 2005) covering the high proper motion stars in the northern sky. The GAIA DR2 catalog contains in total 78,279 high (>150mas/yr) proper motion objects in the northern sky compared to 61,977 LSPM objects which means an increase of 26%. A cross-match of LSPM and HPMSNS objects suggests a "loss" of several thousand LSPM objects – a closer look made clear that this is mostly caused by LSPM objects with GAIA DR2 proper motion values smaller than 150mas/yr missing for this reason the cut. Several thousand HPMSNS objects come in pairs up to 60 arc seconds separation. A good part of these pairs are already listed in the WDS catalog, the rest are newly discovered pairs most of them with common proper motion. Several hundred of the newly discovered CPM pairs have parallax data similar enough to be considered as potentially gravitationally bound while the rest travel most probably by chance in the same direction with similar 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. This list includes several pairs with potential gravitational relationships but proper motion different enough to be considered not quite common up to quite different – we consider these pairs also as potential binaries assuming that fast orbits add extra motion to the proper motion of the pairs as system.

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). Together with the amazingly small error range of the huge amount of measurement results this provides a mixed message of so far unprecedented data precision with a general uneasiness regarding data reliability beyond any error range. We tried therefore 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.

1. Introduction

The LSPM catalog contains 61,977 high proper motion stars with speed >150mas/yr (Lépine and Shara 2005) and 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.

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The availability of about 496,644,216 GAIA DR2 objects in the northern sky with proper motion data given made it rather easy to select the 78,279 objects with a proper motion vector larger than 150mas/yr and declination larger 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). Consequently, 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). On the other hand high proper motion stars are in most cases rather close to our Sun system enhancing the probability of good data quality.

Most interesting is also the comparison with the number of 90,455 GAIA DR2 high proper motion stars in the southern sky, which reflects the much higher star density in the southern sky if not to the full extent of the relation 3:7 north to south according to the corresponding star count in GAIA DR2.

2. High Proper Motion Stars in the Northern Sky

In Table 1 we list a subset of the data for the first 20 high proper motion objects in the northern sky. The full data set with 78,279objects is available for download on the JDSO website as "HPMSNS".

All HPMSNS objects were cross-matched with the LSPM north catalog with a result of 57,851 matches after eliminating duplicates for close objects within the 5" search radius. This means a recovery rate of 93% compared to the total of 61,977 LSPM objects - at first look rather disappointing low. We had then a closer look at the LSPM objects not matched and found for the major part of "lost" LSPM objects that GAIA DR2 lists these objects with less than 150mas/yr – 2,372 of them down to 100mas/yr but 222 also significantly less down to nearly zero. Including this number in the recovery rate we get now up to 97.5% which means more or less up to the expectations. We give a sample of LSPM objects with proper motion less than 150mas/yr in Table 2.

There still remains the question about the rest of the

Table 1. High proper motion stars in the northern sky (HPMSNS) catalog

HPMSNS	gaia dr2 source_id	ra	dec	Pmra	pmdec	pmvd	pmvl	vmag
1	394020956870508672	0.012351494	50.66149471	197.145	-33.574	99.66480874	199.9834106	21.332
2	2745374882658545920	0.013204006	6.267432701	111.316	-101.248	132.2882373	150.4739491	13.783
3	2875125810310195712	0.01582912	34.18830854	-224.498	-54.93	256.2510381	231.1204381	9.103
4	2765667056943710720	0.016390428	11.36269777	149.160	-96.393	122.8721182	177.5959348	16.992
5	2875105641143726080	0.019172013	33.88023899	175.594	1.948	89.36439969	175.604805	16.313
6	2740326852975975040	0.019647984	3.946410503	223.124	-11.367	92.91639879	223.413357	12.413
7	2875119243304430592	0.01980133	34.01341385	146.339	-85.626	120.3327926	169.5491516	20.072
8	2846308881856186240	0.021035353	20.03527505	-206.469	-195.796	226.51983	284.5444106	9.963
9	2767355150889886592	0.023318167	13.79968823	183.829	-127.922	124.8330906	223.9578963	16.624
10	2875543345555313792	0.035958628	35.52824056	152.325	-67.144	113.7876143	166.4668807	12.516
11	2882276999577911680	0.043413956	41.36147432	237.924	-21.656	95.200769	238.9075388	16.173
12	421077635926960256	0.051079523	57.17693474	169.559	20.221	83.19922925	170.7604852	20.188
13	2881755246950572032	0.064445994	39.047639	210.961	62.672	73.45444181	220.0734493	10.990
14	2873854843587915008	0.069224509	32.65278809	148.830	-31.192	101.8368063	152.0635057	14.929
15	564627228347120000	0.072025977	79.4121273	162.359	-28.071	99.80915974	164.7677939	11.408
16	2546035657925014144	0.076290664	0.055785767	237.192	-64.697	105.2569787	245.8571672	14.936
17	393886301059134336	0.079244358	49.91322072	143.334	73.261	62.92747605	160.9714561	17.598
18	384491695747484544	0.08071937	43.21169829	200.435	-72.116	109.7886014	213.013865	11.862
19	429495290799321600	0.089408582	61.51725037	239.109	-13.193	93.15813097	239.4726897	19.566
20	566887652452750848	0.091649892	82.49464124	253.721	72.275	74.09985965	263.8143693	21.089

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.):

- HPMSNS 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

missing LSPM objects. We found that about 500 remaining missed matches are GAIA DR2 objects without proper motion data with some of them as expected very fast LSPM objects with proper motion >600mas/yr. About 1,000 not recovered LSPM objects remain at the moment without explanation.

Counter-checking the HPMSNS catalog for negative parallaxes, parallax values smaller than 3 times the given error range, objects with duplicity issues or issues with the visibility periods used we found in total ~22% objects with potentially contaminated data - especially the 5% with negative parallax values might be listed with suspect proper motion values. On the other hand high proper motion values indicate a positive selection of objects rather near the sun system even if 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 the formula (estimated)

$$V_{mag} = 3.9379083526304 + 0.269235360436179 * G_{mag}^{1.36701081887491} - 0.123879978164097 * \left[G_{mag} - R_{mag}\right] - 0.943379695375539 * \left[G_{mag} - B_{mag}\right]$$

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 (< 10 Gmag) and very faint (> 18 Gmag) objects according to Evans et al. 2018 and Riello et al. 2018.

For about 2% of the objects GAIA DR2 provided no B- and R-mag data so we estimated in these cases Vmag from Gmag plus an average difference Vmag to Gmag of 0.318 according to our data sample.pairs

Table 2. Sample of LSPM objects with proper motion less than 150mas/yr

LSPM	pmra	pmdec	pm/yr
J0001+0842	-34.015	-144.665	148.610169
J0002+2223	147.637	-7.269	147.815839
J0002+4422	149.345	5.618	149.450630
J0002+5512	145.136	24.077	147.119545
J0002+5725	126.525	67.676	143.487340
J0003+5649	-101.150	-108.688	148.473580
J0003+5207	148.445	4.747	148.520881
J0003+5349	148.192	14.030	148.854660
J0003+0654	139.053	-43.783	145.783016
J0003+0406	142.767	-44.982	149.685659

Table 2 content description

- LSPM = LSPM catalog ID
- pmra = GAIA DR2 proper motion RA in mas/yr
- pmdec = GAIA DR2 proper motion Dec in mas/yr
- pm/yr = total proper motion in mas/yr

3. HPMSNS Pairs

As visually close pairs with high proper motion are according to our experience often common proper motion pairs we selected from the HPMSNS catalog all objects with a neighbour within 60 arcseconds to verify this assumption – 3,937 such pairs are to be found in the HPMSNS catalog.

3.1 HPMSNS Pairs Cross-Matched with WDS

In the next step we cross-matched this list with the WDS catalog with a search radius of 5 arc seconds to identify the objects already WDS listed. To avoid issues with reversed components we did this cross-match for both components. 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 making the BC component obsolete
- Components A or B were resolved into Aa;Ab or Ba;Bb making the A or B component obsolete
- WDS multiples were matched to only one HPMSNS pair because the other components are not high proper motion stars
- The matched WDS object had only one component identical with the HPMSNS 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. Finally 2,038 of the HPMSNS 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. As the search radius for HPMSNS pairs is restricted to 60 arcseconds all WDS objects with larger separations are not covered by this matching process.

The assessment for being physical is based on the scheme presented in Knapp 2018 (see Appendix A) with the following results: Out of the 2,038 pairs found to be already included in the WDS catalog 1,592 are pairs with common proper motion and 1,295 pairs can be considered as probably physical by means of common parallax but “only” 996 pairs show positive assessment for both parameters. 596 CPM pairs seem to be just random common travelers with a distance between the components making gravitational relationship rather impossible while 299 pairs are close enough for gravi-

tational relationship but have somewhat different proper motion data suggesting with some probability an orbit.

In Table 3 we list a subset of the data for the first 20 HPMSNS pairs found to be existing WDS pairs. The full data set is available for download on the JDSO website as "HPMSNS_pairs_WDS_matches".

3.2 HPMSNS pairs with negative parallax

About 2% of the HPMSNS objects are listed in GAIA DR2 with a negative parallax or with Plx values smaller than 3 times the given error range. In the list of HPMSNS pairs matched positively with the WDS catalog only 2 such objects "survived," while for the assessment procedure of the other HPMSNS pairs for being potentially physical, all pairs with one or both such components were excluded.

3.3 HPMSNS 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, in our procedure for potential gravitational assessment (Appendix A) we stick with the "naïve" parallax inversion (Bailer-Jones 2015) 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 in total 1,215 HPMS pairs are considered optical due to a distance between the components making gravitational relationship rather impossible. A total of 918 of those HPMSNS pairs qualify as CPM pairs, which means that the components of these pairs travel in space in same direction with the same speed but are too distant to be gravitationally connected. These pairs are reported here just for purpose of completeness but not as double stars to be included in the WDS catalog. In Table 4 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 "HPMSNS_optical_pairs".

Many HPMSNS common proper motion pairs assessed as opticals are listed with rather similar Plx values – this might indicate that originally physical pairs have separated over time. With a less restrictive assessment these might be also be considered as physicals.

3.4 HPMSNS pairs probably physical

The standard assessment scheme provides by means of common proper motion and common parallax allowing for potential gravitational relationship about 490 most probably physical HPMSNS pairs. Additionally we have the pairs with different proper motion but components close enough for gravitational relationship which gives in total about 640 probably physical pairs. To detect any connections with existing WDS objects we calculated for each pair the corresponding WDS ID for the position of the primary as well as for the secondary and compared these IDs with the WDS "precise" list. This way we detected in several cases connections with the WDS catalog so far missed. Being then aware of such issues we did then a complete manual countercheck by optical comparison of all objects with the WDS catalog with the Field of View feature of AstroPlanner using the WDS catalog per August 2018.

The following issues were this way detected:

- Resolution of components being doubles themselves as for example A into Aa;Ab making it necessary to delete false positives from the WDS matches list as already mentioned above
- Confirmations for first observation data identifying last observation data being in error
- References to WDS objects with separations larger than 60 arcseconds not covered in this report
- Redundant pairs as for example AC for existing AB and BC triple
- Positive WDS matches missed due to wrong WDS J2000 positions (for example NSN 26 with correct J2000 position 06:11:55.99 +33:25:50.5 instead of 06:11:56.18 +33:25:43.0)
- In several cases a newly resolved Aa;Ab pair is not listed as probably physical due to not fully common Plx data, yet one pair like B;Ab remained as probably physical. It might very well be that in such cases with a third component involved the Plx assessment is too restrictive
- Potential positive matches with WDS objects with probably erroneous data – yet kept in the list due to undecidability
- Redundant pairs due to switched sequence of components.

32 objects were detected as potential matches with given WDS objects despite significant differences to the WDS data given for J2000 position, separation and position angle. These objects are listed in Table 5 as cases to decide by the keepers of the WDS catalog.

The comparison of J2000 and J2015.5 values for separation and position angle indicates in some cases significant differences proposing a fast orbit and shows that the matching of pairs can get quite complicated if high proper motion is involved. Future GAIA data re-

(Text continues on page 51)

Table 3. WDS pairs in the HPMSNS catalog

HPMSNS ID	WDS	Disc	Comp	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
00078+00077	00012+1357	WNO 12	AB	0.305053780	13.97572070	11.64836	203.83704	9.8721	10.4465	26.070	160.186	26.368	149.523	23.2455	27.7679	5	1
00127+00124	00021+2929	SLW 1		0.516589329	29.47530296	16.77665	191.55701	16.5187	18.6922	199.828	38.937	199.552	38.676	3.8425	3.3020	100	1
00311+00313	00057+0626	BFR 1		1.423473717	6.43993976	6.06492	43.23486	16.1605	20.2794	203.669	-123.680	206.218	-121.306	12.8878	12.0613	100	20
00316+00315	00057+4549	STT 547	AB	1.426413637	45.81139650	6.03771	188.20835	8.2482	8.3010	888.615	-162.470	845.890	-148.540	86.8735	86.9402	5	100
00336+00337	00059+1805	STF3060	AB	1.480470056	18.07524491	3.40703	134.86534	8.9372	9.1826	-147.614	-145.798	-154.409	-150.572	26.5370	26.5422	5	100
00400+00402	00069+2328	CRB 8		1.733210985	23.47255696	8.08700	160.17030	12.0868	14.1955	206.091	15.180	206.353	17.023	22.1840	22.3562	100	100
00420+00421	00073+5241	LDS5262		1.833048099	52.69187328	4.09306	178.42289	11.9698	14.9064	321.901	-48.822	321.167	-48.236	25.8768	25.9583	100	100
00429+00428	00074+0445	CRB 9		1.853376827	4.75453634	6.39026	319.45060	12.8272	14.9672	171.953	-70.870	171.427	-72.368	13.0597	13.1643	100	80
00449+00448	00078+5801	CBL 560		1.953231562	58.01399420	8.65624	320.28845	13.9164	16.1513	203.984	6.999	202.387	7.861	11.5302	11.3956	100	20
00487+00484	00088+6607	LDS3127		2.181994332	66.13232472	28.66944	280.22262	13.3913	16.8873	176.567	20.476	178.991	20.123	8.4702	8.4690	78	80
00496+00495	00089+1634	CLZ 16		2.224294294	16.56452252	13.75264	323.90369	19.7668	20.2357	136.350	-111.159	143.429	-111.827	9.3507	8.2829	4	19
00514+00515	00091+4051	BU 483	AB	2.266029061	40.84212253	2.06759	34.04501	6.6889	11.1066	126.532	-171.143	119.707	-178.928	16.7115	16.5777	16	80
00523+00519	00093+2517	GIC 2	AB	2.316429647	25.28133176	29.61156	237.12999	7.6058	10.8913	175.348	-158.970	171.422	-145.634	24.8900	22.4794	4	1
00535+00530	00094+4819	LDS3128		2.349971553	48.32768843	51.99721	295.81558	13.8800	15.6050	204.424	-4.532	204.728	-4.360	5.3330	5.2477	97	20
00549+00544	00097+3107	GIC 3		2.412038268	31.14600142	50.00598	262.09584	12.4481	16.7272	-358.702	-395.585	-358.931	-395.548	18.6581	18.6377	100	100
00565+00563	00100+3056	LDS3133		2.487165189	30.93914159	15.80285	216.65411	14.0735	16.3882	190.123	-46.092	190.869	-47.212	11.3320	11.0785	100	20
00575+00576	00102+5852	MRI 43		2.540696588	58.85986504	6.63224	98.37211	13.8027	16.8201	-64.752	-138.418	-64.852	-138.828	4.9684	4.9260	100	20
00583+00584	00103+0526	CBL 562		2.565734324	5.42640997	9.45587	107.81588	15.1860	15.5095	58.207	-167.805	58.589	-167.581	4.9494	4.7659	100	1
00596+00597	00104+2150	LDS3134		2.607097773	21.85100791	11.47820	179.08286	12.8786	17.5675	154.365	-7.901	154.721	-7.860	4.6152	4.4377	100	20
00619+00620	00109+1705	GWP 24		2.723873879	17.08332814	13.71008	97.87133	11.9126	17.7896	163.668	-16.826	163.739	-16.870	9.9028	9.9992	100	20

Description of the table content per WDS pair:

- HPMSNS ID gives the HPMSNS object ID for both components
- WDS gives the WDS ID
- Disc gives the WDS discoverer code
- Comp gives the components, blank means AB
- 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 GAIA DR2 Gmag
- 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)

Table 4: Optical pairs in the HPMSNS catalog

HPMSNS 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
00084+00083	0.33210685	65.5531862	2.10713	203.57527	15.66460	18.76940	92.962	171.360	93.220	169.389	8.5914	8.4859	100	20
00103+00100	0.40860198	23.2970500	30.99743	277.66291	17.25530	18.64870	129.851	-131.294	213.518	-98.045	9.9874	8.9711	0	1
00177+00176	0.77236532	10.8288067	1.82832	226.08516	12.69410	15.49900	250.671	3.480	251.447	0.890	11.6161	11.3091	100	20
00221+00222	1.02177586	6.54187127	1.29920	11.07875	15.24080	16.80040	118.254	-107.992	120.929	-105.936	10.1638	9.5907	80	1
00248+00247	1.16753123	38.6219382	2.35927	356.84618	12.78230	17.86170	175.181	12.845	175.326	9.729	9.3431	9.6935	80	20
00329+00330	1.46505517	9.97383267	1.71673	155.72463	12.60250	15.76770	202.633	-41.936	201.628	-41.095	11.2386	11.0289	100	20
00425+00424	1.84463621	26.4500954	17.94233	338.39198	7.03970	17.53220	130.102	-117.443	130.890	-116.895	7.6866	7.8467	97	20
00427+00426	1.84926117	10.8490815	0.71452	351.68053	13.50400	14.76470	363.689	45.325	365.208	46.732	6.3123	6.0140	100	20
00498+00499	2.22532843	28.3637467	0.99634	115.97831	14.97500	15.47790	150.486	49.476	154.027	46.406	11.3033	11.7507	64	20
00578+00579	2.55052102	11.0502097	2.19027	156.20025	11.12790	15.51970	162.729	-50.028	160.385	-53.151	10.5390	10.7026	80	20

Description of the table content per WDS pair:

- HPMSNS ID gives the HPMSNS 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 GAIA DR2 Gmag
- 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

Table 5: Undecidable HPMSNS pairs

HPMSNS ID	WDS	Comp	RA2000 A	DE2000 A	Sep 2000	PA 2000	Sep 2015.5	PA 2015.5	M1	M2	pmRA1	pmDE1	pmRA2	pmDE2	Plx1	Plx2	CPM Score	Plx Score	Notes
00358+00357	00063+5826		1.565888493	58.43669861	1.74092	331.30760	1.54820	357.09057	7.40732	7.52227	237.89	36.693	286.741	37.92	47.8005	46.2077	4	100	Probably match with STF3062 despite some differences to WDS PA and Sep values
01237+01236	00206+2712		5.164450161	27.21230964	1.92035	317.23722	1.87921	318.22948	16.59024	16.92103	-75.814	-179.023	-72.458	-179.562	12.1748	12.2128	100	80	Probably match with LDS3154 despite somewhat different WDS J2000 position and PA and Sep
06372+06373	01474+7745		26.70608604	77.73811275	1.97637	151.32930	1.95004	152.15968	15.58224	16.60160	175.624	0.5	173.209	1.126	12.8816	12.7754	80	80	Might be match with LDS1536 despite rather different WDS values
09518+09519	02406+3420		40.14778882	34.32961723	54.20296	0.05628	54.24584	0.06657	13.10723	14.29122	291.742	-40.592	292.321	-37.826	17.8155	17.8732	97	100	Probably match with GIC 33 AC despite some differences to WDS values
11418+11419	03135+2818		48.37222489	28.29563638	5.60449	116.40538	5.59824	116.32445	13.73594	14.89577	208.809	-28.39	208.676	-27.754	12.3011	12.3249	100	100	Probably match with UC 966 - but with data of first observation
16296+16295	04515+5550	AC	72.8630825	55.83672248	3.35727	338.97387	3.35710	339.48709	8.63715	13.44210	51.588	-207.034	53.407	-206.355	18.1606	18.1389	100	100	Primary probably identical with LDS5615 A despite slightly different J2000 position. Component B outside the 60" the search radius
23988+23990	07483+6900		117.0342903	69.00619066	2.54277	59.60882	2.53775	61.95804	15.20015	15.82254	-320.003	-54.189	-316.996	-60.212	25.311	25.3866	80	100	Looks like a confirmation of LDS1657 with first observation data
26544+26545	08427+0935		130.6855405	9.556693191	1.37429	79.63380	1.49643	41.40759	10.08796	12.19560	223.712	-631.918	200.347	-575.47	64.368	61.7634	5	100	Might be a match with ST 8 despite large PA difference
27369+27368	08582+1945		134.5628075	19.76340108	2.61068	155.79819	2.13143	228.79183	14.01049	14.65003	-766.029	-99.27	-938.546	-36.237	194.7225	195.0836	0	100	Might be match with LDS3836 despite quite different Sep and PA
28469+28465	09187+1059		139.6649352	10.96790392	24.91517	255.93815	24.95728	255.96697	17.21588	18.55773	-278.613	-197.816	-281.424	-197.693	19.2279	19.2418	100	100	Possible match with LDS3871 - WDS PA seems erroneously for changed sequence of components
29614+29613	09402+0908		145.0745013	9.121177798	8.52867	241.47760	8.48640	241.62119	16.76487	18.30090	-238.652	-65.401	-236.907	-62.892	20.2733	20.3554	100	80	Probably match with LDS3914 - WDS J2000 position seems in error
32113+32114	10236+5825	CB	155.9348768	58.40848411	2.20712	61.88120	2.17557	62.73345	17.12288	17.28780	-150.492	-148.912	-151.314	-151.719	16.3768	16.1304	80	80	Probably match with LDS2312 BC despite wrong WDS J2000 position and sequence of components changed
36542+36541			172.8383784	78.23660033	2.76488	208.04830	2.79293	207.70322	16.03071	19.14519	-93.053	-168.9	-92.947	-171.003	24.1515	23.9902	100	100	Possible match with WDS X-coded 11313+7814 - LDS1734

Table 5 continues on the next page.

Table 5 (continued) Undecidable HPMSNS pairs

HPMSNS ID	WDS	Comp	RA2000 A	DE2000 A	Sep 2000	PA 2000	Sep 2015.5	PA 2015.5	M1	M2	pmRA1	pmDE1	pmRA2	pmDE2	Plx1	Plx2	CPM Score	Plx Score	Notes
52266+52267	15190+2541		229.746043	25.69174831	3.40267	164.51137	3.33022	158.41172	8.71153	12.23419	-564.565	-125.142	-544.126	-113.366	29.4186	29.3295	5	100	Possible match with LDS6304 despite large PA difference
56500+56502	16345+5709		248.584708	57.16232376	26.44117	22.07739	26.71692	21.92571	12.96777	14.89771	-1113.61	1181.211	-1110.87	1199.405	67.34	67.3216	100	100	Probably match with LDS1436 despite wrong WDS J2000 position
57949+57950	17039+3212		255.9701993	32.19611391	1.32348	122.91503	1.38396	150.52946	12.07902	13.08490	192.41	99.967	164.674	68.628	52.28	53.3747	0	100	Possible match with DAE 6 despite some diffence in PA and Sep
61208+61209	18150+3840		273.7644722	38.6592636	2.71935	177.36927	2.55387	179.14223	13.63947	13.75212	-61.11	-244.186	-66.703	-233.677	26.8998	26.9705	4	100	Probably match with LDS4781 with changed sequence of components
61372+61373	18186+0255		274.6571918	2.913164121	3.07836	152.07311	2.90872	152.26543	14.13104	14.12252	-79.892	-186.107	-85.568	-176.731	31.384	31.5067	1	100	Potential match with LDS6326 despite a huge difference in PA
63029+63028	18570+3254		284.2568128	32.90131138	1.28326	283.34068	1.27489	242.31594	6.68281	7.78510	165.432	-132.864	173.165	-190.185	66.5742	67.7815	0	100	Probably match with BU 648 despite a huge difference in PA contradicting also the currently given orbit
63048+63047	18576+5331		284.4081641	53.52090237	2.36697	190.52978	2.29187	196.74983	13.10340	13.18039	256.122	-52.723	241.408	-44.176	40.2978	40.3304	4	100	Potential match with LDS4802 despite huge difference in PA and Sep
66295+66296	20030+0804		300.7512738	8.062376646	11.42824	170.91786	11.40283	170.99173	12.13201	17.59767	-121.023	-188.214	-122.229	-186.744	16.4322	16.3958	100	100	Probably match with FMR 156 with erroneous J2000 position and M1/M2 switched
67625+67623	20311+3935		307.7595867	39.57960589	7.67629	346.67760	7.79385	346.18384	14.43900	18.24863	416.778	129.796	410.796	136.161	28.374	28.5441	80	100	Potential match with LDS6414 despite large differences in PA and Sep
69121+69123	21058+1432		316.3486938	14.53985732	2.55464	40.79759	2.65073	41.47602	10.78983	14.70720	509.082	-3.524	514.653	-0.164	25.1839	25.2421	80	100	Probably match with WNO 11 for first observation data
70160+70161	21270+7339		321.7402371	73.64574016	1.74066	168.70939	1.88518	166.90262	12.75378	14.96015	55.137	-313.953	60.709	-322.286	45.0427	45.145	40	100	Potential match with ZUC 15 despite large delta to WDS data
70428+70427	21324+2434		323.0919077	24.5616678	1.08549	260.01337	1.53167	241.19222	13.11070	12.59849	229.542	-8.707	211.917	-44.177	48.6656	48.8403	0	100	Probably match with MCT 12 despite some differences to WDS PA and Sep
70808+70809	21400+5407		325.0044374	54.13824674	1.42909	67.38178	1.23109	78.33710	13.04640	14.35230	473.367	339.516	466.05	320.113	34.0267	34.1197	32	100	Probably match with GIC 169 despite some differences to WDS PA
72973+72974	22234+3228		335.870913	32.45896386	2.14528	39.73958	1.27019	72.27314	11.36997	11.21956	254.849	-170.211	244.407	-251.686	65.4804	65.8608	0	100	Potential match with WOR 11 despite some difference to WDS PA and Sep

Table 5 concludes on the next page.

Table 5 (conclusion) Undecidable HPMSNS pairs

HPMSNS ID	WDS	Comp	RA2000 A	DE2000 A	Sep 2000	PA 2000	Sep 2015.5	PA 2015.5	M1	M2	pmRA1	pmDE1	pmRA2	pmDE2	Plx1	Plx2	CPM Score	Plx Score	Notes
73207+73206	22280+5742		336.9981565	57.69502238	7.90011	13.97719	1.41861	290.35226	10.20511	10.82552	-725.227	-223.461	-934.098	-686.244	249.3926	249.9668	0	100	Probably match for KR 60 AB with Sep and PA from 2015.5 - see note 1)
73746+73745	22380+4914		339.5114181	49.23089908	1.67300	226.95597	1.70560	227.96725	12.21027	15.06850	189.463	149.393	186.622	149.389	12.1073	12.1979	100	80	Might be a match with TDT3626 despite PA and Sep quite different from WDS
75569+75567	23121+2656		348.0276074	26.92902356	15.24532	329.50461	15.20413	328.69514	11.34500	15.11849	160.207	-129.311	149.66	-138.717	23.6944	24.0165	1	80	Potential match with LEP 113 AC despite somewhat different WDS PA and Sep data
76808+76807	23344+5726		353.6077711	57.43384188	2.60258	325.99668	2.59689	324.85723	11.18237	14.48428	150.132	-40.006	147.584	-42.199	8.5089	8.5094	64	80	Potential match with TDT4104 despite very different WDS PA and Sep data
77827+77825	23524+7533		358.1058612	75.54454683	1.91532	259.62982	2.14254	313.17506	7.52794	10.89760	310.493	24.474	331.246	141.293	91.6755	92.5488	0	100	Potential match with BU 996 AB despite quite different WDS PA and Sep values but somewhat near the current 6th orbit values

Description of the table content per HPMSNS pair with parallax data and in most cases proper motion similar enough to be considered probably physical but undecidable if this is a newly detected pair or a match with an existing WDS object:

- HPMSNS ID = HPMSNS object ID for both components
- WDS = WDS reference to an existing WDS object as potential match
- Comp = components (AB if blank)
- RA2000 and DE2000 = RA/DE J2000 coordinates of the primary calculated by VizieR from the GAIA DR2 2015.5 coordinates using the proper motion data
- Sep 2000 = separation in arc seconds calculated from the RA/DE J2000 coordinates
- PA 2000 = position angle in degrees calculated the RA/DE J2000 coordinates
- Sep 2015.5 = separation in arc seconds calculated from the GAIA DR2 RA/DE J2015.5 coordinates
- PA 2015.5 = position angle in degrees calculated the GAIA DR2 RA/DE J2015.5 coordinates
- M1 and M2 = estimated Vmags derived from GAIA DR2 G/B/R-mags if available (= 3.9379083526304 + 0.269235360436179*Gmag^1.36701081887491 - 0.123879978164097*[Gmag-Rmag] - 0.943379695375539*[Gmag-Bmag]) else as crude averaged estimation Gmag plus 0.318
- pmRA and pmDE = proper motion data for RA and Dec for both components in mas/yr
- Plx = parallax value for both components in mas
- CPM Score = estimated probability for common proper motion according to the used CPM assessment scheme (Appendix A)
- Plx score = estimated probability for assumed gravitational relationship according to the used Plx assessment scheme (Appendix A)
- Notes = Comments regarding the potential match with an existing WDS object

A Catalog of High Proper Motion Stars in the Northern Sky (HPMSNS Catalog)

(Continued from page 45)

leases with a longer time line than currently DR2 will hopefully differentiate between the proper motion of a system and the extra motion due to an orbit.

The extreme case of HPMSNS pair 73207+73206 aka KR 60 AB demonstrates also the limited use of the concept of proper motion as linear vector leading in case of fast orbits probably to wrong calculated J2000 positions then of little use for cross-matching based on J2000 positions.

Another 24 objects were deleted for different reasons with a few of them suggesting the need of changes in the WDS data as given in Table 6.

To avoid reporting pairs already covered in earlier reports so far not published we counterchecked the existence of such cases and ended up with the objects given in Table 7.

Finally this gives then 556 HPMSNS pairs carefully checked for being probably physical pairs to be reported as new discoveries. In Table 8 we list a subset of the data for the first 20 such objects. The full data set is available for download on the JDSO website as "HPMSNS_probably_physical_pairs".

Note regarding J2000 coordinates: These are calculated from the GAIA DR2 J2015.5 positions and proper motion data. In case of extra motion due to orbits or other influences this calculation might give slightly wrong J2000 positions.

159 pairs from the total of 556 objects show some differences in proper motion suggesting a fast orbit.

3.5 Observation history

To provide for each object an observation history we cross-matched the objects reported as probably physicals with the following catalogs: 2MASS, UCAC4, UCAC5, URAT1, USNO-B1, USNO-A2, SDSS DR9, PS1 and GAIA DR1. In average we got 2 additional observations confirming the GAIA DR2 objects but a total of 126 pairs 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 positions over time, especially if a catalog gives positions without proper motion data. 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. 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, UCAC5, URAT1, USNO-A2 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. In Table 9 we give the observation history with the first 20 records as example. The complete list with the observation history is available for download on the JDSO website as "HPMSNS_probably_physical_pairs_observation_history".

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.

4. Summary

This report selects not only the high proper motion stars in the northern sky from GAIA DR2 to extend the LSPM north catalog significantly but checks also for so far ~550 unknown double stars with common proper motion of significant speed and stellar distance small enough to allow for gravitational relationship, which in all probability are newly discovered binaries.

5. Acknowledgements:

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

- Washington Double Star catalog
- GAIA Archive
- GAIA Helpdesk
- GAIA DR2 catalog
- GAIA DR1 catalog
- 2MASS catalog
- UCAC4 catalog
- UCAC5 catalog
- URAT1 catalog
- PS1 catalog
- USNO-B1 catalog
- USNO-A2 catalog
- SDSS DR9 catalog
- LSPM catalog
- 2MASS and DSS images
- Aladin Sky Atlas v9 and 10
- SIMBAD, VizieR, TAP Vizier, X-Match
- AstroPlanner V2.2

(Text continues on page 57)

Table 6: HPMSNS pairs suggesting need of changes in the WDS catalog

HPMSNS ID	WDS	RA 2000	Dec 2000	Sep 2000	PA 2000	Sep 2015.5	PA 2015.5	M1	M2	pmra1	pmdec1	pmra2	pmdec2	Plx1	Plx2	CPM Score	Plx Score	Notes
19807+19806	06119+3326	92.98329071	33.4306951	12.36655	189.97253	12.29820	190.26293	13.3589	17.5636	137.121	-416.819	133.933	-411.771	25.9936	25.7993	80	100	NSN 26 - not included in the WDS match list due to wrong WDS J2000 position
20623+20622	06323+2745	98.0794037	27.75827707	2.10608	264.09075	2.06794	262.64864	15.9601	16.4606	-118.078	-93.33	-115.242	-96.411	25.4872	25.3723	80	100	FMR 198 - not included in the WDS match list due to wrong J2000 position
25999+25998	08317+1924	127.9059715	19.39713461	1.10550	208.05129	0.97260	185.32869	12.2733	12.9649	-233.023	-128.092	-205.322	-127.625	60.1378	62.0284	0	100	PA and Sep suggest match with BEU 12 but this would then be actually Ba;Bb instead of Aa;Ab. DEL 1 Ba;Bb with wrong J2000 position or bogus?

Description of the table content:

- HPMSNS ID = HPMSNS object ID for both components
- WDS = WDS reference to an existing WDS object as potential match
- RA2000 and DE2000 = RA/DE J2000 coordinates of the primary calculated by VizieR from the GAIA DR2 2015.5 coordinates using the proper motion data
- Sep 2000 = separation in arc seconds calculated from the RA/DE J2000 coordinates
- PA 2000 = position angle in degrees calculated the RA/DE J2000 coordinates
- Sep 2015.5 = separation in arc seconds calculated from the GAIA DR2 RA/DE J2015.5 coordinates
- PA 2015.5 = position angle in degrees calculated the GAIA DR2 RA/DE J2015.5 coordinates
- M1 and M2 = Gmags from GAIA DR2
- pmRA and pmDE = proper motion data for RA and Dec for both components in mas/yr
- Plx = parallax value for both components in mas
- CPM Score = estimated probability for common proper motion according to the used CPM assessment scheme (Appendix A)
- Plx score = estimated probability for assumed gravitational relationship according to the used Plx assessment scheme (Appendix A)
- Notes = Comments regarding the potential match with an existing WDS object

Table 7. HPMSNS pairs reported earlier but not yet published (per August 2018)

HPMSNS ID	WDS	RA 2000	Dec 2000	Sep 2015.5	PA 2015.5	M1	M2	pmra1	pmdec1	pmra2	pmdec2	Plx1	Plx2	CPM Score	Plx Score	Notes
06677+06679	01518+2256	27.93856712	22.93235554	15.73973	67.71414	11.3305	14.0525	93.825	-136.777	95.36	-136.666	16.3159	16.5282	100	80	Already reported as KPP1992 in 2126 CPM pairs/Knapp 2018
03696+03695	01022+1009	15.54053597	10.15054428	3.371	284.458	12.3267	12.6121	156.954	16.375	156.704	14.745	18.8597	18.8578	100	100	Already reported as NSN n+2 in LSPM V/ Knapp&Nanson 2018
08925+08926	02302+4201	37.55552948	42.02325836	5.189	72.054	10.8899	13.2486	169.777	-18.547	175.136	-15.448	21.6398	21.2055	32	80	Already reported as NSN n+4 in LSPM V/ Knapp&Nanson 2018
10815+10817	03033+5016	45.82786744	50.26672933	6.983	140.060	15.0559	16.2196	152.923	-80.522	151.992	-80.429	8.1738	8.1139	100	80	Already reported as NSN n+5 in LSPM V/ Knapp&Nanson 2018
13797+13799	03593+5824	59.82394574	58.39532672	7.148	40.686	15.2199	16.9636	114.82	-176.291	115.467	-177.256	14.5533	14.4633	100	80	Already reported as KPP n+6 in LSPM V/ Knapp&Nanson 2018
15764+15763	04393+3907	69.81728222	39.11012469	9.447	235.562	16.0078	17.6285	196.858	13.334	197.582	15.235	8.7026	8.7365	100	80	Already reported as NSN n+6 in LSPM V/ Knapp&Nanson 2018
21562+21564	06535+6046	103.3751011	60.75837481	4.602	131.074	11.0537	14.7299	-49.088	-168.345	-46.049	-166.959	13.7893	13.9068	80	80	Already reported as KPP n+9 in LSPM V/ Knapp&Nanson 2018
24082+24083	07503+4828	117.5703915	48.4736541	9.632	21.949	12.151	20.454	-60.642	-275.824	-60.478	-277.607	15.9961	15.7936	100	80	Already reported as KPP n+11 in LSPM V/ Knapp&Nanson 2018
24580+24579	08015+5759	120.3717182	57.99060115	3.926	277.108	12.4279	14.6815	-51.824	-225.951	-49.837	-223.116	13.5704	13.7213	80	80	Already reported as NSN n+11 in LSPM V/ Knapp&Nanson 2018
40130+40127	12232+0442	185.792314	4.704098848	4.794	233.428	13.3623	16.0494	-168.836	49.305	-165.51	49.538	12.1228	12.1273	80	80	Already reported as NSN n+17 in LSPM V/ Knapp&Nanson 2018
41168+41164	12375+2953	189.3636664	29.87878605	9.539	263.698	12.6063	16.5728	-156.522	-98.488	-156.454	-101.992	20.2136	20.3165	100	100	Already reported as NSN n+18 in LSPM V/ Knapp&Nanson 2018
45032+45033	13284+3545	202.0978488	35.75692641	2.952	101.048	14.1688	14.3916	-185.607	-36.049	-176.512	-44.006	36.3644	35.2707	0	80	Already reported as NSN n+20 in LSPM V/ Knapp&Nanson 2018
45643+45644	13375+1613	204.3768885	16.21996575	4.504	44.518	13.8466	17.865	-189.304	-42.716	-193.352	-41.53	13.6087	13.6308	80	80	Already reported as KPP n+21 in LSPM V/ Knapp&Nanson 2018
52225+52224	15184+5149	229.6106234	51.81411061	4.605	274.081	14.4372	16.0897	56.438	-184.496	56.211	-185.148	5.2414	5.215	100	80	Already reported as NSN n+22 in LSPM V/ Knapp&Nanson 2018
52518+52519	15232+1614	230.7926527	16.22559492	17.213	44.075	14.6904	18.1684	-184.108	44.737	-185.084	45.336	14.6888	14.7754	100	80	Already reported as NSN n+23 in LSPM V/ Knapp&Nanson 2018
55569+55567	16165+7457	244.1310996	74.94373427	4.353	254.365	11.2158	15.3453	-143.613	68.608	-143.455	71.201	13.7596	13.6955	100	100	Already reported as KPP n+25 in LSPM V/ Knapp&Nanson 2018
56688+56685	16377+3712	249.4357752	37.19951398	23.448	238.713	12.3843	16.3269	-163.585	51.066	-163.315	51.309	11.0302	10.954	97	80	Already reported as NSN n+25 in LSPM V/ Knapp&Nanson 2018
57351+57352	16510+2747	252.7431867	27.78993587	20.997	44.199	14.3443	18.7202	-123.021	120.74	-123.797	121.525	13.632	13.4713	97	80	Already reported as NSN n+26 in LSPM V/ Knapp&Nanson 2018
61177+61178	18140+3853	273.5106782	38.88197048	6.582	124.407	10.0554	14.9999	-44.327	161.361	-52.043	161.277	21.6928	21.7848	16	100	Already reported as NSN n+28 in LSPM V/ Knapp&Nanson 2018
63163+63165	19005+0552	285.1145175	5.860456567	17.291	26.251	13.8734	14.4487	76.109	-190.646	72.997	-191.868	16.6554	16.5896	100	80	Already reported as NSN n+29 in LSPM V/ Knapp&Nanson 2018
64201+64199	19224+0454	290.5936274	4.907803106	10.179	189.492	13.3455	17.5122	-197.163	84.332	-196.648	87.906	21.3813	21.5147	100	100	Already reported as KPP n+30 in LSPM V/ Knapp&Nanson 2018
69254+69250	21080+3116	317.0081564	31.27012206	7.646	221.772	13.631	16.4375	254.739	134.614	257.06	135.019	19.3703	19.3971	100	100	Already reported as NSN n+35 in LSPM V/ Knapp&Nanson 2018

Table 7 concludes on the next page.

Table 7 (conclusion). HPMSNS pairs reported earlier but not yet published (per August 2018)

HPMSNS ID	WDS	RA 2000	Dec 2000	Sep 2015.5	PA 2015.5	M1	M2	pmra1	pmdec1	pmra2	pmdec2	Plx1	Plx2	CPM Score	Plx Score	Notes
70010+70008	21237+4419	320.9310348	44.32443795	17.241	230.751	13.9968	16.4701	124.954	189.639	124.437	189.46	7.4187	7.398	100	80	Already reported as KPP n+37 in LSPM V/ Knapp&Nanson 2018
70517+70516	21342+2804	323.546947	28.0630521	4.130	275.567	15.2742	15.9655	-122.154	-109.625	-122.53	-111.913	13.5828	13.508	80	80	Already reported as NSN n+37 in LSPM V/ Knapp&Nanson 2018
71386+71385	21524+2823	328.0882388	28.37806322	5.101	285.434	14.269	14.373	196.572	59.793	196.896	61.781	19.9334	19.7382	100	100	Already reported as NSN n+39 in LSPM V/ Knapp&Nanson 2018
71845+71844	22016+4528	330.3905973	45.46304397	7.901	293.107	10.9013	15.0162	143.66	104.372	144.656	102.725	9.6184	9.5841	100	80	Already reported as KPP n+40 in LSPM V/ Knapp&Nanson 2018
73388+73389	22314+3811	337.8555423	38.1757409	6.247	22.615	15.3563	15.8762	-170.646	-115.841	-172.329	-116.216	10.4413	10.3997	100	80	Already reported as KPP n+41 in LSPM V/ Knapp&Nanson 2018
73908+73906	22411+3909	340.2745185	39.14632923	19.872	315.984	14.0685	17.4484	229.79	148.884	228.201	147.53	18.205	18.2567	100	100	Already reported as NSN n+41 in LSPM V/ Knapp&Nanson 2018
76470+76467	23284+4742	352.088941	47.69562036	11.305	236.245	13.9621	17.0204	169.576	-22.138	169.701	-22.257	18.6099	18.633	100	100	Already reported as NSN n+44 in LSPM V/ Knapp&Nanson 2018

Description of the table content:

- HPMSNS ID = HPMSNS object ID for both components
- WDS = calculated WDS ID for an already reported object
- RA2000 and DE2000 = RA/DE J2000 coordinates of the primary calculated by VizieR from the GAIA DR2 2015.5 coordinates using the proper motion data
- Sep 2015.5 = separation in arc seconds calculated from the GAIA DR2 RA/DE J2015.5 coordinates
- PA 2015.5 = position angle in degrees calculated the GAIA DR2 RA/DE J2015.5 coordinates
- M1 and M2 = Gmags from GAIA DR2
- pmRA and pmDE = proper motion data for RA and Dec for both components in mas/yr
- Plx = parallax value for both components in mas
- CPM Score = estimated probability for common proper motion according to the used CPM assessment scheme (Appendix A)
- Plx score = estimated probability for assumed gravitational relationship according to the used Plx assessment scheme (Appendix A)
- Notes = Comments regarding the match with an already reported but not yet published physical pair

Table 8: Probably physical pairs in the HPMSNS catalog

HPMSNS ID	Disc	RA 2000	DE 2000	Sep 2015.5	PA 2015.5	Mag A	Mag B	pmRA A	pmRA B	pmDE A	pmDE B	Plx A	Plx B	CPM Score	Plx Score
00126+00128	KPP n+1	0.51565748	4.13686413	1.90475	62.37498	14.717	14.804	195.551	-205.732	196.633	-203.087	25.4658	25.4919	100	100
00184+00185	NSN n+1	0.81077094	74.7803814	17.82031	4.13202	16.197	20.555	155.119	27.154	155.894	26.512	9.3211	9.2624	97	80
00296+00297	KPP n+2	1.37021009	22.2244948	3.63998	117.15129	9.622	13.515	169.496	-74.265	166.835	-73.759	21.2364	20.9312	80	80
00560+00559	NSN n+2	2.47320422	53.0205906	2.32788	351.10774	13.395	16.477	248.854	30.114	247.276	32.231	15.6319	15.7098	100	100
00697+00696	KPP n+3	3.01490445	11.6120547	3.20022	227.33686	12.282	16.225	171.969	-3.278	173.855	-3.788	7.1457	7.1038	80	80
00715+00714	NSN n+3	3.07809521	57.0281058	1.50375	190.06546	17.428	17.004	207.022	61.039	207.483	62.246	11.4442	11.3364	100	80
00770+00773	KPP n+4	3.26511456	51.194979	13.31554	99.45443	17.999	19.650	228.025	-20.464	228.42	-21.27	10.5754	10.4912	100	80
00954+00953	NSN n+4	4.07069063	41.3821926	1.32207	253.01316	13.398	16.646	177.116	111.122	182.201	110.676	20.2467	20.342	80	80
01281+01282	KPP n+5	5.3770111	5.52923383	2.76203	80.02556	15.763	16.007	118.402	-94.054	119.179	-98.243	19.5583	19.643	32	100
01368+01369	NSN n+5	5.79662829	12.5547688	1.16865	1.76614	13.248	13.721	-129.646	-177.998	-123.898	-170.349	26.1131	25.5697	5	80
01486+01487	KPP n+6	6.22096943	40.0187419	1.89027	136.73883	13.280	14.430	179.28	40.442	178.409	35.154	17.9076	17.9603	64	100
01798+01797	NSN n+6	7.46807917	58.7641333	1.13141	219.33825	13.416	14.013	-34.343	-160.385	-34.494	-160.209	17.4954	17.4951	100	100
01824+01823	KPP n+7	7.5959379	11.0906284	3.71652	250.60893	15.689	15.711	148.535	62.568	149.81	64.479	14.6531	14.5852	80	100
01860+01861	NSN n+7	7.7432604	25.85295	1.03364	6.63311	13.042	14.755	-77.061	-226.558	-67.228	-234.135	22.6218	22.3636	16	100
02076+02075	KPP n+8	8.62379659	47.915542	3.43484	323.25953	8.206	13.252	396.44	60.538	410.44	54.486	20.9305	20.8066	4	100
02380+02379	NSN n+8	9.91763879	21.8887289	2.40230	207.55904	11.937	15.240	203.369	-60.054	209.332	-64.18	20.5563	20.3091	5	100
02621+02622	KPP n+9	11.0080366	7.15829612	1.27338	166.04208	15.314	15.420	116.092	-119.8	116.827	-121.962	5.9136	5.9212	80	80
02769+02770	NSN n+9	11.4878184	52.4731566	1.50222	49.92719	15.277	15.419	209.581	-70.552	210.121	-69.084	9.2659	9.3467	100	80
02791+02789	KPP n+10	11.5740679	18.2447328	5.20576	271.52128	11.538	17.994	195.784	-65.11	194.715	-71.628	10.7705	10.7687	80	80
02883+02882	NSN n+10	11.9784492	20.9253454	30.14371	197.69267	7.551	15.413	158.424	13.834	158.59	12.942	15.7838	16.0013	97	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:

- HPMSNS ID = HPMSNS object ID for both components
- Disc = discoverer code KPP+/NSN+ running number
- RA and Dec = GAIA DR2 RA/DE coordinates of the primary for epoch 2000
- Sep = separation in arc seconds for epoch 2015.5
- PA = position angle in degrees for epoch 2015.5
- M1 and M2 = estimated Vmags in most cases derived from GAIA DR2 green, blue and red magnitudes iv available, else as rough average estimation from Gmag +0.318
- 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

Table 9: Probably physical pairs in the HPMSNS catalog - observation history

HPMSNS ID	Disc	RA	DE	Sep	PA	M1	M2	pmRA1	pmDE1	e_pm1	pmRA2	pmDE2	e_pm2	Date	Notes
00126+00128	KPP n+1	0.516501633	4.135978337	1.90475	62.375	14.717	14.804	195.551	-205.732	0.141	196.633	-203.087	0.161	2015.50000	GAIA DR2. M1 and M2 are estimated Vmags
00184+00185	NSN n+1	0.810811000	74.780388000	17.78689	4.126	11.397	13.957							2000.53903	2MASS. M1 and M2 are K-band
00184+00185	NSN n+1	0.813152760	74.780491190	17.83268	4.274	16.903	21.358							2011.86332	Pan-STARRS release 1 (PS1) Survey. M1 and M2 are PS1 gmags
00184+00185	NSN n+1	0.812972200	74.780482800	17.87503	4.255			158.900	26.600	6.300	160.100	32.700	6.500	2013.49000	URAT1. M1 and M2 are Vmags
00184+00185	NSN n+1	0.813232814	74.780494680	17.81958	4.125	14.897	14.897							2015.00000	GAIA DR1. M1 and M2 are Gmags
00184+00185	NSN n+1	0.813315040	74.780498340	17.82031	4.132	16.197	20.555	155.119	27.154	0.112	155.894	26.512	0.530	2015.50000	GAIA DR2. M1 and M2 are estimated Vmags
00296+00297	KPP n+2	1.370688000	22.224230000	3.53037	110.848	9.481	25.114							2009.79380	SDSS DR9. M1 and M1 are gmags
00296+00297	KPP n+2	1.370885300	22.224195140	3.90937	115.802	9.584								2012.69334	Pan-STARRS release 1 (PS1) Survey. M1 and M2 are PS1 gmags
00296+00297	KPP n+2	1.370998432	22.224175080	3.63998	117.151	9.622	13.515	169.496	-74.265	0.103	166.835	-73.759	0.199	2015.50000	GAIA DR2. M1 and M2 are estimated Vmags
00560+00559	NSN n+2	2.474893760	53.020709320	2.31821	349.641	14.020								2013.45211	Pan-STARRS release 1 (PS1) Survey. M1 and M2 are PS1 gmags
00560+00559	NSN n+2	2.474985417	53.020720300	2.32788	351.108	13.395	16.477	248.854	30.114	0.051	247.276	32.231	0.139	2015.50000	GAIA DR2. M1 and M2 are estimated Vmags
00697+00696	KPP n+3	3.015291000	11.612016000	3.03951	227.353	12.863	17.186							2008.82770	SDSS DR9. M1 and M1 are gmags
00697+00696	KPP n+3	3.015448020	11.612047610	3.09657	225.526	12.823								2011.48203	Pan-STARRS release 1 (PS1) Survey. M1 and M2 are PS1 gmags
00697+00696	KPP n+3	3.015660343	11.612040560	3.20022	227.337	12.282	16.225	171.969	-3.278	0.143	173.855	-3.788	0.279	2015.50000	GAIA DR2. M1 and M2 are estimated Vmags
00715+00714	NSN n+3	3.079733021	57.028368610	1.50375	190.065	17.428	17.004	207.022	61.039	0.139	207.483	62.246	0.198	2015.50000	GAIA DR2. M1 and M2 are estimated Vmags
00770+00773	KPP n+4	3.260028000	51.193942000	12.71000	101.983	12.100	13.700							1953.75100	USNO A2. M1 and M2 are Rmags
00770+00773	KPP n+4	3.270353000	51.194448000	13.99738	98.132						18.000	20.000	3.606	1987.50000	USNO-B1. M1 and M2 are Imags
00770+00773	KPP n+4	3.266591270	51.194897690	13.38735	99.453	18.674	19.755							2012.52802	Pan-STARRS release 1 (PS1) Survey. M1 and M2 are PS1 gmags
00770+00773	KPP n+4	3.266630866	51.194893760	13.31520	99.452	16.443	16.443							2015.00000	GAIA DR1. M1 and M2 are Gmags
00770+00773	KPP n+4	3.266681214	51.194890940	13.31554	99.454	17.999	19.650	228.025	-20.464	0.146	228.420	-21.270	0.649	2015.50000	GAIA DR2. M1 and M2 are estimated Vmags

Description of the table content:

- HPMSNS ID = HPMSNS ID for both components
- Disc = Discoverer code KPP/NSN (in all cases with components AB)
- RA = RA primary
- DE = Dec primary
- Sep = Separation in arcseconds
- PA = Position angle in degrees
- M1 = Mag primary. Content depending on available catalog data
- M2 = Mag secondary. Content depending on available catalog data
- pmRA1 = Proper motion RA primary in mas/yr
- pmDE1 = Proper motion Dec primary in mas/yr
- e_pm1 = Error proper motion primary
- pmRA2 = Proper motion RA secondary in mas/yr
- pmDE2 = Proper motion Dec secondary in mas/yr
- e_pm2 = Error proper motion secondary
- Date = Averaged observation date
- Notes = Reference to catalog used and comments

A Catalog of High Proper Motion Stars in the Northern Sky (HPMSNS Catalog)

(Continued from page 51)

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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):

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