Reliability of UCAC5 Proper Motion Data for Common Proper Motion Assessment of Double Stars

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Abstract: Proper motion data should be as reliable as possible to be of use for common proper motion assessment of double stars. The UCAC5 catalog was created to deliver just that. Intensive use of this catalog for this purpose (see Knapp and Bryant 2018) raised some doubts about the overall UCAC5 proper motion data quality and led to a detailed examination of this proposition with some surprising and interesting results which we present in this report.

1. Introduction

The most reliable proper motion data with the smallest error range is currently (as of November 2017) to be found in the GAIA DR1/TGAS catalog. But the TGAS subset of GAIA DR1 covers only about 2 million stars so it rarely includes both components of pairs to be checked for common proper motion. The next reliable source of precise proper motion data is the UCAC5 catalog containing proper motion data for more than 100 million stars. UCAC5 is based on a re-reduction of the UCAC images using the TGAS objects as reference stars to determine UCAC5 object positions. Proper motion data is then gained by comparing the UCAC5 positions with those in the GAIA DR1 catalog. The description of the UCAC5 catalog (Zacharias et al. 2017) indicates typical proper motion errors about 1-2 mas/yr for objects with Rmag between 11 and 15 and about 5mas/yr for objects with Rmag 15 to 16. Yet many of the UCAC5 objects have far larger proper motion error values (see Knapp and Bryant 2018) – good reason to have a closer look, as the comparison of 2MASS to GAIA DR1 positions might be a better alternative offering a typical proper motion error of less than 6mas/yr in RA and Dec.

2. Results

The UCAC5 catalog contains 107,758,513 rows providing the following data for each object:

- J2000 coordinates for the UCAC5 positions with UCAC observation date.
- J2000 coordinates for the GAIA DR1 positions at observation date 2015.0 with GAIA ID and GAIA position errors given as well.
- RA and Dec proper motion data with error range.
- Number of UCAC images used for mean position.
- TGAS/NOMAD flag.
- G-band magnitude (Gmag) from the matched GAIA DR1 object.
- Mean UCAC model magnitude (Umag).
- J/H/K-band magnitudes (J/H/Kmag) from the matched 2MASS objects.
- R-band magnitude (Rmag) from the matched NOMAD objects.

A detailed examination of UCAC5 catalog objects based on several samples drawn by different criteria using the CDS TAP VizieR and X-Match services, as well as our own programs using the full UCAC5 catalog, led to the following results which can easily be reproduced by using the above mentioned tools.

2.1 UCAC5 data completeness:

- Coordinates, proper motion data with error range, Gmag and Umag are given for all UCAC5 objects.
- Nearly 9% of the UCAC5 objects are listed without J/H/Kmag data. While a few 2MASS objects lack one of these magnitude values, there is no 2MASS object with all 3 missing so this indicates that there is no 2MASS match for these UCAC5 objects. Additionally, about 2% of the UCAC5 objects are listed with J/H/Kmag values of 30 while no such values are to be found in 2MASS, so these objects also do not have corresponding 2MASS matches. As the 2MASS catalog contains more than four times the number of objects in the UCAC5 catalog, it seems a bit surprising that about 11% of the UCAC5 objects should miss corresponding 2MASS objects even if the UCAC images record blue stars while the 2MASS images do not.
- About 15% of the UCAC5 objects are listed without a valid Rband magnitude, either based on matched NOMAD objects with Rmag missing (indicated by Rmag 30 in UCAC5) or due to a missing NOMAD match (indicated by a blank Rmag in UCAC5).
- No position error is given for the UCAC5 observation epoch coordinates. This is most surprising as other contemporary star catalogs include by default position error data. But this gap is easily filled by using the UCAC5's proper motion error data multiplied by the time span between UCAC and GAIA observation epoch. Perhaps this is why position errors are not given explicitly.

2.2 UCAC5 position and proper motion error:

- The mean UCAC5 position error calculated by multiplying the proper motion error by the delta time between the observation epochs of UCAC5 given per object and the overall GAIA DR1 observation epoch 2015.0 is (based on a sample of 213,496 objects with RA 179-180 degrees) about 83.5mas in RA and 81.1mas in Dec. These values are at best comparable to the typical 60/60mas position error of 2MASS and over 40% of the UCAC5 objects have position errors larger than 60 mas in RA or Dec. Compared with URAT1 (Zacharias et al. 2015) with a positional precision of about 30 mas (for a similar sample limited to the northern sky) such values seem not overly impressive. Additionally the spread is huge as the UCAC5 position error values go up to incredible 1,495 mas in RA and 1,444 mas in Dec.
- The mean UCAC5 proper motion error is (based on the same sample) about 5.2 mas/yr in RA and 5 mas/yr in Dec. This confirms the precision claim of the UCAC5 description even without the restriction regarding magnitudes, but again the spread is huge with up to 103.1 mas/yr in RA and 99.6 mas/yr in Dec.
- The large spread of these numbers indicates a serious issue with a large part of the UCAC5 position data and suggests further investigations, even if such extreme cases are to some degree to be expected when handling millions of stars in an automatic way.

2.3 UCAC5 proper motion error and magnitude:

The UCAC5 documentation indicates, with reference to the image material used to generate the catalog, a relationship between Rband magnitudes and proper motion data error. This was counter-checked using the same UCAC5 object sample as above:

- For Rmag 11 to 15, the average proper motion error is less than 2mas/yr in RA and Dec but with a spread of up to 41.6 mas/yr in RA and Dec. For Rmag 15 to 16, the average proper motion is about 5 mas/yr with a spread of up to 46 mas/yr in RA and Dec. For Rmag 16, and fainter the average proper motion error is about 9.2 mas/yr in RA and 8.8 mas/yr in Dec.
- As Rmag is not given for all UCAC5 objects (see paragraph 2.1) a statistic based on Gmag might be of more interest. In Table 1, all of the UCAC5 stars are binned by their Gmag values. For each bin, we list the percentage of stars in that bin, the average proper motion error vector (e_pm) and the standard deviation of that average for the members of that bin. Please note that the proper motion error vectors are calculated as:

$$e\_pm = \sqrt{e\_pmDec^2 + e\_pmRA^2}$$

This distribution shown in Figure 1 corresponds to the statement in the UCAC5 catalog description (Zacharias et al. 2017) that the proper motion data error increases exponentially with the faintness of stars. The given standard deviation is not a perfect measure of the e_pm spread as this is not a symmetrical distribution, but indicates the increasing spread of the given proper motion error data for objects brighter than 15Gmag. As over 50% of the UCAC5 objects are fainter than 15Gmag, we recognize that the proper motions of these faint UCAC5 objects are rather uncertain. This shows that Gmag offers a better discrimination in terms of average proper motion error than Rmag.

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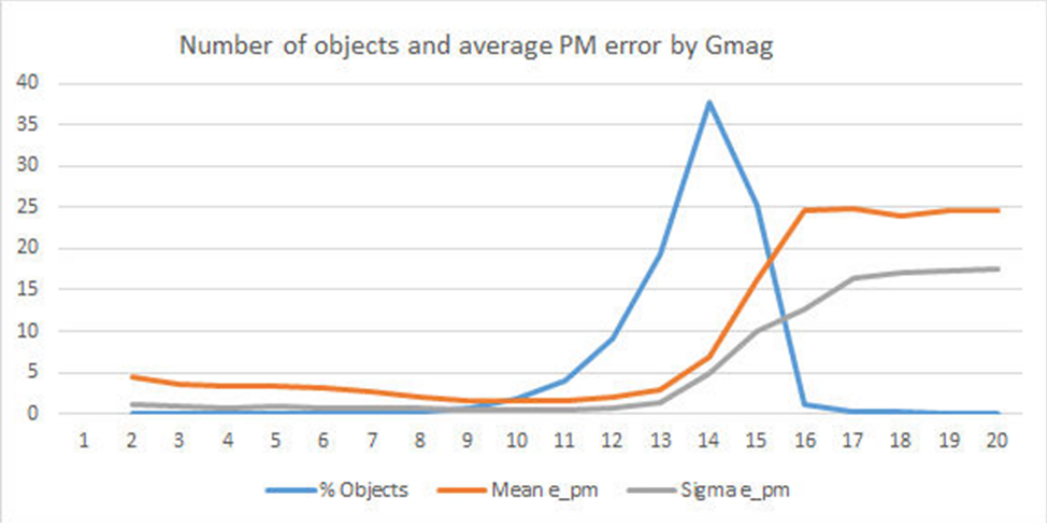
Table 1: UCAC5 objects statistic e_pm by Gmag

Gmag Bin	Star Cnt	% Objects	Mean e_pm	Sigma e_pm
3	22	0.00	4.4323	1.0676
4	300	0.00	3.6063	0.8767
5	1,822	0.00	3.4375	0.7273
6	13,315	0.01	3.3593	0.9100
7	40,929	0.04	3.1428	0.7714
8	116,118	0.11	2.5731	0.6717
9	311,841	0.29	2.0622	0.7024
10	783,954	0.73	1.5869	0.4394
11	1,947,321	1.81	1.5651	0.3761
12	4,425,735	4.11	1.6226	0.3924
13	9,809,189	9.10	1.9193	0.5975
14	20,721,174	19.23	2.9787	1.3616
15	40,581,837	37.66	6.8781	4.8012
16	27,219,714	25.26	16.233	10.054
17	1,245,923	1.16	24.723	12.727
18	213,350	0.20	24.844	16.318
19	205,902	0.19	24.043	17.184
20	118,807	0.11	24.533	17.418
21	1,258	0.00	24.737	17.503



X-axis: Percentage of objects (blue), average proper motion error (orange) with standard deviation (grey)
Y-axis: Gmag

Figure 1. Average proper motion error with increasing Gmag

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2.4 UCAC5 positions compared with 2MASS positions:

The 2MASS positions are within the given position error range considered as reliable – at least thus far we have found no reason to question this, and we shared this assessment with the USNO. For example, the proper motion data of URAT1 is based on the comparison between URAT1 and 2MASS positions. The UCAC5 observation epoch positions should be close to 2MASS positions, because the observation epoch delta is only a few years. Below are listed the results of the cross-match of the UCAC5 sample within RA179-180 degrees with 2MASS with a search radius of 2 arcseconds:

- Of 213,496 UCAC5 objects in the sample, 209,830 were matched with 2MASS objects based on the given observation epoch positions within a search radius of 2 arcseconds. This means that with the exception of a few objects with extremely fast proper motion speed (> 500 mas/yr) only about 2% of the UCAC5 objects probably do not have a corresponding 2MASS object – this rather small number of missing matches might be explained by the fact that UCAC images cover blue stars which 2MASS images do not. To show that the UCAC5 and 2MASS objects were identical, the given J- and K-band magnitudes from both catalogs were compared and, if identical, the match was considered to be confirmed. This step reduced the number of matched objects to 188,383. Besides the unavoidable mis-matches in dense star fields or with close double stars, the eliminated objects were mostly UCAC5 objects with missing J/K-mags or J/K-mags of 30.
- A closer look at these "missing" objects offered a surprise: More than 90% are rather close UCAC5/2MASS matches within 0.5 arcseconds with valid J/H/K-band magnitudes, confirming the impression that the UCAC5/2MASS matching process was not a complete one. This is not necessarily an indication of a general data quality problem, as a complete match with 2MASS is not claimed by UCAC5. But we also noticed that nearly all of these objects are in the southern sky, which indicates a systematic bias.
- Looking for another potential systematic bias, we checked the direction of the position difference between 2MASS and UCAC5 but found no preferred direction.
- Calculating an overall position difference vector as

$$\sqrt{e\_Pos\_M^2 + e\_Pos\_U^2 + PM^2 + e\_PM^2}$$

with *e_Pos_M* for the 2MASS position error vector, *e_Pos_U* for the UCAC5 position error vector, *PM* for the UCAC5 proper motion vector, and *e_PM* for the UCAC5 proper motion error vector (for the time span between the 2MASS and UCAC5 observation epochs) and comparing this value with the effective position distance gives about 36% UCAC5 positions outside this range. Even when taking the worst case with all these values simply

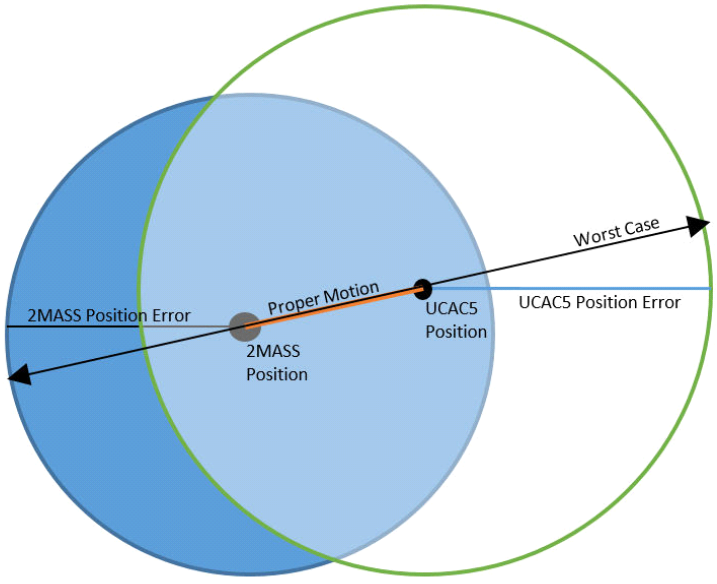
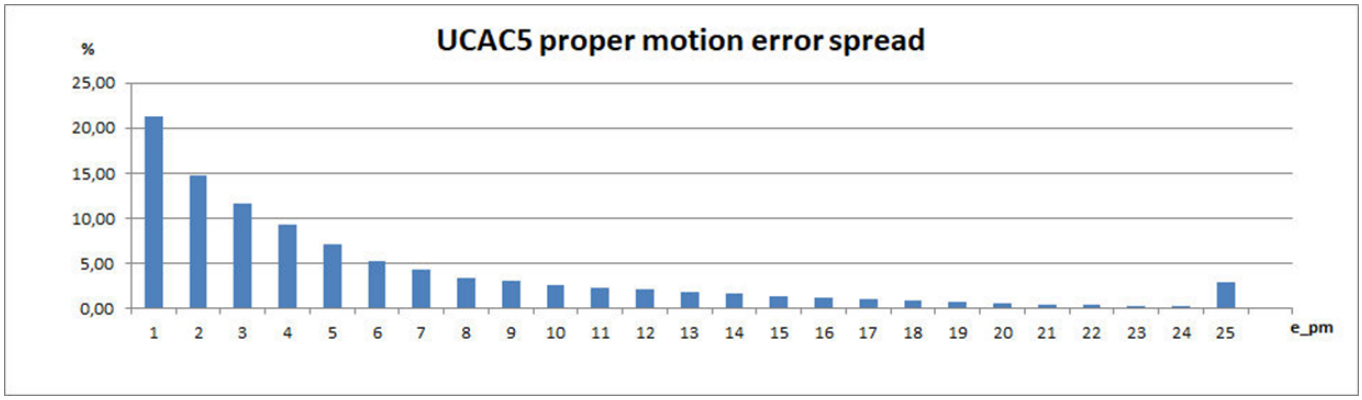


Image 2: Worst Case 2MASS to UCAC5 Position Difference



X-axis: Percentage of objects per e_pm step
Y-axis: Proper motion error in steps of 1mas/yr (with exception of 25 meaning >25mas/yr)

Figure 3. Percentage of UCAC5 objects by proper motion error

added up (see Figure 2) then still about 14% of the UCAC5 positions data are outside this range.

This result suggests that even the given large proper motion errors are in many cases not sufficient to explain the difference between UCAC5 and 2MASS positions.

As already mentioned standard deviation is not well suited to represent the large spread in the UCAC5 proper motion error values. Figure 3 gives the percentage of UCAC5 objects grouped by e_pm values.

2.5 Reliability check of UCAC5 objects with small proper motion errors:

If we adopt the idea that the UCAC5 objects with very small proper motion errors should be considered to be reliable, then this proposition should be checked explicitly.

We selected from the same sample used above the objects with a proper motion error vector of up to 1.414 mas/yr (corresponds with e_pmRA < 1 and e_pmDec < 1) and got a total 14,268 such objects and applied the same worst case scenario error window. The result was positive for about 88% of the objects. This means that about 12% of these objects showed a position difference larger than the worst case upper limit. While this is slightly better than for the overall sample, this confirms the caveats about the reliability of the UCAC5 proper motion data even for the objects with a very small UCAC5 position error. The precise answer to this question will probably have to wait for the upcoming GAIA DR2 release.

2.6 Comparison of UCAC5 to TGAS:

If the minimum quality benchmark for UCAC5 proper motion data is the comparison of 2MASS to GAIA DR1 positions with a typical proper motion error range of about 6mas/yr in RA as well as Dec then the best case quality benchmark for UCAC5 proper motion data might be TGAS, which was used as the basis for UCAC5 plate solving. UCAC5 might not be expected to be better than TGAS, but it might well be expected to not be much worse. For this reason, we compared TGAS proper motion data with UCAC5 proper motion data for a random sample of 120 TGAS objects with the following results:

- We checked these objects to verify that all proper motion values are within the combined TGAS and UCAC5 error range. This is the case for both RA and Dec for 91 objects, but for 24 objects either the pmRA or pmDec value is outside the error range and for 5 objects both pmRA and pmDec values are outside the error range. While not perfect this seems to be acceptable – but there are several objects with unexpectedly large proper motion error values.
- Next step is a kind of ”Gedankenexperiment” with the TGAS and UCAC5 objects considered as components of a double star being checked for common proper motion indicated by identical proper motion speed in the same direction using the CPM assessment scheme, according to Knapp and Nanson 2017. From the 120 objects there are:
  - ◊ 17 undecidable due to the relation to pm error values with very small pm values (sum of e_pm vectors greater than 30% of the sum of the pm vectors)
  - ◊ 28 identical within the error range in speed and direction
  - ◊ 17 identical in direction within the error range and identical in speed within twice the error range or the other way around

- ◊ 7 identical in direction and speed within twice the error range
- ◊ 39 either in speed or direction or both outside twice the error range
- ◊ 12 in speed and direction outside triple the error range.

This means that less than 50% of the objects would, with the given TGAS and UCAC5 proper motion values, qualify as "common proper motion pairs". To give a visual impression of a typical difference, we took an Aladin screenshot of GAIA ID 427793757888822656 (certainly not the worst case) with TGAS and UCAC5 catalog overlay with the proper motion vectors added, see Figure 4.

A table with the data of all 120 objects comparing UCAC5 and TGAS proper motion data is given in the Appendix.

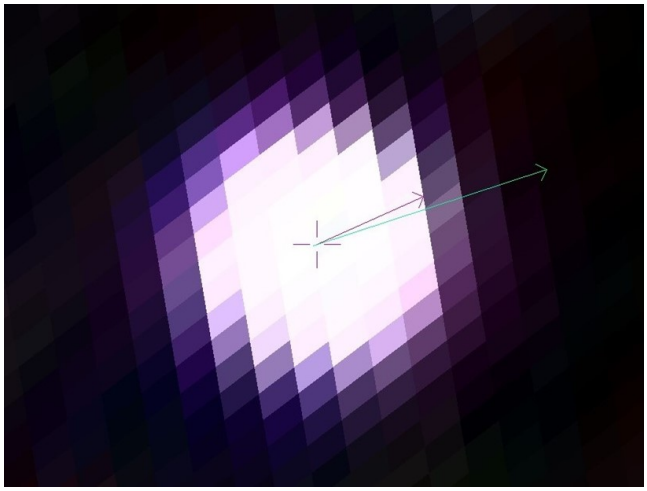


Figure 4. Different UCAC5 and TGAS proper motion vectors for GAIA ID 427793757888822656

3. Summary

- About 11,000,000 out of 107,758,513 UCAC5 objects are listed without J/H/K-band magnitudes, rendering the quality of the matching process between UCAC5 and 2MASS as incomplete because a good part of these 11 million stars have a corresponding 2MASS object. As already mentioned this does not necessarily indicate an overall data quality issue for these objects.
- About 2/3 of the UCAC5 objects are fainter than Gmag 15 with an increased risk that the proper motion data listed for such objects might be questionable. The user of such data has to be aware that proper motions of faint stars in UCAC5 have been given for completeness - at the price that errors are unavoidable.
- About 1/3 of the UCAC5 objects are listed with the small proper motion error range of 1-2 mas/yr with the caveat that at least 12% of these objects show an unexpected large position difference to their 2MASS counterparts.
- The comparison of proper motion data from UCAC5 with TGAS is not very favorable as only 50% of the checked objects would qualify as common proper motion pairs.
- Overall we conclude that UCAC5 is a valuable source for common proper motion assessment, but users must be aware of its limitations. Especially when they are using it to assess faint double star components with UCAC5 e_pm values larger than 6mas/yr. A counter-check with data from other catalogs (e.g. URAT1 or 2MASS to GAIA DR1 position comparison) is to be recommended.

Overall conclusion: Never trust a single source, especially not without carefully checking the catalog description for potential caveats and certainly not without taking the catalog's error data seriously.

4. Acknowledgements

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

- Washington Double Star Catalog as data source for the selected objects
- UCAC5 catalog
- GAIA DR1 catalog
- 2MASS catalog
- NOMAD catalog
- URAT1 catalog
- Aladin Sky Atlas v8.0 for counterchecks
- 2MASS All Sky Survey Images for counterchecks
- VizieR and TAP VizieR

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5. References

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Zacharias, N., Finch, C., Subasavage, J., Bredthauer, G., Crockett, C., Divittorio, M., Furguson, E., Harris, F., Harris, H., Henden, A., Kilian, C., Munn, J., Rafferty, T., Rhodes, A., Schultheiss, M., Tilleman, T., and, Wieder, G., 2015, "The First U.S. Naval Observatory Astrometric Robotic Telescope Catalog (URAT1)", *The Astronomical Journal*, **150** (4).

Appendix

To give a full impression of the TGAS to UCAC5 comparison Table 3 with the data for all by random selected objects is presented beginning on the next page.

Column description:

- SrcID = GAIA ID of the object
- RA/Dec = GAIA position in degrees for the primary
- pmRA/DE = Proper motion data RA and Dec
- e_pmRA/DE = Proper motion error RA and Dec
- PMVD° = Proper motion vector direction in degrees
- Δ PMVD° = Delta proper motion direction between UCAC5 and TGAS
- PMVL = Proper motion vector length
- Δ PMVL = Delta proper motion vector length between UCAC5 and TGAS
- "CPM" Rat = "Common proper motion" rating according to Knapp and Nanson 2017

Table 3: Proper motion data comparison between TGAS and UCAC5 (random sample)

SrcID	RA	Dec	UCAC5 pmRA	UCAC5 e_pmRA	TGAS pmra	TGAS e_pmra	UCAC5 pmDE	UCAC5 e_pmDE	TGAS pmdec	TGAS e_pmdec	PMVD° UCAC5	PMVD° TGAS	Δ PMVD°	PMVL UCAC5	PMVL TGAS	Δ PMVL	"CPM" Rat
47028166345142840 32	10.0005581	-68.8608347	66.70	0.90	67.154	0.734	33.30	0.90	33.87	0.64	63.47	63.24	0.23	74.55	75.21	0.66	AA
49280408712263973 12	20.0000761	-50.1227611	-4.60	0.80	-4.032	0.461	-34.70	0.80	-34.11	1.02	187.55	186.74	0.81	35.00	34.35	0.66	AA
49678263215202329 60	30.0027453	-37.2968256	110.50	0.90	109.936	0.384	35.50	0.90	35.65	0.47	72.19	72.03	0.16	116.06	115.57	0.49	AA
50697830383306677 76	40.0025506	-26.768105	91.30	1.10	90.471	0.751	2.00	1.10	2.22	0.65	88.75	88.60	0.15	91.32	90.50	0.82	AA
51000757519071600 64	50.0026239	-20.8531506	0.60	1.20	0.180	0.728	-111.30	1.20	-111.45	1.07	179.69	179.91	0.22	111.30	111.45	0.15	AA
61370004977732157 44	200.0012236	-42.49517	-57.80	0.90	-57.424	1.818	-32.70	0.90	-31.99	0.59	240.50	240.88	0.38	66.41	65.73	0.68	AA
61894569605825073 92	200.0003853	-27.0682181	-42.60	0.90	-43.443	1.373	-4.10	0.90	-4.18	0.38	264.50	264.50	0.00	42.80	43.64	0.85	AA
65493423033571905 28	350.0004989	-37.7000681	32.70	1.10	32.336	0.681	-29.00	1.10	-29.27	0.61	131.57	132.15	0.58	43.71	43.61	0.09	AA
67892691064763809 28	320.0004925	-29.3491658	51.80	1.80	53.733	0.062	26.70	1.70	26.68	0.04	62.73	63.59	0.86	58.28	59.99	1.72	AA
786314022619247 36	30.0022294	15.8775467	11.80	1.20	12.167	1.019	-12.40	1.20	-11.72	0.34	136.42	133.92	2.50	17.12	16.89	0.23	AA
39848242715861171 2	20.0017647	47.3089628	31.40	1.50	31.846	0.583	-17.00	1.50	-16.85	0.50	118.43	117.89	0.54	35.71	36.03	0.32	AA
18592675998592691 20	310.0007075	30.2885678	-6.90	1.10	-6.454	0.647	-19.60	1.10	-20.06	0.97	199.39	197.84	1.56	20.78	21.07	0.29	AA
19181619437686008 32	350.0023247	40.2764922	-24.20	1.10	-24.832	0.800	9.70	1.10	10.17	0.34	291.84	292.27	0.43	26.07	26.83	0.76	AA
23817189322569879 04	350.0011653	-24.3803328	-17.90	1.00	-17.838	1.019	-12.50	1.00	-12.54	0.66	235.07	234.90	0.18	21.83	21.80	0.03	AA
24229282157491654 40	0.0010767	-9.8565461	-11.50	1.00	-11.350	1.384	-17.70	1.00	-16.97	0.72	213.01	213.77	0.76	21.11	20.42	0.69	AA
49764775882450074 88	0.0015675	-51.2440447	-13.60	1.00	-12.678	0.228	-16.90	1.00	-17.31	0.49	218.82	216.22	2.60	21.69	21.45	0.24	AA
50692718685037405 44	40.0021889	-27.8849658	-6.00	0.90	-6.255	0.694	-16.00	0.90	-15.39	0.70	200.56	202.12	1.57	17.09	16.61	0.48	AA
61380887394049792 00	200.0016708	-39.9390411	-1.70	1.70	-1.622	0.178	-23.50	1.70	-24.58	0.14	184.14	183.78	0.36	23.56	24.63	1.07	AA
5723786779471267 84	20.0023708	83.3308844	5.20	1.00	5.529	0.667	12.90	1.00	13.36	0.85	21.95	22.48	0.53	13.91	14.46	0.55	AA
18564546711593606 40	310.0012319	27.6679003	0.10	1.00	0.377	0.673	-12.00	1.00	-12.11	1.54	179.52	178.22	1.31	12.00	12.11	0.11	AA
20602439286957269 76	300.0006967	37.5623764	15.90	2.30	15.260	1.034	18.10	2.30	18.16	0.87	41.30	40.04	1.26	24.09	23.72	0.37	AA
25642776166851084 80	20.0015428	5.2533342	-3.10	1.20	-3.699	2.240	-22.10	1.20	-21.31	0.31	187.98	189.85	1.86	22.32	21.63	0.69	AA
47036895436675193 60	10.0005167	-67.7429414	11.70	0.90	11.344	0.566	-3.20	0.90	-3.29	0.48	105.30	106.18	0.89	12.13	11.81	0.32	AA
47165034926956431 36	20.0024381	-60.9745333	3.80	1.20	3.400	0.577	-10.40	1.20	-10.55	0.61	159.93	162.13	2.21	11.07	11.08	0.01	AA
58392490724766993 92	200.0008858	-73.8314789	-10.40	1.00	-9.943	0.631	0.00	1.00	0.48	1.04	270.00	272.77	2.77	10.40	9.95	0.45	AA
60684680067318597 12	200.0014183	-52.4932494	-18.10	0.90	-18.733	2.374	-4.10	0.90	-4.21	0.57	257.24	257.33	0.09	18.56	19.20	0.64	AA
413799586209675648	20.0008136	57.9476303	-1.40	1.50	-1.233	0.764	-6.30	1.50	-6.12	0.69	192.53	191.40	1.13	6.45	6.24	0.22	AA
20292825402459388 16	300.0004347	29.0260189	7.90	1.10	7.786	0.626	2.30	1.10	2.61	0.86	73.77	71.44	2.33	8.23	8.21	0.01	AA
66859314030597314 56	300.0008028	-43.4053564	1.80	0.90	1.894	0.868	0.90	0.90	0.83	1.26	63.43	66.28	2.85	2.01	2.07	0.06	-
24430951487881918 72	0.0004286	-5.4944061	24.20	1.40	22.196	0.562	-11.50	1.40	-11.86	0.44	115.42	118.11	2.70	26.79	25.17	1.63	AB
60882947783632693 76	200.0000128	-43.6431061	-40.60	1.00	-37.576	2.267	0.90	1.00	1.42	0.73	271.27	272.16	0.89	40.61	37.60	3.01	AB
463367769409956224	50.0013061	61.2592228	12.10	1.30	12.896	1.155	-3.20	1.30	-3.48	0.58	104.81	105.11	0.29	12.52	13.36	0.84	AB
20635010944695728	310.0011358	38.2078569	10.20	1.30	9.700	0.914	10.00	1.30	8.89	1.04	45.57	47.49	1.92	14.28	13.16	1.12	AB
23744965839715770 88	10.0016078	-13.6877419	12.00	1.20	13.173	1.384	9.20	1.10	9.70	0.85	52.52	53.65	1.12	15.12	16.36	1.24	AB
46846123984506763 52	10.00109	-75.6690683	14.20	1.00	13.267	1.183	5.80	1.00	6.04	1.39	67.78	65.51	2.27	15.34	14.58	0.76	AB
31266838959685830 40	100.0003969	1.8476847	-5.00	1.10	-5.382	1.193	-4.60	1.10	-5.22	1.02	227.39	225.90	1.49	6.79	7.49	0.70	AB
68275511120581130 24	320.0013128	-23.9538656	1.30	1.20	1.238	1.441	-6.90	1.20	-7.64	0.63	169.33	170.80	1.47	7.02	7.74	0.72	AB
28137048187434055 68	350.0027703	13.8102317	-18.60	1.10	-20.553	2.964	-21.40	1.10	-23.70	0.94	221.00	220.94	0.06	28.35	31.37	3.01	AC
333411542320052608	40.0023125	36.5462042	-6.00	1.60	-6.525	1.253	-5.40	1.60	-6.22	0.42	228.01	226.36	1.65	8.07	9.02	0.94	AC
50283861850273840 64	20.00224	-31.7488042	-13.20	0.90	-11.227	0.585	-29.00	0.90	-24.09	0.63	204.47	204.99	0.52	31.86	26.58	5.29	AD
9441884330483493 12	30.0027044	20.9966192	14.30	1.20	16.652	3.625	0.50	1.20	0.16	0.90	88.00	89.44	1.44	14.31	16.65	2.34	AD
27798292090891352 32	10.0004939	15.5409375	-8.80	2.00	-10.641	1.353	-7.70	2.00	-8.65	0.66	228.81	230.89	2.08	11.69	13.71	2.02	AD

Table 3 continues on the next page.

Table 3 (continued) Proper motion data comparison between TGAS and UCAC5 (random sample)

SrcID	RA	Dec	UCAC5 pmRA	UCAC5 e_pmRA	TGAS pmra	TGAS e_pmra	UCAC5 pmDE	UCAC5 e_pmDE	TGAS pmdec	TGAS e_pmdec	PMVD° UCAC5	PMVD° TGAS	Δ PMVD°	PMVL UCAC5	PMVL TGAS	Δ PMVL	"CPM" Rat
1726185323773319424	200.0014453	83.9356322	-113.70	1.20	-113.525	0.807	50.30	1.20	52.59	0.91	293.86	294.85	0.99	124.33	125.11	0.78	BA
944687918000276608	100.0004722	37.9196392	-50.60	1.20	-48.686	3.358	-19.10	1.20	-23.38	3.88	249.32	244.35	4.97	54.08	54.01	0.08	BA
3609561296619441280	200.0010844	-12.47004	-44.40	1.70	-42.570	0.792	-8.80	1.70	-11.16	1.25	258.79	255.32	3.47	45.26	44.01	1.26	BA
5016264309848670592	20.0021131	-32.6583683	19.70	0.90	20.874	0.672	16.10	0.90	14.77	0.60	50.74	54.72	3.97	25.44	25.57	0.13	BA
395709630632787072	0.0011892	52.1778547	14.20	1.30	14.524	1.333	3.20	1.30	1.82	0.56	77.30	82.85	5.55	14.56	14.64	0.08	BA
415611821887325824	10.0021889	50.8511186	2.70	1.40	3.684	1.011	-12.50	1.40	-12.21	0.41	167.81	163.21	4.60	12.79	12.76	0.03	BA
6670473472164011648	300.0001219	-49.0633731	5.50	0.90	6.080	0.503	-10.70	0.90	-10.31	0.88	152.80	149.47	3.33	12.03	11.97	0.06	BA
345879935460492416	30.0022956	42.0064997	-6.60	1.00	-7.113	1.867	-5.00	1.00	-4.81	0.83	232.85	235.91	3.06	8.28	8.59	0.31	BA
1937895359989637632	350.0026897	44.9287975	8.00	1.10	7.644	0.956	-3.00	1.10	-3.58	0.48	110.56	115.12	4.56	8.54	8.44	0.10	BA
365475775287147904	10.0014003	35.3608014	24.00	1.00	27.293	1.433	-15.00	1.00	-13.98	0.57	122.01	117.13	4.88	28.30	30.67	2.36	BB
1184193608167941l2	50.0016364	27.3249217	-6.90	1.30	-5.157	1.339	-14.50	1.20	-13.66	0.60	205.45	200.68	4.76	16.06	14.60	1.46	BB
531415753778269312	0.0036458	72.1641883	-2.80	1.30	-3.792	1.205	13.10	1.30	14.22	0.81	347.94	345.07	2.86	13.40	14.72	1.32	BB
1790273520094155904	320.0009475	20.0681364	-8.20	1.20	-7.616	2.035	-15.60	1.20	-16.97	0.99	207.73	204.17	3.56	17.62	18.60	0.98	BB
141039201218726528	40.0015719	35.3047169	3.00	0.90	3.019	2.601	-4.30	0.90	-4.89	0.95	145.10	148.32	3.22	5.24	5.75	0.51	BB
1963963784254779904	320.0006539	37.4571297	-2.90	1.30	-2.324	0.755	-8.20	1.30	-7.93	0.93	199.48	196.33	3.15	8.70	8.27	0.43	BB
6792303655489676032	310.0003786	-33.0228864	-10.30	1.00	-11.153	1.944	3.00	1.00	2.24	1.74	286.24	281.35	4.89	10.73	11.38	0.65	BB
4300736742748596224	300.0004933	10.72745	-16.40	1.30	-22.036	1.662	-60.10	1.30	-64.24	1.11	195.26	198.93	3.67	62.30	67.91	5.61	BC
5100163918995801856	50.0014747	-20.4805336	-15.20	1.80	-14.889	0.584	-21.40	1.80	-24.94	0.49	215.39	210.84	4.55	26.25	29.05	2.80	BC
1968781053933400192	320.0018661	41.2909219	-2.90	1.30	-2.803	1.771	-4.90	1.30	-5.65	1.10	210.62	206.37	4.24	5.69	6.31	0.62	BC
620796978145612l0	50.0015644	21.6971667	-4.70	1.20	-4.429	0.799	-9.40	1.20	-11.49	0.41	206.57	201.08	5.48	10.51	12.31	1.80	BD
2176124585874978176	320.0001219	54.1913647	3.70	1.50	6.363	1.994	1.00	1.50	1.18	0.92	74.88	79.49	4.62	3.83	6.47	2.64	BD
2523195704743041408	10.000285	-7.8719308	5.20	2.50	6.903	0.071	-1.80	2.40	-1.83	0.05	109.09	104.85	4.25	5.50	7.14	1.64	BD
2738327524223598464	0.0008722	1.08898	-7.40	1.90	-5.986	0.082	-5.60	1.90	-5.07	0.04	232.88	229.71	3.17	9.28	7.85	1.43	BD
4752871901368421376	40.0014019	-47.5981592	-12.80	1.10	-16.096	0.582	-31.60	1.10	-28.59	1.13	202.05	209.38	7.33	34.09	32.81	1.29	CA
2927146621702482048	100.0008314	-20.8516097	8.00	1.80	6.269	0.572	-12.00	1.80	-13.04	0.62	146.31	154.33	8.02	14.42	14.47	0.05	CA
5074012138008219776	50.0018819	-25.1138908	1.50	1.00	2.529	0.660	-10.30	1.00	-9.83	0.68	171.71	165.57	6.14	10.41	10.15	0.26	CA
393457315422167168	0.0016475	49.0361997	-6.90	1.20	-6.273	1.203	-3.50	1.20	-4.46	0.42	243.10	234.60	8.50	7.74	7.70	0.04	CA
1735376244550467840	310.000425	4.7893342	0.90	1.90	-1.842	0.922	-24.30	1.90	-25.87	0.66	177.88	184.07	6.19	24.32	25.93	1.62	CB
2312711074236860160	0.0011886	-34.697945	20.30	1.10	17.306	0.904	-14.90	1.10	-16.39	0.86	126.28	133.44	7.16	25.18	23.84	1.35	CB
1469659434128292224	200.0001961	32.7471356	5.40	1.30	5.724	0.368	-6.10	1.30	-4.84	0.40	138.48	130.23	8.25	8.15	7.50	0.65	CB
4945856842245881600	40.00234	-44.9075731	10.00	1.00	10.674	0.506	1.00	1.00	-0.25	0.65	84.29	91.32	7.03	10.05	10.68	0.63	CB
5133588488365248512	40.0031883	-16.3083914	20.80	2.80	20.163	0.034	-5.00	2.80	-2.00	0.04	103.52	95.66	7.86	21.39	20.26	1.13	CB
5162511038653924864	50.0010303	-11.7315642	6.10	1.00	3.817	1.291	-14.80	1.00	-14.36	0.84	157.60	165.11	7.51	16.01	14.85	1.15	CB
393361211233831040	0.0030181	48.9056047	-0.70	1.20	-0.562	1.201	-0.70	1.20	-0.72	0.58	225.00	218.09	6.91	0.99	0.91	0.08	-
6350548024074180224	350.0012122	-81.9075578	-1.70	1.10	-1.139	0.583	-3.20	1.10	-3.16	0.64	207.98	199.84	8.14	3.62	3.36	0.27	CB
371759587319735680	20.0012883	39.9521794	-6.40	1.30	-6.793	2.291	-4.10	1.30	-5.39	0.52	237.36	231.55	5.80	7.60	8.67	1.07	CC
1827037649874025088	300.0000417	22.2479044	-2.80	1.20	-2.640	1.220	-3.70	1.20	-4.58	0.96	217.12	209.98	7.14	4.64	5.28	0.64	CC
5857938364970526976	200.0017069	-66.0045075	-1.70	0.90	-2.168	0.644	-6.20	0.90	-5.35	0.81	195.33	202.07	6.73	6.43	5.77	0.66	CC
6864276862009397504	300.0006672	-21.9195119	-7.00	1.00	-8.211	1.055	4.10	1.00	3.62	0.75	300.36	293.80	6.56	8.11	8.97	0.86	CC
427793757888822656	10.0022961	62.6521478	-2.70	1.30	-5.812	0.963	1.20	1.30	1.89	0.85	293.96	288.03	5.93	2.95	6.11	3.16	CD
2298682233579383040	320.0016886	82.4094392	5.30	1.10	3.676	0.979	-1.70	1.10	-0.66	0.70	107.78	100.18	7.61	5.57	3.73	1.83	CD
2926649951684132352	100.0002875	-21.7156217	-4.60	1.10	-3.573	0.709	-2.70	1.10	-2.66	0.70	239.59	233.29	6.30	5.33	4.46	0.88	CD
4547153344568782l8	40.0022239	56.3555567	1.70	1.20	-1.573	1.089	7.80	1.20	7.97	0.49	12.30	348.84	156.54	7.98	8.12	0.14	DA

Table 3 concludes on the next page.

Table 3 (conclusion) Proper motion data comparison between TGAS and UCAC5 (random sample)

SrcID	RA	Dec	UCAC5 pmRA	UCAC5 e_pmRA	TGAS pmra	TGAS e_pmra	UCAC5 pmDE	UCAC5 e_pmDE	TGAS pmdec	TGAS e_pmdec	PMVD° UCAC5	PMVD° TGAS	Δ PMVD°	PMVL UCAC5	PMVL TGAS	Δ PMVL	"CPM" Rat
2030036736506436864	300.0001811	29.1810689	-0.20	1.10	2.038	1.094	-14.40	1.10	-13.98	1.25	180.80	171.70	9.09	14.40	14.12	0.28	DA
2066444865030173824	310.0001403	42.4087456	-1.10	1.20	-2.757	3.887	-4.60	1.20	-3.75	0.88	193.45	216.33	22.88	4.73	4.65	0.08	-
6863189857327828352	310.0012483	-15.4122917	2.00	1.20	6.029	2.083	-14.80	1.20	-12.99	1.05	172.30	155.10	17.20	14.93	14.32	0.61	DA
360217807604762112	30.0000383	53.2235472	14.20	1.30	16.746	1.361	-9.50	1.30	-7.62	0.51	123.78	114.48	9.30	17.08	18.40	1.32	DB
1833330945193711488	300.0005797	23.3157317	-5.10	1.00	-4.174	1.581	2.60	1.00	3.11	0.81	297.01	306.69	9.68	5.72	5.21	0.52	DB
3103597793915579648	100.0004297	-5.4301414	-6.90	1.40	-8.417	1.358	-3.80	1.40	-1.97	1.11	241.16	256.85	15.69	7.88	8.64	0.77	DB
505515005039705984	30.0016319	58.5477036	1.80	1.40	-1.541	1.407	-5.40	1.40	-6.34	0.69	161.57	193.66	32.09	5.69	6.53	0.84	DC
515676863302518400	40.0024219	63.8381597	1.80	1.40	3.628	0.825	-7.20	1.40	-7.78	1.12	165.96	154.99	10.98	7.42	8.58	1.16	DC
529282598141166592	10.0015256	67.4371092	-1.70	1.30	-0.312	1.053	-1.70	1.30	-2.07	1.02	225.00	188.56	36.44	2.40	2.10	0.31	-
992535365506045568	100.0005614	51.9809386	-5.50	2.00	-6.000	0.571	0.60	2.00	-2.00	0.67	276.23	251.57	24.66	5.53	6.32	0.79	DC
2873720836312767360	0.0034036	31.5320539	8.40	1.70	8.420	0.710	-2.60	1.70	-5.00	0.41	107.20	120.68	13.48	8.79	9.79	1.00	DC
3133393425157364992	100.0004486	6.29338	-1.40	1.20	-1.137	5.553	1.10	1.20	-1.65	4.70	308.16	214.51	93.65	1.78	2.01	0.23	-
54383975413620736	50.0026653	15.7746897	1.90	1.10	0.735	0.777	-6.20	1.10	-5.01	0.38	162.96	171.65	8.69	6.48	5.06	1.42	DD
62186109924593920	50.0004353	22.4068842	3.60	1.20	1.647	1.545	-4.40	1.20	-3.61	0.81	140.71	155.47	14.76	5.69	3.97	1.72	DD
330860812783367936	30.0022028	37.5040272	-1.40	1.00	-4.888	3.435	-3.60	1.00	-1.35	0.90	201.25	254.56	53.31	3.86	5.07	1.21	-
355999599963408256	30.0007008	46.4167911	-2.10	1.40	0.604	3.131	2.90	1.40	2.75	0.80	324.09	12.40	131.69	3.58	2.81	0.77	-
447795248787630976	50.0002822	56.0858881	7.90	1.60	4.676	1.296	-8.10	1.60	-6.80	0.65	135.72	145.48	9.77	11.31	8.25	3.06	DD
504470194117201664	30.0026128	55.3379269	-5.30	1.30	-1.553	1.485	-0.80	1.30	0.30	0.75	261.42	280.76	19.34	5.36	1.58	3.78	-
541946257674490240	40.0006197	69.5123028	0.30	2.10	0.387	0.793	3.00	2.10	1.15	1.03	5.71	18.57	12.86	3.01	1.22	1.80	-
1817363184504888448	310.0004931	20.3816647	4.30	1.20	3.320	1.216	-0.10	1.20	-1.16	0.92	91.33	109.18	17.85	4.30	3.52	0.79	DD
1822880568218198656	300.0005869	18.8088228	-4.60	1.20	-4.333	2.025	-6.10	1.20	-4.08	1.46	217.02	226.71	9.69	7.64	5.95	1.69	DD
1856409041426833152	310.0008469	27.2328711	2.40	1.20	3.603	0.861	-1.90	1.20	-0.54	1.47	128.37	98.48	29.89	3.06	3.64	0.58	-
1995787018014958976	350.0004933	54.0135656	-1.70	1.20	1.183	1.064	1.00	1.20	0.91	0.42	300.47	52.55	67.91	1.97	1.49	0.48	-
2009314928044954624	350.0015708	56.8284911	-13.50	1.20	-10.861	1.086	-2.00	1.20	-3.67	0.54	261.57	251.35	10.22	13.65	11.46	2.18	DD
2014149583753775104	350.0027	61.1498531	-1.30	3.20	-0.434	0.025	43.40	3.20	1.69	0.03	358.28	345.59	12.70	43.42	1.74	41.68	DD
2164779172069144832	320.0012569	48.2464667	3.30	1.40	-1.683	1.464	-0.70	1.40	-0.14	0.54	101.98	265.11	163.13	3.37	1.69	1.68	-
2171972142775253760	320.0003722	50.6764281	-3.40	1.30	-8.701	3.924	-2.30	1.30	-3.55	1.83	235.92	247.83	11.90	4.10	9.40	5.29	-
2172302683455654016	320.0012839	51.5902714	-0.90	1.40	-2.285	1.342	-1.30	1.40	-1.50	0.63	214.70	236.75	22.06	1.58	2.73	1.15	-
2180425737927963136	310.0001056	50.9194711	0.40	1.30	-2.243	3.499	2.90	1.30	4.36	1.11	7.85	332.77	144.91	2.93	4.90	1.97	-
2472378751208487808	20.0000922	-7.8525733	-0.70	1.30	-3.113	2.684	-6.60	1.20	-8.04	0.61	186.05	201.18	15.12	6.64	8.62	1.98	DD
2508242518403978624	30.0026467	0.8256581	3.50	1.00	6.895	6.955	-2.40	1.00	-2.77	2.05	124.44	111.88	12.56	4.24	7.43	3.19	-
2840974596897783808	350.0011842	24.6258753	-2.50	1.00	0.805	1.893	-6.30	1.00	-8.41	0.66	201.64	174.53	27.11	6.78	8.45	1.67	DD
2894128699837447808	100.0000072	-31.1959472	1.40	1.00	1.631	1.411	-4.60	1.00	-2.91	1.08	163.07	150.73	12.34	4.81	3.34	1.47	DD
3131039954877316224	100.001175	5.2602994	7.50	1.20	1.883	2.063	-7.90	1.20	-4.66	1.73	136.49	158.01	21.53	10.89	5.03	5.86	DD
5280074945065376640	100.0000431	-68.259285	-2.70	1.00	-3.797	1.973	2.20	1.00	1.73	1.75	309.17	294.53	14.64	3.48	4.17	0.69	-