Physical Double Stars in TGAS

Wilfried R.A. Knapp
Vienna, Austria
wilfried.knapp@gmail.com

Abstract: TGAS is a subset of GAIA DR1 objects comprising those stars in the Hipparcos and Tycho-2 catalogs for which proper motion as well as parallax data are available. Good reason to have a look if this data is of use for checking if existing WDS catalog objects are to be considered physical or not.

Introduction

The TGAS subset of GAIA provides PM and Plx data for stars already covered in the Tycho and Hipparcos catalogs (Michalik at al. 2015) thus bright enough for visual observation. The data in TGAS was checked by sorting the catalog by RA/Dec coordinates and looking then for close objects with nearly identical parallax. Next step was then to identify these objects in the 2MASS images and load the GAIA DR1 data to check the PM values for common proper motion. Next step was to load the WDS catalog to check if they are already included in this catalog and V-coded as binaries. The results for a few by random selected TGAS objects with nearly identical Plx are given in Table 1.

To make the CPM assessment more transparent the proper motion vector attributes direction and length and the differences are given in Table 2 as well as the TGAS Plx data with a calculation of the distance between the components for three cases:

- Best case: The Plx values are assumed to be identical within the given error range taking the average of Plx1 and Plx2 – the distance is then simply the part of the circumference with a radius given by the average Plx
- Realistic case: Using the given GAIA DR1 values Plx1 and Plx2 – this adds to the best case the distance of the Plx data calculated approximately using the Pythagoraean theorem
- Worst case: The given Plx errors work to full extent giving the largest possible distance – again calculated approximately using Pythagoras.

The assessment of a potential gravitational relation between the components is then based on a quite simple approach assuming average means Sun-like star mass with a then assumed gravitational "border" at the outer rim of the Oort cloud at ~100,000 AU. If the "realistic" distance between the components is therefore less than 200,000 AU then potential gravitational relation is assumed to be given with high probability because of the (staying with the example of our Sun) then overlapping Oort cloud.

The results in Tables 1 and 2 show that checking close TGAS objects with nearly identical parallax is a good procedure to detect common proper motion and potential gravitational relationship for objects already included in the WDS catalog with a small chance to detect binaries so far not WDS listed despite being bright enough to be observed visually. Combining the results from Tables 1 and 2, we get the following overall assessment:

- In total 17 objects with 16 already WDS listed
- 3 out of 16 WDS objects are V-coded, all of them confirmed by GAIA PM data as at least potential CPM pairs
- 14 out of in total 17 objects suggest at least to some degree common proper motion by GAIA PM data (with 9 of them to be considered as solid CPM candidates) and only 3 seem to be most probably "only" optical – this pattern seems remarkable: Optical close pairs with similar parallax show with a high probability common proper motion features

(Text continues on page 584)

Table 1: CPM Rating for the selected TGAS objects

Description of the table content:
- Header line: Gives the WDS catalog data available for the selected object with year of last observation in the Date column, for one object without WDS data the Tycho II data is given
- GAIA DR1 line:
-- RA and Dec give the GAIA DR1 coordinates in decimal degrees format as these values are directly usable for calculating Sep and PA
*- Sep gives separation in arcseconds calculated from the coordinates of both components as SQRT(((RA2-RA1)*cos(Dec1))^2+(Dec2-Dec1)^2) in radians (Buchheim 2008)*
*-- PA gives position angle in degrees calculated from the coordinates of both components as arctan((RA2-RA1)*cos(Dec1))/(Dec2-Dec1)) in radians depending on quadrant (Buchheim 2008)*
-- M1 and M2 give GAIA Gmags
-- pmRA1 and pmDec1 with e_pm1 give the GAIA proper motion data for A and pmRA2, pmDec2 and e_pm2 for B
-- Ap indicates in the aperture used (calculated circular surface diameter)
-- Me indicates the WDS code for the used observation method
-- Date is the GAIA DR1 observation epoch
-- CPM Rat gives the rating of the CPM assessment based on comparison of the given PM data (description see Appendix)
-- Source/Notes finally indicates additional comments and explanations if considered necessary

Name	RA	Dec	Sep	PA	M1	M2	pmRA1	pmDec1	e_pm1	pmRA2	pmDec2	e_pm2	Ap	Me	Date	CPM Rat	Source/Notes
ARG 10	03:06:06.91	+53:03:04.5	3.9	265.0	9.77	9.80	30	78		-16	-82				2015		WDS03061+5303 catalog data per 2016_8
	46.52875587	53.0509325	4.01	264.2	9.49	9.44	7.77	-77.24	1.21	4.90	-87.22	1.20	0.96	Hg	2015	CCAA	GAIA DR1. Seems optical pair
ES 929	00:09:54.70	+54:09:19.1	3.3	118.0	10.36	11.81	-25	-13		-10	-43				2003		WDS00099+5409 catalog data per 2016_8
	2.47774295	54.1551978	3.30	117.4	10.10	11.45	-17.80	-16.39	1.21	-20.23	-15.39	2.04	0.96	Hg	2015	BABB	GAIA DR1. Potential CPM pair
ES 1214	01:57:04.66	+46:53:56.6	3.9	220.0	10.47	11.27	5	-21		-3	-32				2002		WDS01570+4653 catalog data per 2016_8
	29.26939274	46.8989164	3.89	220.0	10.27	11.05	-5.45	-31.98	1.32	-4.84	-30.48	1.85	0.96	Hg	2015	AABB	GAIA DR1. Solid CPM candidate
FRK 2	01:56:26.92	+30:26:22.9	53.8	307.0	7.95	9.12	-23	-28		-26	-30				2011		WDS01564+3026 catalog data per 2016_8
	29.11204677	30.4395869	53.56	306.6	7.83	8.98	-24.08	-27.73	0.08	-24.41	-28.62	0.88	0.96	Hg	2015	ABAC	GAIA DR1. Seems good CPM candidate with hint of orbit
GRV 29	00:33:08.32	+07:35:08.6	81.0	130.0	9.46	10.56	43	39		43	42				2010		WDS00331+0735 catalog data per 2016_8
	8.28484438	7.5858827	80.99	129.7	9.23	10.43	42.27	39.93	0.13	43.76	40.28	2.19	0.96	Hg	2015	AAAC	GAIA DR1. Solid CPM candidate
GRV 704	23:58:20.82	+02:17:21.7	59.7	59.0	9.59	10.35	23	-15		21	-14				2010		WDS23583+0217 catalog data per 2016_8
	359.5868270	2.2893049	59.84	58.6	9.37	10.09	21.46	-14.67	1.02	22.84	-13.94	1.64	0.96	Hg	2015	BABC	GAIA DR1. Potential CPM candidate
HLD 6	01:35:55.11	+33:03:19.1	2.1	295.0	10.00	10.08	-19	59		-28	64				2009		WDS01359+3304 catalog data per 2016_8
	23.97943998	33.0555955	2.15	293.9	9.75	9.85	-32.75	63.63	1.78	-31.38	66.41	0.98	0.96	Hg	2015	BAAA	GAIA DR1. Good CPM candidate
HU 14	02:04:07.81	-11:00:58.7	3.5	17.0	10.29	10.44	-53	-45		-45	-13				2000		WDS02041-1101 catalog data per 2016_8
	31.03231971	-11.0164324	3.58	16.1	9.98	10.05	-48.95	-37.18	1.37	-52.88	-35.62	1.62	0.96	Hg	2015	BBAA	GAIA DR1. Potential CPM but rather optical pair
HU 418	01:24:32.05	-16:14:24.8	4.1	102.0	10.66	10.97	-30	9		6	10				2003		WDS01245-1615 catalog data per 2016_8
	21.13357757	-16.2402014	4.11	102.1	10.49	10.67	8.05	9.43	0.93	7.90	9.19	1.48	0.96	Hg	2015	AACB	GAIA DR1. Solid CPM candidate
J 1245	02:47:29.96	-06:00:51.8	2.6	20.0	11.00	11.04	35	-46							2015		WDS02475-0601 catalog data per 2016_8
	41.87501175	-6.0144363	2.35	11.5	10.58	10.77	39.23	-30.67	1.48	39.53	-30.67	1.62	0.96	Hg	2015	AAAA	GAIA DR1. Solid CPM candidate
KR 3	00:15:02.05	+55:42:25.1	3.4	223.0	9.75	9.86	57	29		29	35				2011		WDS00150+5542 catalog data per 2016_8
	3.75916285	55.7071589	3.45	222.4	9.54	9.59	52.91	31.47	1.00	53.66	27.08	1.04	0.96	Hg	2015	CBAA	GAIA DR1. Rather optical pair
KR 22	04:18:37.64	+60:49:59.4	3.5	186.0	10.15	10.16	19	-8		19	-29				2003		WDS04187+6050 catalog data per 2016_8
	64.65695726	60.8330002	3.52	185.7	9.92	10.00	16.60	-30.06	1.32	15.52	-29.52	1.27	0.96	Hg	2015	AAAB	GAIA DR1. Solid CPM candidate

Table 1 concludes on next page.

Table 1 (conclusion). CPM Rating for the selected TGAS objects

Name	RA	Dec	Sep	PA	M1	M2	pmRA1	pmDec1	e_pm1	pmRA2	pmDec2	e_pm2	Ap	Me	Date	CPM Rat	Source/Notes
NI 8	03:44:48.90	+57:01:41.6	16.5	315.0	11.46	11.64	116	-163		116	-158				2015	V	WDS03448+5702 catalog data per 2016_8
	56.20463585	57.0275591	16.49	315.1	10.73	10.73	114.56	-159.62	1.63	111.43	-159.51	1.41	0.96	Hg	2015	BAAA	GAIA DR1. Obviously solid CPM pair with pm vector direction difference in need of clarification
SKF 845	02:57:23.64	+00:58:18.6	99.3	16.0	10.70	10.84	-44	-44		-45	-47				2002	V	WDS02574+0058 catalog data per 2016_8
	44.34831207	0.9716313	99.28	16.2	10.47	10.59	-45.76	-46.76	1.97	-46.20	-47.02	2.30	0.96	Hg	2015	AAAC	GAIA DR1. Solid CPM pair
SKF 927	20:25:49.82	+00:58:18.4	66.0	230.0	9.14	10.71	22	38		21	38				2000	V	WDS20258+0058 catalog data per 2016_8
	306.45766449	0.9719352	65.94	229.6	8.90	10.35	20.78	36.12	1.01	23.67	36.43	2.29	0.96	Hg	2015	BABC	GAIA DR1. PM vector direction difference a bit too large to be a solid CPM candidate
STI 416	02:58:34.40	+59:28:01.9	3.6	87.0	11.41	11.37	-79	-27		16	-16				2012		WDS02586+5928 catalog data per 2016_8
	44.64337177	59.4671077	3.53	86.1	11.08	11.19	10.69	-18.56	1.25	9.79	-19.05	1.23	0.96	Hg	2015	AABB	GAIA DR1. Solid CPM candidate
TYC0587-00132-1	23:58:46.59	+00:14:56.5	376.35	103.84	11.26	11.25	-9	-80		-10	-78				1991.5		Tycho-2 data for TYC0587-00132-1 and TYC0587-00432-1. Date is average Tycho observation epoch
	359.6940575	0.2487344	376.29	103.85	10.80	10.72	-11.09	-77.03	1.21	-12.98	-77.44	2.26	0.96	Hg	2015	AAAC	GAIA DR1. Solid CPM candidate

Table 2: PM evaluation data and Plx Rating for the selected TGAS objects

Description of the table content:
- Name: Object WDS discoverer ID or Tycho catalog ID
- PMVD: Proper motion vector direction in degrees for A and B and delta AB
- PMVL: Proper motion vector length for A and B and delta AB derived from GAIA DR1 pm values
- Plx: Parallax A and B end parallax error A and B from GAIA DR1
- Dist AB min: Approx. minimum distance between the components in AU assuming equal averaged Plx
- Dist AB Plx: Approx. distance between the components in AU according the given GAIA DR1 parallax values
- Dist AB max: Approx. maximum Distance between the components in AU according to the given GAIA DR1 Plx values with full error range applied
- Plx Rating:
For potential gravitational relationship with "A" for less than 200,000 AU (assuming average mass stars like our sun with then overlapping Oort clouds), "B" for less than 300,000 AU (with some probability for a smaller distance within the given Plx error range) and "C" for above.
For relation Plx error to Plx value with "A" for less than 5%, "B" for less than 10% and "C" for above

Name	PMVD A	PMVD B	ΔPMVD	PMVL A	PMVL B	ΔPMVL	Plx A	Plx B	e_Plx A	e_Plx B	Dist AB min	Dist AB Plx	Dist AB max	Plx Rat	Notes
ARG10	174.25	176.78	2.53	77.63	87.35	9.73	13.36	13.66	0.24	0.22	294	339,077	860,844	CA	PM vector direction and vector length similar but too different to allow for common proper motion. Best case distance would allow gravitational relationship but such an assessment seems overly optimistic
ES929	227.37	232.74	5.37	24.20	25.42	1.22	5.43	5.77	0.34	0.39	572	2,238,399	7,039,139	CB	PM vector length similar but direction too different to allow for solid common proper motion. Best case distance would allow gravitational relationship but such an assessment seems overly optimistic
ES1214	189.68	189.03	0.65	32.44	30.87	1.57	5.78	5.54	0.24	0.26	674	1,545,994	4,802,148	CA	PM vector direction suggests common proper motion. Best case distance would allow gravitational relationship but such an assessment seems overly optimistic
FRK2	220.96	220.46	0.51	36.72	37.62	0.89	5.23	5.35	0.23	0.25	10,012	884,683	4,420,064	CA	PM vector direction suggests common proper motion, small difference in vector length might suggest an orbit. Best case distance would allow gravitational relationship but such an assessment seems overly optimistic
GRV29	46.63	47.38	0.74	58.15	59.47	1.32	8.46	8.31	0.25	0.52	9,574	440,207	2,796,849	CA	PM vector direction suggests common proper motion. Best case distance would allow gravitational relationship but such an assessment seems overly optimistic
GRV704	124.35	121.39	2.96	25.99	26.76	0.77	8.95	8.58	0.44	0.57	6,687	993,883	3,784,564	CB	PM vector direction difference too large to suggest solid common proper motion. Best case distance would allow gravitational relationship but such an assessment seems overly optimistic
HLD6	332.76	334.71	1.94	71.56	73.45	1.89	6.72	7.15	0.54	0.27	301	1,845,982	5,577,808	CB	PM vector direction too different to suggest solid common proper motion. Best case distance would allow gravitational relationship but such an assessment seems overly optimistic
HU14	232.78	236.03	3.26	61.47	63.76	2.28	7.35	7.46	0.27	0.29	481	413,810	2,518,686	CA	PM differences too large to suggest common proper motion. Best case distance would allow gravitational relationship but such an assessment seems overly optimistic
HU418	40.46	40.71	0.25	12.40	12.12	0.28	7.38	7.12	0.54	0.38	558	1,020,637	4,559,646	CB	PM values suggest common proper motion. Best case distance would allow gravitational relationship but such an assessment seems overly optimistic
J1245	128.02	127.81	0.21	49.79	50.03	0.24	5.77	5.79	0.25	0.24	406	123,484	3,160,444	AA	PM values suggest common proper motion. Plx data offers a solid chance for a gravitational relationship
KR3	59.26	63.22	3.96	61.56	60.10	1.46	6.23	5.94	0.25	0.31	554	1,616,433	4,805,845	CA	PM differences too large to suggest common proper motion. Best case distance would allow gravitational relationship but such an assessment seems overly optimistic
KR22	151.09	152.27	1.17	34.34	33.36	0.98	6.14	6.27	0.26	0.25	562	696,533	3,443,414	CA	PM values suggest common proper motion. Best case distance would allow gravitational relationship but such an assessment seems overly optimistic
NI8	144.33	145.06	0.73	196.48	194.57	1.90	16.22	16.36	0.33	0.32	1,008	108,830	614,811	AA	Difference PM vector direction needs clarification but otherwise obviously solid CPM pair. Plx data suggests good probability for gravitational relationship
SKF845	224.38	224.49	0.11	65.43	65.92	0.49	7.45	7.38	0.28	0.25	13,327	262,953	2,245,557	BA	PM values suggest common proper motion. Plx data offers a small chance for a gravitational relationship
SKF927	29.91	33.02	3.11	41.67	43.44	1.77	12.57	11.70	0.28	0.55	5,246	1,220,215	2,447,407	CA	PM vector direction difference too large to suggest common proper motion. Best case distance would allow gravitational relationship but such an assessment seems overly optimistic
STI416	150.06	152.79	2.73	21.42	21.41	0.01	5.14	5.10	0.25	0.27	686	314,747	4,436,969	CB	PM values suggest solid common proper motion. Best case distance would allow gravitational relationship but such an assessment seems overly optimistic
TYC587-132-1	188.19	189.52	1.33	77.82	78.52	0.70	9.03	9.63	0.57	0.65	39,075	1,423,754	4,316,780	CB	PM values suggest solid common proper motion pair. Best case distance would allow gravitational relationship but such an assessment seems overly optimistic

Table 3.

pm RA A	pm Dec A	e_pm A	pm RA B	pm Dec B	e_pm B	
-79.39	-21.28	1.100	-74.09	-7.48	1.460	Own calculation
-79.46	-21.23	0.781	-74.04	-8.44	0.808	TGAS

(Continued from page 580)

- 3 out of 9 solid CPM objects are most probably gravitationally bound, 2 of them WDS V-coded
- J 1245 is the only object with a perfect "AAAA" CPM and "AA" distance rating but is not V-coded.

TGAS Proper Motion Error

The proper motion data given by GAIA DR1/ TGAS is based on comparison of Tycho-2 to GAIA DR1 positions using an average Tycho-2 observation epoch (according to Michalik et al., 2015). A counter-check for a few objects showed these values being correct with minor differences compared to the results based on calculation using the precise Tycho-2 observation epoch. But using the given Tycho-2 position errors for calculating the PM data error range by dividing the overall position error SQRT(e_RAmdeg^2 + e_Decmdeg^2) by the timespan between Tycho-2 and GAIA DR1 observation epoch results in much higher values by about the factor 2 compared to the TGAS values.

As an example: Double star MLR 391 with GAIA source IDs 491707784695048960 and 491707784696611072 are given in Table 3. It suggests that the given TGAS PM error data might be a bit over-optimistic. I contacted the authors of the TGAS paper (Michalik at al. 2015) via email for an explanation and got the following answer: "... may be explained by the optimum way TGAS combines the old (Tycho-2) and Gaia observations. TGAS takes into account the spread of observations over the 14 months of data included in the solution, which for many well-observed stars improves the proper motion estimates significantly compared with a straightforward combination of the two positions."

Summary

As shown the TGAS catalog is a good source to get precise proper motion and parallax data for double stars already included in the WDS catalog as good base for evaluating if physical or "only" optical. The hit rate is surprisingly high – with only very few exceptions all close TGAS objects with identical parallax (within the given error range) are already listed in the WDS catalog but in most cases without being V-coded so far. So the described procedure is a good approach to re-discover already existing WDS objects as binaries and also to identify a few new potential candidates. This result also demonstrates that the visual double star observer community did quite a good discovery job in the past.

Acknowledgements

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

- Washington Double Star Catalog
- Tycho-2 catalog
- GAIA DR1 Catalog including TGAS
- Aladin Sky Atlas v9.0
- VizieR
- AstroPlanner v2.2

Special thanks to Lennart Lindegren (Lund Observatory, Department of Astronomy and Theoretical Physics) for the clarification how the discrepancy between TGAS PM error data and the values gained by direct comparison of Tycho-2 with GAIA DR1 positions may be explained.

References

Buchheim, Robert – 2008, CCD Double-Star Measurements at Altimira Observatory in 2007, Journal of Double Star Observations, Vol. 4 No. 1 Page 28

Knapp, Wilfried R.A. and Nanson, John – 2017, A new concept for counter-checking of assumed CPM pairs, Journal of Double Star Observations, Vol. 13 No. 2 Page 139

Michalik, Daniel, Lindegren, Lennart and Hobbs, David – 2015, The Tycho-Gaia Astrometric Solution, Astronomy & Astrophysics, 574A, 115-115