Estimating Visual Magnitudes for Wide Double Stars with Missing or Suspect WDS Values

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Abstract: The WDS catalog often gives visual magnitudes of fainter objects rather as rough estimations instead of precise measurements or magnitudes of the blue or red band depending on availability and in some cases the given magnitude for the secondary is simply blank. This report suggests for a good part of such objects a rather precise Vmag estimation calculated from GAIA DR1 Gmag and 2MASS J/H/K-mag data. As side result a cross-match of the WDS catalog with GAIA DR1 is presented to provide recent precise measurements for about 80,000 WDS objects. During the research for this report several errors were found in the WDS as well as the GAIA DR1 catalog.

2. Introduction

With the availability of GAIA DR1 we have for a good part of the WDS pairs not only precise coordinates for both components given but also an overall visual G-band magnitude including blue and red wavelength (Jordi et al. 2010). We have with 2MASS for a smaller subset also J/H/K-band magnitudes available. The latter are if only to some degree usable for estimating Vmags for example with the formula given in Caldwell et al. 1993. Statistical analysis of a dataset with over 15,000 stars with precise Vmags matched with GAIA DR1 Gmags and 2MASS J/H/K-mags (Knapp and Nanson 2018) allowed the development of a very reliable formula for estimating Vmags based on these values. As follow up we present here the results of the application of this concept as far as possible on the full WDS catalog.

2. Cross-matching of catalogs

To get the necessary G/J/H/K-mags for the WDS objects in question requires the cross-matching of the WDS catalog with the GAIA DR1 catalog to get Gmags and then with 2MASS to get the J/H/K-mags. An alternative for the cross-match WDS to GAIA DR1 might be the cross-match of WDS to UCAC5 offering Gmags as well as J/H/K-mags but as the UCAC5 catalog is regarding matching with 2MASS not complete (see Knapp and Bryant 2018) we preferred the direct comparison with GAIA DR1 and 2MASS. The *Centre de Données astronomiques de Strasbourg* (CDS) offers the X-Match tool for cross-matching of catalogs including user specific tables which uses either positions at epoch of observation or positions computed at epoch 2000 (depending on the availability of proper motion data for each object).

2.1 Matching the WDS catalog with GAIA DR1 for the primary

Using CDS X-match for the WDS catalog (142,202 objects per Jan 2018) with GAIA DR1 with a search radius of 5 arcseconds around the given WDS coordinates for the primary results in 163,369 matching objects including multiple matches due to the large search radius. Eliminating all multiple matches but the closest ones reduced the number of objects to 128,956 – this means that about 10% of the WDS objects cannot be located within a 5” search radius around the given WDS position. The concept that in case of multiple matches the star closest to the given WDS position is to be considered as correct identification includes the risk of false positives caused for example by fast proper motion of the primary – most of such false positives should be eliminated by the next step of matching for the secondary as the chance to find a corresponding star at the given separation and position angle seems in case of a wrong matched primary rather negligible.

2.2 Matching the WDS catalog with GAIA DR1 for the secondary

Taking the positions of the matched GAIA objects and calculating the positions of the secondary using the WDS separation and position angle gives the base for the next x-matching with GAIA for the secondary this time with a search radius of 2”. The result are 118,184 objects again including multiple matches especially self -matching for objects with a separation of less than 2”. Eliminating in a first step all objects with identical GAIA ID and in a second step all other multiple matches but the closest ones reduces this number to 84,173. This means that only about 60% of the WDS objects are covered in GAIA DR1 with both components indicating less a problem with the WDS data but with the GAIA DR1 sky coverage.

Next step was then the elimination of the few “surviving” objects with a separation of 999.9” indicating a separation larger than 1,000 arcseconds as by chance a “match” was found for a few such objects. A few objects with a WDS PA value of “-1” indicating an unknown value were checked manually for plausibility and kept if the separation was close to the WDS value. Next came a check for corresponding position angle which eliminated all objects with a difference between WDS PA and GAIA match PA of 10 or more degrees. We are well aware of the risk to eliminate here correct matches with a changing PA due to fast proper motion – but we thought it better to be on the safe side without facing the task of manual checking ~900 objects for this possibility. This step had for smaller separations also to consider the possibility of mis-identification of primary and secondary resulting in a delta in position angle of ~180°. In all such cases the sequence primary/ secondary was accordingly changed.

Next step was the elimination of false positives based on the difference between the given WDS separation and the calculated separation of the GAIA match. Even with the modest tools available to amateurs the measurement error range for separations of double stars should be less than 0.2” but on the other side many older measurements were done with tools less reliable so for larger separations an error range of 10% should allow even for some proper motion. Excessive large differences in separation are even for very large separations despite the 10% rule impossible due to the applied limited 2” search radius for the matching. Eliminating objects with this criterion is done at the cost of eliminating several obviously correct matches as for example HEI 352 with a last “measurement” of 1 arcsecond while GAIA DR1 confirms the first measurement with 2.6”. This led to the additional check of the differences between first and last measurement showing some incredible huge differences not to be explained by measurement errors but most probably simply by errors in data processing. For this reason the objects with the most obvious suspect differences between first and last measurement were checked for a GAIA match corresponding with the first measurement and if positive kept in the data set.

The resulting number of objects after this step was then 81,924.

Finally we did a plausibility control by comparing WDS mags with Gmags – with the exception of missing WDS mags or such in the blue or red band the difference should not be larger than 4 as this threshold is based on our experience with estimated Vmags for Jonckheere doubles with Vmag differences up to 3.5 and the fact that Gmags are in average 0.5mag brighter than Vmags. All objects violating this threshold were deleted.

Final number of objects now 81,734 with ~55% with a delta in separation of less than 0.1” and in position angle of less than 1°. Interesting side effect: For about 40 bogus X-coded WDS objects both components were easily found. A manual counter-check for some of these objects confirmed the positive results.

A special issue are close components of multiples which are for historical reasons often given in the WDS catalog with not resolved combined components as for example STF 1386 AB,CD – in total ~800 such components are identified in the list which should in most cases be resolved in GAIA DR1 so all such identifications for combined components are false positives and have to be deleted. In case of a missing resolution of combined components in GAIA DR1 this can be considered as an error in GAIA DR1 taking the claimed resolution limit into account – so again such objects have to be deleted from the WDS XX GAIA list but might be of use for the intended magnitude counter-check with 2MASS as such objects will most often not be resolved in 2MASS.

Special issues in the WDS XX GAIA list mostly caused by questionable WDS catalog data:

- Potential duplicity of SCA 174 AC with HEI 79 AB with the former not resolved with some doubts that it exists at all – so it was deleted from the list.
- STF 368 AB and AC: Mis-identification due to wrong WDS position for A. Correct position:

03:21:45.97 +68:30:01.5.

- Seemingly duplicity of MZA 28 AB with MZA 28 AC due to a wrong recent measurement result for the AB pair so we had to delete it.
- Potential duplicity of KOI 2790 AC with KOI 2790 AH with the latter not resolved with some doubts that it exists at all – so it was deleted from the list
- Wrong match for KOI 364 AB due to wrong WDS parameters for separation and position angle, same for KOI 554 AD, KOI 253 AC and CVN 58 AU – all deleted.
- Either HTP 46 AG is not resolved by GAIA or it is ident with HTP 46 AE. We assumed the former and deleted HTP 46 AG.
- Mis-match for BAL 2954 AB due to wrong WDS parameters from a recent measurement (while the first measurement was correct).
- BAL 897 AC seems to be ident with BAL 897 AB, the former seems bogus or wrong measurement, so we deleted it.
- CRT 9 AG is either duplicate with CRT 9 AJ or the former was not resolved by GAIA. Deleted CRT 9 AG.
- CRT 9 AV is either duplicate with CRT 9 A,Wf or the latter was not resolved by GAIA. Deleted CRT 9 A,Wf.
- CRT 9 AK is either duplicate with CRT 9 AO or the former was not resolved by GAIA. Deleted CRT 9 AK.
- CRT 6 AU is either duplicate with CRT 6 A,Wb or the former was not resolved by GAIA. Deleted CRT 6 AU.
- CRT 6 A,Wj is either duplicate with CRT 6 A,Ws or the former was not resolved by GAIA. Deleted CRT 6 A.Wj.
- CRT 25 AL is either duplicate with CRT 25 AK or the former was not resolved by GAIA. Deleted CRT 25 AL.
- CRT 2 AT is either duplicate with CRT 2 AS or the former was not resolved by GAIA. Deleted CRT 2 AT.
- CRT 8 AT is either duplicate with CRT 2 A,Wc or the former was not resolved by GAIA. Deleted CRT 8 AT.
- CSN 12 AQ is either duplicate with CSN 12 AL or the former was not resolved by GAIA. Deleted CSN 12 AQ.
- Mis-match for RST 4553 AC due to different proper motion for B and C. Deleted.
- STF 2400: Odd change of parameters between first and last observation. AC and BC correctly identified but not B in AB due to fast proper motion of A.
- BWL 46 AE and BWL 46 AF are either identical or one component (if yes then probably F) is not resolved in GAIA DR1. Deleted BWL 46 AF.
- STF 2359 AC and STF 2359 AD identical with STF 2358. STF 2359 AC and STF 2359 AD deleted
- STI 1717 A is a double itself: Aa,Ab with RA 28.99768158 Dec 57.47534431 Sep 3.068 PA 355.904 Gmag1 11.611 Gmag2 13.551.
- OGLT 113 AL either ident with OGLT 113 AN or not resolved in GAIA. OGLT 113 AL deleted.
- OGLT 113 A,Xl either ident with OGLT 113 A,Xq or not resolved in GAIA. OGLT113 A,Xl deleted.
- OGLT 211 AR either identical with OGLT 211 AS or not resolved in GAIA, OGLT 211 AR deleted.
- LDS 6215 obviously identical with LDS 215 with a curious parameter change between first and last observation. LDS 6215 deleted.
- KOU 43 AC most probably identical with KOU 43 AB or not resolved in GAIA. KOU 43 AC deleted.
- MLB 308 AB: WDS separation and position angle point to component C resulting in a mis-match for B, deleted.
- KOI 2479 AC seems a suspect WDS object, in any case is C too close to B to be resolved in GAIA, deleted.
- OGL 222 AB: GAIA objects for A and B seem to be in error. All OGL 222 objects deleted.
- OGL 70 AB: Not resolved in GAIA. All OGL 70 objects deleted.
- MRI 41 AC might be identical with STI 1717 AB. Both deleted.
- RST 4822 BC is identical with BAL 709 AC. Both objects deleted.
- GWP 913: B is actually a double itself but not resolved in GAIA and WDS. In doubt deleted.

Several objects were found to be probably duplicates (KSA 133 AE, KSA 133 AF and KOH 76 AC even triple) with very similar WDS catalog data and identical matches with GAIA DR1. As we could in several cases not make a justified selection these objects were both deleted in the WDS XX GAIA list but given in Table 1 for documentation.

The total number of objects in the WDS XX GAIA list after this last step is 80,800.

The full WDS XX GAIA spreadsheet is available for download (http://www.sterngucker.eu/WDSXXGAIAXX2MASS/WDS XX GAIA.xlsx) and selected columns for the first 20 objects are given in Table 2.

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Table 1: List of Assumed WDS Duplicates

WDS ID	Disc	C	PA	Sep	M1	M2	N	RA1 GAIA	Dec1 GAIA	RA2 GAIA	Dec2 GAIA	GAIA PA	GAIA Sep	GAIA source_id1
04299+2607	ITO 28	AC	305	10.5	8.42	13.67	NK	67.4648493	26.1123716	67.4620981	26.1140733	304.561	10.799	151297953943202432
04299+2607	HER 9	AB	303	10.5	13.53	15.9	NU	67.4648493	26.1123716	67.4620981	26.1140733	304.561	10.799	151297953943202432
21074+3841	MLB1019		246	5.9	12.1	13.5	R	316.820995	38.6863298	316.819462	38.6858748	249.179	4.608	1872034235534016512
21072+3841	MLB1018		249	4.6	12.3	13.7		316.820995	38.6863298	316.819462	38.6858748	249.179	4.608	1872034235534016512
19360+4643	KOI2579	AB	355	3.5	13.99	19.42	K	293.988676	46.7180012	293.988569	46.7189895	355.742	3.568	2128198969966349056
19360+4643	KOI2579	AC	355	3.5	15.1	18.7	R	293.988676	46.7180012	293.988569	46.7189895	355.742	3.568	2128198969966349056
22499+8807	WIS 372		153	15.2	16.4	16.3	VR	342.482643	88.119537	342.542277	88.1157692	152.554	15.284	2304680791063753728
22505+8807	LDS2019		152	15.2	20	20.4		342.482643	88.119537	342.542277	88.1157692	152.554	15.284	2304680791063753728
23184-0015	GWP3273		44	11.6	16	17.2	V	349.603283	-0.24529565	349.60553	-0.24297854	44.121	11.620	2645036883184272512
23180-0014	GRV1144		44	11.6	15.5	16.6		349.603283	-0.24529565	349.60553	-0.24297854	44.121	11.620	2645036883184272512
12596-1026	GWP1885		128	18.6	12.5	14.5	V	194.905245	-10.4415987	194.9094	-10.4447537	127.675	18.584	3625660517672431616
12596-1027	GWP1886		128	18.6	12.4	14.8	VR	194.905245	-10.4415987	194.9094	-10.4447537	127.675	18.584	3625660517672431616
14082-0030	GWP2236	AB	295	86.5	15.5	17.4	V	212.060619	-0.50833173	212.038785	-0.49823355	294.821	86.599	3659835194490169472
14082-0030	GWP2237	AC	295	86.1	15.5	16.5	V	212.060619	-0.50833173	212.038785	-0.49823355	294.821	86.599	3659835194490169472
12029+0004	GWP1737		100	12.1	14.3	16.6	V	180.732582	0.06828706	180.735888	0.06775106	99.208	12.058	3698969081064986112
12020+0004	GRV1068		100	12.1	13.9	16.5	V	180.732582	0.06828706	180.735888	0.06775106	99.208	12.058	3698969081064986112
17325-0901	GWP2723		342	7.6	12.4	12.9	VR	263.141575	-9.02195604	263.140956	-9.01992503	343.256	7.635	4166869660174061312
17326-0901	LDS 605		342	7.6	12.3	12.9	R	263.141575	-9.02195604	263.140956	-9.01992503	343.256	7.635	4166869660174061312
02543+5246	EDG 1	AB	107	51.6	3.95	12.28	N	43.5644334	52.7624576	43.5868083	52.758292	107.101	50.997	441161688978532480
02543+5246	BU 1376	AC	107	50.9	3.95	12.7	N	43.5644334	52.7624576	43.5868083	52.758292	107.101	50.997	441161688978532480
01560+5728	MRI 41	AC	223	7.9	11.7	13.6		28.9976816	57.4753443	28.9949442	57.4737518	222.744	7.806	505339839093159680
01560+5728	STI1717	AB	223	7.9	11.7	12.7		28.9976816	57.4753443	28.9949442	57.4737518	222.744	7.806	505339839093159680
12001-7812	GRY 1	AH	183	27.6	7.3	16.8	NK	180.020395	-78.192959	180.019286	-78.2006111	181.698	27.560	5836666560181202176
12001-7812	GRY 1	AG	184	27.2	6.59	14.2	N	180.020395	-78.192959	180.019286	-78.2006111	181.698	27.560	5836666560181202176
14040-6259	LDS 470		315	6.1	16.6	17.3		210.96643	-62.9807901	210.963812	-62.9795817	315.460	6.104	5865974454959096832
14139-6259	VVV 17		315	6.1	14		V	210.96643	-62.9807901	210.963812	-62.9795817	315.460	6.104	5865974454959096832
15541-2920	LAF 82	AF	205	10.8	8.73	17.4	UK	238.514781	-29.337753	238.513374	-29.3404289	204.624	10.597	6041105938319563136
15541-2920	LAF 82	AE	204	9.8	8.73	17.73	UK	238.514781	-29.337753	238.513374	-29.3404289	204.624	10.597	6041105938319563136
16298-2152	MET 77	AH	353	10.4	7.76	16.4	UK	247.45286	-21.8700783	247.452526	-21.8671204	354.024	10.706	6052280000114084352
16298-2152	MET 77	AF	351	10.2	7.76	18.9	UK	247.45286	-21.8700783	247.452526	-21.8671204	354.024	10.706	6052280000114084352

Table 1 concludes on next page.

Table 1 (conclusion). List of Assumed WDS Duplicates

WDS ID	Disc	C	PA	Sep	M1	M2	N	RA1 GAIA	Dec1 GAIA	RA2 GAIA	Dec2 GAIA	GAIA PA	GAIA Sep	GAIA source_id1
16029-2402	LAF 97	AG	56	11.1	8.93	18	UK	240.713391	-24.0327291	240.71618	-24.0309472	55.020	11.190	6236273890814541568
16029-2402	LAF 97	AF	55	10.3	8.93	19.58	UK	240.713391	-24.0327291	240.71618	-24.0309472	55.020	11.190	6236273890814541568
16069-2416	LAF 109	AF	218	9.5	8.86	18.77	UK	241.726596	-24.2697865	241.725059	-24.2719931	212.406	9.409	6242013410230303488
16069-2416	LAF 109	AE	213	9.6	8.86	16.35	UK	241.726596	-24.2697865	241.725059	-24.2719931	212.406	9.409	6242013410230303488
16014-2241	MSR 6	AE	283	14.6	9.3	16.5	N	240.356738	-22.6779564	240.352545	-22.6770706	282.895	14.290	6243197584253409024
16014-2241	MSR 6	AF	283	14.6	9.3	17.4	NK	240.356738	-22.6779564	240.352545	-22.6770706	282.895	14.290	6243197584253409024
16057-2150	LAF 104	AE	224	10.7	7.14	16.73	UK	241.430738	-21.8388904	241.4285	-21.8410627	223.718	10.820	6243323443975514112
16057-2150	LAF 104	AF	224	11	7.14	16.18	UK	241.430738	-21.8388904	241.4285	-21.8410627	223.718	10.820	6243323443975514112
16104-1904	KSA 133	AE	333	4.4	9.62	14	NK	242.590555	-19.0685979	242.58997	-19.0674878	333.519	4.465	6245781092981280000
16104-1904	KSA 133	AF	332	4.5	9.62	14.1	NK	242.590555	-19.0685979	242.58997	-19.0674878	333.519	4.465	6245781092981280000
16104-1904	KOH 76	AC	333	4.2	9.62	14.1	NK	242.590555	-19.0685979	242.58997	-19.0674878	333.519	4.465	6245781092981280000
13515-1641	GWP2105	AB	121	6.8	9.5	11.1	VK	207.875291	-16.6850045	207.876964	-16.6859804	121.341	6.755	6295491529796518528
13515-1641	GWP2106	AC	121	6.8	9.1	11.5	VK	207.875291	-16.6850045	207.876964	-16.6859804	121.341	6.755	6295491529796518528
08136+2543	HJ 441	AC	67	24.9	11.61	12.51		123.420125	25.7269063	123.427282	25.7293388	69.329	24.806	682613793897472768
08136+2543	FOX 13	BC	67	24.5	11.74	12.51		123.420125	25.7269063	123.427282	25.7293388	69.329	24.806	682613793897472768
20287-1129	BWL 55	AF	95	20.2	7.56		K	307.182447	-11.4756449	307.188082	-11.4760729	94.432	19.938	6904064442608878464
20287-1129	BWL 55	AG	100	20.2	7.56		K	307.182447	-11.4756449	307.188082	-11.4760729	94.432	19.938	6904064442608878464
10222+4114	MUG 7	EG	57	26.2	12		NK	155.551288	41.2301215	155.559182	41.2340744	56.343	25.677	804745827527474432
10222+4114	MUG 7	EF	58	24.7	12	12.2	NK	155.551288	41.2301215	155.559182	41.2340744	56.343	25.677	804745827527474432

Table 2: Data Sample Cross-Match WDS XX GAIA

WDS ID	Disc	C	PA	Sep	M1	M2	N	RA1 GAIA	Dec1 GAIA	GAIA PA	GAIA Sep	GAIA Source ID1
00000+3852	BU 860		108	6.6	6.62	11.4		0.005056903	38.85926989	107.330	6.595	2881742976228516992
00000+4004	ES 2543	AB	253	4.2	12.1	13.1		0.015231703	40.08870061	253.407	4.408	2881879556188096896
00000+4004	ES 2543	AC	66	14.5	12.1	14.1		0.015231703	40.08870061	66.192	14.402	2881879556188096896
00001+2329	SLW9018		92	2.1	16.7	17.1		0.033153544	23.48981119	91.766	2.095	2848389634598757248
00001+5400	ES 704		116	4.4	9.5	11.5		0.028113282	54.00012739	116.148	4.476	396305565933900800
00001-0122	CLZ 1		347	5.7	12.3	16.4		0.016408262	-1.373304178	347.372	6.186	2449529078517072000
00001-2432	UC 301		283	47	10.49	12.99	V	0.021178676	-24.52939809	283.349	47.021	2339620934132012928
00002+0014	SKF1061		174	1.4	17.3	18		0.054136168	0.234760715	173.381	1.409	2738196171238583168
00002+0146	WEI 45		84	1.8	10.09	10.52	N	0.050617921	1.771346495	82.549	1.834	2738669094385981824
00002+4119	FYM 352	AC	261	16.5	10.3	13.2		0.044559142	41.32467462	259.794	16.415	2882276136288699904
00002-0021	ITF 44		28	3.8	13	15.8	V	0.043266234	-0.343853134	31.126	3.891	2449930675139119232
00002-2519	COO 273		10	8.3	10.13	10.2	T	0.040492722	-25.32483653	10.546	8.440	2335010475718372480
00002-3623	LDS5152		7	84.6	18.5	18.5		0.083351099	-36.39685101	7.172	84.248	2308012964130615040
00003+0800	UC 302		130	51.5	7.68	14.41	V	0.066644045	8.007234536	130.325	51.367	2746745660126771328
00003+1642	HJ 318		61	25.9	9.56	12.88	N	0.057552939	16.68239728	61.053	25.966	2772508523232674304
00003+5651	CTT 1		93	46.3	8.59	11.39	U	0.085303984	56.85319277	92.946	46.137	421048700727595136
00003-0654	LDS6079		1	159	17.9	18.2	U	0.101318371	-6.910591468	1.131	159.288	2442653282552787072
00003-4118	SKF1140		290	17.3	9.3	18	V	0.086658096	-41.29828888	290.338	17.283	2305871596516150656
00004+0830	BU 732	AB	152	6	10.05	12.2		0.106162442	8.502132054	151.692	5.769	2747057474749252352
00004+3549	CRB 23		155	37.4	12.9	15.6	V	0.097599108	35.81138611	154.521	37.227	2880054263806535424

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2.3 Matching with 2MASS

A first idea for getting the for the intended Vmag estimation additionally required J/H/K-mags was to use URAT1 for the northern sky already matched with 2MASS but having second thoughts about using a "third party" matching result we decided to stick with the direct cross-match with 2MASS. After deleting all objects with less than 2" separation (best case resolution threshold in 2MASS) 77,976 objects remained for matching with 2MASS using the GAIA DR1 position for the primary. This resulted in 88,956 2MASS objects including multiple hits within the 5" search radius. After deleting the multiple matches 77,356 objects remained – a surprisingly high hit rate of ~99%.

The calculated GAIA separation and position angle data was then used to calculate the corresponding 2MASS position for the secondary used then for the next matching step again with 2MASS. After eliminating a small number of self-identifications, multiple matches and 2MASS objects with missing values in the J/H/K-fields 69,111 objects remained.

2.4 Elimination of outliers

For all objects with now complete G/J/H/K-mags given we calculated estimated Vmags according to Knapp and Nanson 2018. Then the differences between the WDS M1 and M2 values with the estimated Vmags were calculated and the objects with a total difference calculated as SQRT(d_M1^2 + d_M2^2) larger than 5 were considered suspect and eliminated – with the exception of the WDS objects without M2 data or with magnitudes in the red or blue range.

All these objects were manually counter-checked and kept in the data set if the reason for this large difference was due to a WDS error in magnitude but a few objects had to be deleted due to other errors. Examples are

- HJL 1046 with 3 close GAIA objects for the secondary with the wrong one matched due to different proper motion of both components.
- DAM 1298 AC with a GAIA mis-match due to the close AB pair in combination with some proper motion.
- DEA 491 with a galaxy as secondary
- CVR 1113 with a wrong WDS separation 4.6" instead of 6.4" leading to a match with a wrong GAIA object.

A random sample of the objects below this threshold but still with a large magnitude difference was also checked to get an impression what the reasons for such large differences might be – in all checked cases we found WDS magnitude issues. Examples:

- SEI 1180 BC with WDS M1 of 11 and M2 of 11.5 and estimated Vmag1 of 14.79 and Vmag2 of 13.76. The explanation was quickly found as SEI 1180 AB lists B with a magnitude of 14.6 and obviously the BC pair was not updated accordingly
- POU 3685: WDS M1 obviously far too bright as the Vmag given in other catalogs like URAT1 for the primary indicate
- LDS 5637: WDS M1 also obviously far too bright.

We got also access to an earlier WDS to 2MASS cross-match done by the USNO/WDS staff and used this file for an additional counter-check with the following results:

- The number of matched pairs in the USNO list was about 10,000 objects larger than in our list – this is most probably due to our additional matching step with GAIA
- The large majority of identical objects were listed with identical values thus considered to be confirmed by two different matching procedures
- The USNO list included to our surprise about 30 objects with a separation <2 – something we thought impossible with 2MASS as we explicitly eliminated all pairs with a separation <2" from the matching process. We had then a closer look at these objects and found indeed 2MASS objects this close for the doubles in question but quickly it became clear that we have here an issue with these 2MASS positions shaking somehow our long standing trust into the correctness of 2MASS positions. Examples:
  - LDS 4055 AC: 2MASS positions in elongated overlapping star disks already visually questionable. GAIA DR1 positions suggest much larger separation with common proper motion of the components
  - BRT 2901: 2MASS positions in elongated overlapping star disks already visually questionable. GAIA DR1 positions suggest much larger separation
  - A 2085 BC: WDS position oddly at the rim of the elongated star disk in 2MASS image. 2MASS objects for BC oddly positioned. GAIA DR1 confirms only AB but not C component with very different position for B.
- These examples suggest that while a few such WDS objects got meanwhile corrected there are still a few based on questionable 2MASS positions and are in need of updates. This suggests a follow up project examining all close WDS pairs with sep-

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aration <2" based on 2MASS objects.

- Several objects in our list are not present in the USNO list – this is simply due to the fact that meanwhile many new objects have been added to the WDS catalog even if with an observation date <2000. Most of these have been checked manually and found to be correct matches
- With the comparison between the USNO and our list we became aware of the issue with multiple objects with some components of them very close leading to erroneous identical matches. In all these cases we checked for the correct match and deleted the mis-matches. Some cases with complicated data combinations as for example close components resolved in GAIA but not in 2MASS did not allow for identification of a correct match so all such rows are to be considered questionable. Some examples:
  - A 912 AB and A 912 A.BC: Combined objects for BC exist in GAIA as well as in 2MASS but BC not resolved in both catalogs - so the A 912 A.BC line should be correct but not the A 912 AB line as B is not resolved
  - A 98 AB and A 98 A.BC: BC is resolved in GAIA but not in 2MASS – as then no G/J/H/K-mag combination can be the correct one both lines are in error
  - A 76 AB and A 76 A.BC: BC is neither resolved in GAIA nor in 2MASS but the GAIA object seemingly combined for BC is slightly off in position and listed with a far too faint Gmag for a combined object. Both object lines are for this reason questionable.
- A few objects included in both lists showed different values and were all checked manually – we found different reasons especially such as meanwhile changed WDS parameters for separation and position angle.

A final counter-check was to look for multiples with identical 2MASS matches despite different GAIA matches due to non-resolution in 2MASS – such a situation occurred several times. Example is J 425 with in total 4 components all resolved in GAIA but with AB not resolved in 2MASS. For this reason all WDS objects for J 425 had to be deleted because of no use for a visual magnitude estimation.

So far the photometry quality flag in 2MASS had not been taken into account – we decided to eliminate all objects with questionable data quality in any of the J/H/K-bands for both components but to keep values down to grade “D” means a valid measurement if with an error range larger than 0.215. This reduced the number of remaining objects down to ~59,000.

Next check was then done by comparing the estimated visual magnitudes with the corresponding Gmags – a comparison with earlier studies showed a larger percentage of objects with estimated Vmags >1.5mag fainter than Gmags. Manual check of several such objects made us aware that the reason for such large differences was often a GAIA DR1 mis-match due to missing GAIA objects but a false positive identification with a star nearby leading then to a simply wrong Gmag value. We “solved” this issue by simply deleting all objects with such large differences in magnitudes. Then there remained the issue with estimated Vmags brighter than Gmags – basically impossible as the G-band includes B. V and I-band but unavoidable due to measurement errors in the used data. But as any difference here larger than 0.2 is a hint for a serious issue we deleted also such objects reducing the data set to ~58,000 objects considered now of reasonable good data quality.

The final WDS XX GAIA XX 2MASS spreadsheet with 58,034 objects is available for download using http://www.sterngucker.eu/WDSXXGAIAXX2MASS/WDS XX GAIA XX 2MASS.xlsx. About 5.700 objects for which we provide estimated visual magnitudes are listed in WDS with magnitudes in the red band. From the about 100 objects in the WDS XX GAIA list without a WDS magnitude for the secondary only 5 “survived” indicating a lack of corresponding 2MASS objects at least with suitable J/H/K-mags. In all these cases it might be a good idea to use Gmags as Vmag estimations. About 17,500 objects are listed with a difference between WDS magnitude and the estimated Vmag for the secondary larger than 0.5mag indicating a potential need to “repair” the WDS magnitudes. Caveat: The formula used to calculate estimated Vmags aims for faint stars so any estimation results brighter than a threshold of 9mag is considered to be questionable – this is especially the case for about 300 objects with bright primaries. But a good part of such objects is WDS listed with red band magnitudes so in such situations even questionable Vmag estimations might be of better use than the given red band magnitudes. There are also about 40 objects with brighter secondaries with such a data combination but only a few with red band magnitudes – but even seemingly absurd large differences between WDS M2 and the estimated Vmag are worth a look: For example STF760 AB is given with M2 of 8.87 and the estimated Vmag comes with 11.925 – counter-checking with APASS gives then 11.682 visual magnitude so in this case there is simply the WDS mag wrong by ~3mags.

In several cases the given Vmag estimations are slightly brighter than the corresponding Gmags – this should by definition impossible as G-band covers the full visual range from blue to red and can only be explained by photometry error issues but as the upper limit of such differences is below 0.2 this is considered to be within a range to be expected from even very good estimations.

The first 20 rows are given with selected columns in Table 3 with Vest1/2 for the (from G/J/H/K-mags) calculated Vmag estimations and dM1/2 for the differences to WDS Mag1/2:

2.5 Missing WDS X GAIA matches

We had finally a look at the WDS objects not matched with GAIA DR1 objects within the applied 5" search radius to get an idea what might be the reasons. An additional cross-match between WDS and GAIA DR1 with a search radius of 25" yielded in total 138,710 objects which means that about 3.500 WDS objects are at least with the current GAIA data release not to be located even within a search radius this large. In the search radius range from 5 to 25 arc seconds ~9,760 additional matches for the primary of WDS pairs were found. Applying WDS separation and position angle on these positions and cross-matching again for the secondaries reduced the number of matching pairs to ~4,800 – but eliminating self-identifications. multiple matches. mis-matches with too large differences in separation and position angle reduced this number to meagre ~340 most probably correct matches.

A final check for identical matches yielded the result that LDS 9114 and USN 3 are identical objects - both for this reason deleted from the list. Several multiples with close components were correctly resolved at least for some components with STF 2944 demonstrating a gap in the used logic as AC and BC are considered to be resolved correctly but not the close AB pair because the delta in separation between WDS and GAIA DR1 caused probably by the known orbit was considered as being too large despite the correct initial identification.

The complete list of these matched objects is available for download using http://www.sterngucker.eu/WDSXXGAIAXX2MASS/WDS XX GAIA search radius up to 25.xlsx.

We checked then several pairs without matching GAIA components manually and found a multitude of reasons:

- Missing GAIA objects due to the still limited sky coverage of the DR1 catalog
- GAIA DR1 catalog errors (see next paragraph)
- Large proper motion for only one of the components (for example HER 5 A) or very different proper motion for both components (as for example with many components of Kruger 60)
- WDS catalog errors. especially wrong recent "precise" measurements.

3. GAIA DR1 resolution limit and data errors

No star catalog is completely free of errors. This is true also for GAIA DR1 despite its high level of precision. Such errors might remain hidden if the catalog is used manually simply for an object to object comparison but if used with a large number of objects then the analysis of outliers will necessarily uncover also some GAIA DR1 errors as is the case also in this project. In a few cases there are simply Gmag errors as for example for J 1876 with a far too faint Gmag for the primary but we found also a number of potential astrometry errors in form of "ghost" objects with extremely small separations. One example is POU 369 with two GAIA DR1 objects for the secondary with a separation of 0.16" and a ΔM of 4.5 – no realistic chance for resolution even for the GAIA equipment.

The following is a quote from the GAIA performance description (https://www.cosmos.esa.int/web/gaia/science-performance#): "*Regarding multiple stars. the minimum separation to resolve a close. equal-brightness double star in the* on-board star-mapper *detector is 0.23 arcsec in the along-scan and 0.70 arcsec in the across-scan direction. independent of the brightness of the primary. During the course of the mission. a given object will be observed many times with 'random' scanning angles meaning that. typically. close double stars may be resolved on board in some transits and stay unresolved in others. In the* on-ground processing, *however, the full resolution of the astrometric instrument will allow to systematically resolve double stars down to separations of ~0.1 arcsec*". The latter seems despite the simplification "equal-brightness" a bit over-optimistic but even if we accept this claim as realistic then we are at a loss to explain the large number of 230 objects with a separation even smaller than this threshold. Yet we have to notice the pattern that most such objects are matched with WDS objects with WDS separation below 1"and that at least in a few cases also the position angle is a close match. A few such objects are listed in Table 5 (the full list of the mentioned 230 objects is given in the appendix).

A first look at this list shows that most of the closest matches are indeed WDS objects already updated with GAIA DR1 data indicated by the observation epoch 2015. Having the huge number of bogus Tycho double stars in mind we would suggest to be a bit cautious in this regard and take such close "pairs" with a good bit of scepticism especially if the difference in

(Text continues on page 512)

Table 3: Data Sample from the Cross-Match WDS/GAIA/2MASS

WDS ID	Disc	C	PA	Sep	M1	M2	Gmag1	Jmag1	Hmag1	Kmag1	Vest1	dM1	Gmag2	Jmag2	Hmag2	Kmag2	Vest2	dM2
00000+3852	BU 860		108	6.6	6.62	11.4	6.606	6.522	6.562	6.509	6.521	0.099	11.373	9.682	9.406	9.656	12.023	0.623
00000+4004	ES 2543	AB	253	4.2	12.1	13.1	11.995	10.374	9.737	9.658	12.621	0.521	13.543	12.408	12.041	11.963	13.869	0.769
00000+4004	ES 2543	AC	66	14.5	12.1	14.1	11.995	10.374	9.737	9.658	12.621	0.521	13.987	12.858	12.578	12.508	14.298	0.198
00001-0122	CLZ 1		347	5.7	12.3	16.4	12.092	11.051	10.703	10.631	12.396	0.096	15.522	13.401	12.835	12.586	16.354	0.046
00001-2432	UC 301		283	47	10.49	12.99	10.311	9.433	9.15	9.065	10.564	0.074	12.496	11.026	10.435	10.318	13.034	0.044
00002-0021	ITF 44		28	3.8	13	15.8	12.834	11.837	11.477	11.508	13.094	0.094	15.34	13.621	12.979	12.842	15.959	0.159
00002-2519	COO 273		10	8.3	10.13	10.2	9.806	8.949	8.768	8.659	10.057	0.073	9.868	9.021	8.832	8.734	10.112	0.088
00003+1642	HJ 318		61	25.9	9.56	12.88	9.068	7.518	6.979	6.868	9.711	0.151	12.689	11.771	11.448	11.424	12.913	0.033
00003+5651	CTT 1		93	46.3	8.59	11.39	8.513	8.067	7.998	7.978	8.575	0.015	11.342	10.64	10.497	10.433	11.480	0.090
00003-0654	LDS6079		1	159	17.9	18.2	16.793	14.622	14.02	13.828	17.623	0.277	16.691	14.033	13.481	13.126	17.792	0.408
00004+0830	BU 732	AB	152	6	10.05	12.2	9.783	8.628	8.202	8.194	10.190	0.140	11.695	10.7	10.484	10.349	11.983	0.217
00004+3549	CRB 23		155	37.4	12.9	15.6	12.781	11.204	10.662	10.526	13.368	0.468	15.117	12.72	12.097	11.852	16.106	0.506
00004+5044	HJ 1923		279	11.5	11.65	12.14	11.565	10.732	10.477	10.42	11.767	0.117	12.043	11.211	10.92	10.869	12.236	0.096
00004+6026	STI1248		48	12.3	10.37	10.78	9.972	8.911	8.479	8.469	10.327	0.043	10.525	9.325	8.874	8.789	10.949	0.169
00004+7305	HJ 3231	AB	282	23.2	11.11	14	10.767	9.75	9.457	9.378	11.083	0.027	13.366	11.926	11.541	11.381	13.863	0.137
00004+7305	HJ 3231	AC	296	44.7	11.11	11.86	10.767	9.75	9.457	9.378	11.083	0.027	11.564	10.545	10.253	10.203	11.864	0.004
00004-0902	LDS6080		261	15.9	16.9	17.8	15.698	13.041	12.509	12.262	16.804	0.096	16.255	13.622	13.057	12.822	17.339	0.461
00005+4917	HU 700		338	4.7	9.6	14.5	9.547	9.21	9.248	9.202	9.537	0.063	12.802	11.833	11.515	11.5	13.050	1.450
00005+5457	STI3076		277	8.3	11.5	13	11.569	10.617	10.349	10.286	11.834	0.334	12.455	10.882	10.407	10.228	13.046	0.046
00005+5609	STI3078		194	13.8	12.5	12.7	12.354	11.579	11.385	11.406	12.508	0.008	12.172	11.047	10.728	10.663	12.517	0.183

Table 4. Data sample cross-match WDS/GAIA with search radius larger 5" up to 25"

WDS ID	Disc	GAIA RA1	GAIA Dec1	GAIA source_id1	GAIA Sep	GAIA PA	Gmag1	Gmag2
02565+5526	LDS5401	44.1487794	55.4353531	459661938484428288	16.600	21.036	9.562	10.45
23141-0855	S 826 BC	348.534052	-8.9314086	2630189146882272640	64.400	115.288	7.946	8.835
14349+2510	LDS4481	218.712752	25.1661376	1255095271886272512	200.800	205.350	12.372	15.629
04021-3429	LDS3551 AD	60.5163236	-34.48223	4858250268300556160	64.201	313.393	6.97	17.417
21589-3227	LDS4929	329.707194	-32.473123	6612817590665020032	113.101	353.203	13.12	13.762
02260+4228	LDS3383	36.4687382	42.4667829	339492047780765440	6.998	90.070	17.254	18.847
00337-3500	HJ 3375	8.43223986	-35.004238	5005222979723633280	4.402	170.606	6.405	8.229
04591-2745	WIS 111	74.7709125	-27.744263	4880281109772269056	606.302	179.035	13.218	13.34
12229+1725	GIC 107	185.705993	17.4129216	3946871226140144000	6.103	261.473	14.041	14.378
23338-7924	TSN 41	353.456952	-79.397297	6352761001678568576	11.203	123.225	15.134	15.554

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Table 5. Extremely Close GAIA Objects Matched with Close WDS Pairs

WDS ID	Disc	Obs1	Obs2	WDS PA1	WDS PA2	Gaia PA	WDS Sep1	WDS Sep2	Gaia Sep	WDS M1	Gmag1	WDS M2	Gmag2
06165-4338	B 2108	1929	2015	80	112	111.969	0.4	0.1	0.065	11.1	10.291	11.6	10.300
05384+5105	HU 557	1902	2015	286	301	300.916	0.3	0.1	0.074	9.69	8.877	9.61	8.837
03031-2339	DAM1296	2015	2015	85	85	84.895	0.1	0.1	0.060	10.1	9.868	10.1	9.880
04547-2206	RST3406	1936	2015	264	252	252.133	1.6	0.1	0.080	9.91	9.749	14.4	9.739
03395-2209	TDS2614	1991	2015	213	308	307.862	0.6	0.1	0.066	11.32	10.684	11.36	10.658
04385-0524	RST4249	1939	2015	27	84	83.789	0.4	0.1	0.066	8.7	8.292	9.5	8.184
03095-3222	B 1033	1928	2015	321	19	19.217	0.6	0.1	0.092	10.35	9.370	10.36	9.370
04114+6559	TDS2780	1991	2015	9	359	358.750	0.5	0.1	0.071	11.19	10.500	11.24	10.114
05129-4025	I 1149	1926	2015	202	149	148.738	1.1	0.1	0.060	10.11	9.837	11.19	9.810
05083+7538	JNN 266	2012	2015	212	352	352.289	0.2	0.1	0.094	14.07	12.325	15	12.319
21307-3838	B 530 AB	1926	1991	37	44	44.302	1.0	0.9	0.079	7.61	7.382	10.52	7.313
03541-4152	B 1461	1929	2015	137	52	51.673	0.3	0.1	0.072	10.72	9.304	10.05	9.311
05115-4837	RST5213	1946	2015	154	30	29.656	0.2	0.1	0.068	11.3	10.462	11.4	10.481
04242-6411	B 1468 AB	1929	2015	347	93	92.619	0.3	0.1	0.082	9.64	8.911	10.35	8.895
03152-7355	TDS2501	1991	2015	276	250	250.395	0.7	0.1	0.062	11.32	10.603	11.82	10.712
06096-3411	HDS 840	1991	2015	311	125	125.399	0.3	0.1	0.071	8.91	8.423	9.74	8.441
04504+0934	A 2039 BC	1909	2015	100	298	297.585	0.2	0.1	0.095	10.4	9.593	10.4	9.577
04118-2444	DAM1312 Aa;Ab	2015	2015	74	74	74.624	0.1	0.1	0.066	11.4	10.615	11.4	10.606
23197-4619	RST3323	1935	1991	191	196	196.726	0.4	0.6	0.072	8.32	7.793	10.09	8.292
08503+3504	COU1893	1981	1981	149	149	149.879	0.2	0.2	0.099	11.7	10.768	11.7	10.755

(Continued from page 510)

separation and position angle is not really close to the earlier observations. This does not mean that we consider necessarily all these GAIA matches as bogus as for example the last object COU 1893 simply seems too close in separation as well as in position angle but for most objects we have here differences which are not to be considered realistic matches even in case of a so far unknown orbit. And if it is wise to take such close GAIA DR1 objects as "discoveries" as done for DAM 1296 and DAM 1312 Aa/Ab has to remain open until confirmed by future GAIA data releases.

To verify this point we took a GAIA DR1 random sample of a rectangle with 301<RA<302 and -66<Dec< -65 and got in total ~5,900 objects. We looked then for very close objects within a search radius of 1 arcsecond and after eliminating the self-identifications we got a final set of 22 GAIA ghosts as "close doubles" as listed in Table 6.

With 22 ghost objects out of 5,900 GAIA DR1 stars

Table 6: 22 Assumed GAIA Ghosts out of a Sample of All objects with 301<RA<302 and -66<Dec<-65

source_id1	ra1	dec1	Sep	e_Sep	PA	e_PA	Gmag1	Gmag2
6427654953465090560	301.334628	-65.8465657	0.181	0.067	290.809	20.358	17.348	17.367
6427656465293619712	301.308445	-65.7846545	0.991	0.016	272.581	0.938	15.354	20.239
6427662650046092544	301.740636	-65.8945812	0.342	0.006	257.858	0.968	18.971	19.433
6427662997938036608	301.672646	-65.8670079	0.177	0.009	359.952	3.046	16.977	17.033
6427675947265290112	301.60564	-65.7747602	0.292	0.016	349.190	3.075	19.147	19.552
6427676737539309184	301.677392	-65.719968	0.635	0.005	120.833	0.461	20.356	20.469
6427678627324803712	301.965222	-65.6518767	0.074	0.022	355.468	16.833	14.510	19.461
6427678730404599168	301.847077	-65.6704278	0.855	0.014	281.902	0.967	20.177	20.680
6427746354664980480	301.032009	-65.4303553	0.703	0.002	112.713	0.189	19.874	20.168
6427746870061000064	301.240565	-65.3609771	0.147	0.009	176.045	3.684	18.817	18.848
6427754704081207808	301.666291	-65.2202658	0.738	0.003	313.763	0.202	18.859	19.283
6427734294396672000	301.470151	-65.4611964	0.179	0.007	161.797	2.131	14.832	14.854
6427738069672167168	301.941502	-65.3590983	0.127	0.041	175.879	18.100	14.042	19.988
6427688316771015424	301.982732	-65.5231943	0.628	0.010	144.061	0.903	14.539	17.488
6427688900886832512	301.870431	-65.5460005	0.352	0.010	180.069	1.598	16.983	17.098
6427688939541459328	301.896728	-65.5310326	0.151	0.071	344.173	25.309	19.828	19.834
6427704023465952256	301.23265	-65.6977221	0.168	0.062	97.373	20.310	19.101	19.126
6427708554656918144	301.160559	-65.5953001	0.817	0.001	234.140	0.066	12.890	16.228
6427708902548960896	301.021239	-65.6038887	0.206	0.033	276.387	9.218	10.174	10.175
6427708902548978432	301.009529	-65.6030558	0.226	0.034	286.305	8.565	11.443	11.464
6427729445377842816	301.449535	-65.5394522	0.126	0.067	174.291	27.969	14.557	19.512
6427759269630182272	301.404651	-65.1729839	0.642	0.004	358.522	0.359	17.964	18.057

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Table 7. Three Correctly Identified Close Doubles out of 18 in a Random Sample of GAIA Objects

WDS ID	Disc	gaia source_id1	gaia ra1	gaia dec1	Sep	PA
08285-1947	OL 62 AB	5706926455850249984	127.12946	-19.778736	0.916	171.869
22499+6119	HU 986 AB	2206851125508023808	342.475695	61.3099062	0.842	114.541
03356+3141	BU 533 AB	121299703324215040	53.9081108	31.6804408	1.023	220.052

a rough estimation of the total number of GAIA DR1 ghost objects is then between 3 and 4 million. We counter-checked this estimation by checking all 2,320,413 GAIA DR1 objects with RA between 179 and 180 for close "companions" and found 13,513 such pairs. Even if a few of them might be ident with close WDS pairs (WDS lists 61 objects with separation <1" with RA between 179 and 180) there remains a huge number of suspect GAIA objects.

We contacted then the GAIA team and got a confirmation that this problem is known and already described in Arenou at al., 2017. This report mentions that despite the application of a filter to eliminate such duplicate objects some duplicates remained in GAIA DR1 to avoid the elimination of optical close but correctly identified stars in dense populated fields – but we have the impression that this report might be underestimating the dimension of this issue.

Using the "random index" feature of the GAIA Archive we pulled a random sample of 1,000.000 GAIA objects and checked this sample via cross-match with GAIA DR1 for "doubles" with <1 arcsecond separation resulting in 5,559 objects with separations down to 0.059". which means 1 GAIA pixel. A cross-match with WDS for the same sample resulted in 18 doubles with <1" separation with 3 of them correctly identified by GAIA DR1, see Table 7.

A side effect of this effort is the confirmation of the good quality of our cross-match WDS with GAIA as these 3 objects are also included in our WDS XX GAIA list. But with this modest hit rate it seems again rather realistic that the false positives of the detected 5,556 GAIA "doubles" in this sample is quite high. As we currently don't have resources for a counter-check available we cannot verify the status of these objects beyond the general statement that a part of these objects might be real if only optical double stars and that possibly a tiny part may be even physical. This might be even true for a few of the ~190 objects with a separation <0.1" but here even the GAIA helpdesk does not expect a significant number of positive hits. We give below a stub of this file, in Table 8, as an example and make this file available for download (http://www.sterngucker.eu/WDSXXGAIAXX2MASS/Random GAIA doubles.xlsx) but refrain explicitly from reporting these objects as "newly discovered double stars" as we intend a follow up here with future GAIA data releases (never trust a single source. especially not a first data release).

Summary

Cross-matching of catalogs means not only finding corresponding objects but also dealing with errors in the used catalogs. When we started this project with the intention to enhance the data quality of the WDS catalog we were quite familiar with the problems of the

Table 8. Data Sample of Close "Pairs" in a Random Sample of 1 Million GAIA Objects

gaia dr1 source_id1	gaia ra1	gaia dec1	gaia dr1 source_id2	gaia ra2	gaia dec2	Sep"	PA°
1000567920717323008	105.7851461	57.59742526	1000567920717323392	105.7849426	57.59723865	0.778	210.299
1002387573807139840	104.38566	58.868857	1002387578101811200	104.3856305	58.86888478	0.114	331.241
1003468806056307584	100.9044325	59.98496819	1003468810348919680	100.9042532	59.98493159	0.349	247.803
1007834593065931392	94.57176201	63.03346743	1007834593065931264	94.57141095	63.03338655	0.643	243.067
1008214062016960000	90.65645966	64.40172453	1008214057721533056	90.65638421	64.40169701	0.154	229.828
1019834697330628864	141.9518923	52.83955215	1019834693035503104	141.9518048	52.83976823	0.801	346.250
1031079608906618368	130.568166	55.61037417	1031079604611555712	130.5683233	55.61044162	0.402	52.803
1037527179451624960	135.1976184	57.71530281	1037527175156636160	135.1975732	57.71536155	0.229	337.687
1049848130664256640	147.8117683	59.76899136	1049848130659210496	147.8117761	59.76902006	0.104	7.706
1053275445841487744	153.1965782	64.74360495	1053275450136136448	153.1967115	64.74363796	0.237	59.863
107017944927738496	32.4012862	26.5563586	107017940633435392	32.40137098	26.55631892	0.308	117.622
1080715308995555328	173.9587796	77.28349767	1080715304700543872	173.9586764	77.28354278	0.182	333.272
1081076258047310464	119.9410637	55.56786227	1081076253752079744	119.9411132	55.56779916	0.249	156.073
1085810789476375680	113.1602271	59.30319969	1085810789476375808	113.1606703	59.30322021	0.818	84.817

WDS catalog. Regarding GAIA DR1 we were only aware of some limitations in the sky coverage despite the huge number of GAIA objects but were not prepared for unexpected issues with GAIA double star resolution. Only after contacting the GAIA helpdesk to discuss the issue of ghost stars did we became aware of the serious limitation of GAIA DR1 regarding resolution of close double stars already discussed in Arenou et al. 2017. This paper not only documents the rapidly dropping resolution rate for double stars below 4" separation but also the excess of objects with very small separations indicating a problem with ghost stars. In this paper we find on page 13 also for the first time the magic word "preliminary" not to be found in for example the VizieR standard catalog description for GAIA DR1. If we had known these issues at the beginning of our project we might have postponed it but in hindsight the huge benefit of having to deal also with GAIA DR1 shortcomings was a steep learning curve how to handle such issues – a perfect preparation for future projects based on GAIA DR2 with as announced far less such problems.

Regarding 2MASS photometry data in the J/H/K-band we had to realize a quality issue for a good part of the provided magnitudes but this is very well covered with the also given error information including a photometry quality flag. Lesson confirmed: Given catalog error data has to be taken seriously.

Despite the mentioned catalog issues we are able to present recent most precise astrometry measurements for about 60% of the WDS objects and well-founded visual magnitude estimations for about 40% of the WDS objects. About two thirds of these Vmag estimations based on G/J/H/K-mag values from GAIA DR1 and 2MASS rather confirm the given WDS data but for about 15% of the WDS objects we suggest the replacement of given magnitudes based on measurements outside the V-band (blue, red, infrared) or older less precise estimations with the Vmag estimations provided here. We have done our best to eliminate errors as far as possible and are confident that the error contamination in our WDS XX GAIA and WDS XX GAIA XX 2MASS cross-match lists is very low.

Acknowledgements:

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

- 2MASS catalog
- 2MASS images
- Aladin Sky Atlas v9 and v10
- CDS VizieR, TAP Vizier and X-Match
- GAIA DR1 catalog
- GAIA Archive
- UCAC5 catalog
- URAT1 catalog

Special thanks to François-Xavier Pineau/CDS for explaining how X-Match works in detail.

Special thanks to Brian Mason/USNO for making an earlier cross-match WDS with 2MASS available to us allowing for an additional counter-check.

Special thanks to Timo Prusti/ESA for his advice how to use best the GAIA Archive and his reference to Arenou at al. 2017.

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Estimating Visual Magnitudes for Wide Double Stars with Missing or Suspect WDS Values

Appendix

Table 9. List of WDS Objects with GAIA DR1 Separation <0.1" (assumed mostly ghosts)

WDS ID	Disc	Obs1	Obs2	WDS PA1	WDS PA2	Gaia PA	WDS Sep1	WDS Sep2	Gaia Sep	WDS M1	Gmag1	WDS M2	Gmag2
06165-4338	B 2108	1929	2015	80	112	111.969	0.4	0.1	0.065	11.1	10.291	11.6	10.300
05384+5105	HU 557	1902	2015	286	301	300.916	0.3	0.1	0.074	9.69	8.877	9.61	8.837
03031-2339	DAM1296	2015	2015	85	85	84.895	0.1	0.1	0.060	10.1	9.868	10.1	9.880
04547-2206	RST3406	1936	2015	264	252	252.133	1.6	0.1	0.080	9.91	9.749	14.4	9.739
03395-2209	TDS2614	1991	2015	213	308	307.862	0.6	0.1	0.066	11.32	10.684	11.36	10.658
04385-0524	RST4249	1939	2015	27	84	83.789	0.4	0.1	0.066	8.7	8.292	9.5	8.184
03095-3222	B 1033	1928	2015	321	19	19.217	0.6	0.1	0.092	10.35	9.370	10.36	9.370
04114+6559	TDS2780	1991	2015	9	359	358.750	0.5	0.1	0.071	11.19	10.500	11.24	10.114
05129-4025	I 1149	1926	2015	202	149	148.738	1.1	0.1	0.060	10.11	9.837	11.19	9.810
05083+7538	JNN 266	2012	2015	212	352	352.289	0.2	0.1	0.094	14.07	12.325	15	12.319
21307-3838	B 530 AB	1926	1991	37	44	44.302	1.0	0.9	0.079	7.61	7.382	10.52	7.313
03541-4152	B 1461	1929	2015	137	52	51.673	0.3	0.1	0.072	10.72	9.304	10.05	9.311
05115-4837	RST5213	1946	2015	154	30	29.656	0.2	0.1	0.068	11.3	10.462	11.4	10.481
04242-6411	B 1468 AB	1929	2015	347	93	92.619	0.3	0.1	0.082	9.64	8.911	10.35	8.895
03152-7355	TDS2501	1991	2015	276	250	250.395	0.7	0.1	0.062	11.32	10.603	11.82	10.712
06096-3411	HDS 840	1991	2015	311	125	125.399	0.3	0.1	0.071	8.91	8.423	9.74	8.441
04504+0934	A 2039 BC	1909	2015	100	298	297.585	0.2	0.1	0.095	10.4	9.593	10.4	9.577
04118-2444	DAM1312 Aa;Ab	2015	2015	74	74	74.624	0.1	0.1	0.066	11.4	10.615	11.4	10.606
23197-4619	RST3323	1935	1991	191	196	196.726	0.4	0.6	0.072	8.32	7.793	10.09	8.292
08503+3504	COU1893	1981	1981	149	149	149.879	0.2	0.2	0.099	11.7	10.768	11.7	10.755
00579-6634	I 48	1896	1999	342	10	11.004	0.8	0.3	0.096	7.44	6.891	9.31	6.886
01553-2433	HDS 262	1991	1991	48	48	49.656	0.2	0.2	0.059	9.97	9.021	9.99	9.014
20467-3245	RST2160	1934	1944	139	138	139.730	0.4	0.5	0.092	11.2	10.533	12.6	11.306
04002+0818	A 1936 BC	1908	2008	136	310	307.936	0.4	0.3	0.079	9.6	9.904	9.7	9.908
14534-6147	RST5009	1942	1966	119	127	124.559	0.6	0.7	0.071	10.7	10.192	11.7	10.100
15155-4913	I 960	1910	2008	120	114	116.481	0.7	0.9	0.070	8.56	8.360	9.38	8.238
07170-5014	VOU 26	1933	1933	243	243	245.628	0.2	0.2	0.087	9.4	8.830	10.3	8.822
23578+3838	MCT 14	1997	2011	290	247	244.332	0.8	0.5	0.076	9.7	11.287	10.4	11.302
18440-2237	RST5453	1945	2008	197	208	211.106	0.2	0.3	0.066	9.7	8.844	9.7	8.870
21112+3925	COU1969	1981	2008	70	219	215.841	0.2	0.3	0.085	10.6	9.674	10.6	9.672
17174+1319	HDS2444	1991	2010	28	305	301.831	0.1	0.2	0.066	8.56	7.823	8.79	7.821
19269-3900	I 1402	1926	1991	327	314	317.214	0.4	0.3	0.089	10.54	9.773	11.08	9.745
00348-5853	I 439	1911	1991	102	109	112.492	1.1	0.6	0.078	9.96	8.895	9.86	8.887
08052+1127	TDS5511	1991	1991	103	103	107.002	1.2	1.2	0.089	11.08	10.807	11.64	10.774
16063-6022	RST5042	1942	1967	45	40	35.791	0.9	1	0.068	10.8	10.608	13.7	10.561
06585-2736	RST 219	1930	1991	119	117	112.531	0.4	0.5	0.067	11.21	10.687	11.29	10.411
00034-2900	B 634	1926	1991	312	289	284.254	0.5	0.5	0.098	10.23	9.300	10.15	9.302
04160+2726	TDS 132	1991	2007	235	227	222.133	0.9	0.9	0.095	10.91	10.189	11	10.115
17591+3228	HU 1185	1905	2010	184	138	133.096	0.3	0.4	0.078	9.81	9.095	10.48	9.064
15359+0712	A 1123	1905	1963	86	79	84.304	0.5	0.4	0.066	9.67	9.361	10.8	9.361
19422-1015	RST4639	1940	1991	19	29	23.375	0.4	0.4	0.067	10.21	9.555	10.45	9.093
08161+7648	MLR 496	1976	1989	145	127	132.675	0.3	0.3	0.072	10.4	9.610	10.8	9.625
00427-6537	I 440	1907	2009	220	269	274.723	0.4	0.4	0.075	7.27	6.993	8.75	6.968

Table 9 continues on the next page.

Table 9 (continued). List of WDS Objects with GAIA DR1 Separation <0.1" (assumed mostly ghosts)

WDS ID	Disc	Obs1	Obs2	WDS PA1	WDS PA2	Gaia PA	WDS Sep1	WDS Sep2	Gaia Sep	WDS M1	Gmag1	WDS M2	Gmag2
19306+2817	COU1161 Aa;Ab	1973	1992	27	6	11.736	0.1	0.2	0.069	8.1	8.726	8.9	8.725
08498-6047	TDS 495	1991	1991	267	267	261.253	1.1	1.1	0.066	10.92	10.743	12.55	10.851
10287+4558	A 1993	1909	1997	46	155	160.933	0.5	0.3	0.090	9.25	8.581	10.22	8.604
01028+0214	A 2308	1910	2014	338	299	292.719	0.3	0.4	0.060	9.87	9.267	11.73	9.261
20599+4525	HEI 15	1975	2010	322	322	328.324	0.9	0.8	0.083	10	9.427	10.72	9.360
15526-0036	HDS2235	1991	1991	75	75	81.337	0.5	0.5	0.083	10.99	10.207	11.88	10.220
02255-2442	RST2279	1933	1991	77	84	77.550	0.5	0.8	0.095	10.87	10.328	11.24	10.391
07536-6346	RST 293	1930	1993	351	49	55.897	0.3	0.3	0.062	9.8	8.866	9.89	8.818
19104+2320	COU 120	1966	2007	28	50	58.512	0.2	0.3	0.070	10.8	9.749	10.8	9.755
08179-2026	B 1982	1931	1959	161	159	150.231	0.3	0.3	0.066	10.1	9.136	10.5	9.153
16488+6752	MLR 183	1971	2006	38	31	40.178	0.9	0.8	0.082	10.48	10.106	10.76	10.134
04116+2950	YR 11	2000	2014	95	86	76.644	0.5	0.5	0.095	8.31	7.974	11.93	7.971
15497-3925	RST1865	1935	1945	226	220	229.474	0.2	0.2	0.074	10.9	10.231	11.1	10.210
11267+6654	HU 1133	1905	2010	357	346	336.165	0.5	0.8	0.065	8.65	8.357	9.64	8.378
03439+6025	HDS 474	1991	2012	10	20	9.253	1.0	0.8	0.059	10.67	10.047	12.7	9.992
19244+2543	COU 724	1971	2008	169	176	163.973	0.3	0.3	0.090	10.8	9.844	10.9	9.818
23508+7909	MLR 300	1971	2001	185	177	163.404	0.5	0.5	0.087	10.25	9.359	10.23	9.283
16038-4356	DON 774	1930	1991	210	152	137.808	0.3	0.3	0.085	10.44	9.172	10.78	9.186
07404-4346	DON 197	1932	1947	14	13	357.283	0.3	0.3	0.066	11	10.616	12	10.622
18423+3616	A 1381	1906	2016	122	93	108.872	0.7	0.4	0.061	10.43	9.355	10.37	9.355
13033+3435	COU 970	1973	1996	106	94	77.874	0.2	0.2	0.060	11.3	10.292	11.3	10.298
22598-5427	TDT3827	1991	1991	322	322	338.790	0.9	0.9	0.077	10.71	10.384	11.76	10.505
02333+5619	A 1276 AB	1906	2015	200	203	221.167	0.9	0.9	0.085	9.86	8.561	9.92	8.705
03545+0510	A 1831 BC	1908	2015	35	50	68.270	0.2	0.2	0.093	9.38	8.835	10.35	8.824
00371-5429	RST2249	1934	1977	57	98	116.282	0.2	0.3	0.075	10.7	9.721	10.7	9.704
21591+6400	HU 975 AB;C	1904	2008	135	135	153.499	1.9	1.9	0.085	8.9	8.791	11.02	8.802
12492-0549	OCC 718	1987	1987	-1	-1	340.302	0.1	0.1	0.080	9.7	9.109	9.7	9.120
12433-3341	I 1558	1927	1991	271	281	299.983	0.5	0.5	0.072	10.3	9.310	10.56	9.320
10095+4126	A 2143	1910	1991	125	126	145.902	0.9	0.5	0.067	10.51	9.309	10.39	9.317
08090-3905	RST3571	1937	1945	300	305	284.389	0.3	0.3	0.079	10.4	9.951	11.5	9.962
00465-5004	TDS1606	1991	1991	0	0	338.873	0.5	0.5	0.061	10.91	10.045	11.48	10.094
00588+6316	TDS1699	1991	1991	167	167	145.734	0.4	0.4	0.066	11.05	10.052	11.05	10.067
14151-0125	RST4997	1943	2004	33	249	226.197	0.3	0.3	0.092	9.8	9.216	9.8	9.231
23209+1643	HEI 88	1978	2014	193	189	212.784	0.2	0.2	0.086	9.05	8.298	9.84	8.300
10376-5744	JSP 410	1929	1991	274	92	117.681	1.5	0.5	0.090	10.78	10.168	10.87	10.161
15477-3210	B 1306	1928	1991	264	246	272.129	0.5	0.5	0.067	10.62	9.738	10.73	9.725
17542-6143	JSP 738	1930	1991	323	317	290.459	0.2	0.4	0.082	10.5	9.537	10.66	9.537
21339+4833	YR 3	1997	2014	209	214	187.403	0.2	0.3	0.067	9.42	9.026	10.47	9.016
19093+3912	JOD 17 Aa;Ab	2008	2009	162	163	135.517	0.3	0.3	0.069	12	10.272	12.3	10.269

Table 9 continues on the next page.

Estimating Visual Magnitudes for Wide Double Stars with Missing or Suspect WDS Values

Table 9 (continued). List of WDS Objects with GAIA DR1 Separation <0.1" (assumed mostly ghosts)

WDS ID	Disc	Obs1	Obs2	WDS PA1	WDS PA2	Gaia PA	WDS Sep1	WDS Sep2	Gaia Sep	WDS M1	Gmag1	WDS M2	Gmag2
06583-2524	RST2443	1935	1991	357	356	24.094	0.7	0.7	0.092	10.88	10.462	11.35	10.294
23068+6040	TDT3890	1991	1991	15	15	46.091	0.5	0.5	0.087	10.66	9.680	10.89	9.691
18145+3313	COU1007	1973	1997	28	48	15.339	0.3	0.4	0.082	11.1	10.110	11.3	10.129
16422+4112	STF2091	1830	2010	302	324	291.262	1.3	0.4	0.087	8.44	8.020	9.29	8.024
02477+0142	A 2411	1912	2008	262	285	251.408	0.4	0.3	0.094	8.22	7.471	9.62	7.471
08454-2559	I 816 AB	1910	1991	290	281	247.281	0.7	0.6	0.081	9.66	9.301	10.21	9.132
23075+4558	TDT3894	1991	1991	132	132	98.174	0.5	0.5	0.065	11.44	10.705	11.47	10.744
20270-2023	DON 986	1929	1950	131	127	160.922	0.6	0.6	0.062	11.2	10.166	11.6	10.193
17366+4827	COU1922	1980	2012	44	92	126.034	0.4	0.3	0.078	7.72	7.269	9.64	7.290
19504+2409	COU1034	1973	2007	207	208	173.818	0.3	0.3	0.063	8.5	7.562	8.7	7.559
11330+0938	A 2576 AB	1913	1991	201	238	203.635	0.5	0.5	0.070	10.15	9.273	10.23	9.213
20486-1333	RST4069	1938	2008	138	179	215.780	0.2	0.3	0.073	9.6	8.595	9.6	8.578
04410+4302	COU1708 AB;C	1979	2007	100	145	107.594	1.0	0.5	0.092	11.15	10.641		10.589
01581-0418	HDS 265	1991	2011	106	104	66.522	0.6	0.6	0.059	8.88	8.707	12.16	8.675
03433-2217	RST4759	1943	1993	88	231	193.265	0.2	0.1	0.077	9.5	8.936	9.5	8.946
04410+4302	COU1708 AB	1979	2008	143	146	107.594	0.5	0.7	0.092	11.3	10.641	13.1	10.589
17471+3235	COU 634	1971	2008	105	73	33.629	0.2	0.3	0.064	10.8	9.676	10.8	9.679
11578-4343	B 1203 AB	1928	1994	310	218	178.160	0.2	0.2	0.063	8.6	7.933	8.8	7.950
17092-6648	DON 823	1930	1991	7	22	62.622	0.5	0.4	0.082	9.51	8.620	9.5	8.620
19344+7136	KU 2	1889	2000	270	232	191.335	1.4	0.6	0.078	6.92	6.580	8.78	6.606
00410+5854	MLR 444	1981	2008	156	153	193.772	0.6	0.8	0.097	10.85	10.229	11	10.234
16233+3251	COU 619	1971	2016	156	202	243.958	0.5	0.6	0.069	9.59	8.685	9.67	8.622
08225-4102	TDS5772	1991	1991	227	227	182.633	0.8	0.8	0.062	11.29	11.101	11.8	11.108
19569+3706	COU2409	1986	2013	319	320	6.044	1.1	1.2	0.066	10.34	10.172	10.42	10.279
06359-3605	RST4816 Ba;Bb	1942	2015	312	112	158.373	0.2	0.2	0.066	7.77	7.034	8.61	7.032
10172-7252	HEI 494 AC	2015	2015	302	302	253.802	0.7	0.7	0.061	9.1	9.185	12.1	9.182
11471-1149	RST3756 AB	1937	2014	215	156	107.232	0.7	1.2	0.073	9.21	8.556	12.71	8.556
10227-2350	B 197	1926	1993	174	63	112.686	0.3	0.1	0.067	9.2	8.859	9.8	8.860
16287-6110	RST5055	1942	1970	254	256	205.317	0.5	0.5	0.090	9.5	9.310	11.5	9.762
12014-4739	TDS8174	1991	1991	6	6	314.174	0.5	0.5	0.072	10.89	10.136	11.18	10.068
20302+2651	WOR 9 AB	1959	2016	334	230	177.068	1.3	0.6	0.082	10.5	9.309	10.63	9.074
11041-4749	RST 523	1930	1990	157	168	114.184	0.4	0.6	0.070	9.8	9.054	11.3	9.288
00211+3539	HU 1202	1905	2009	204	196	250.587	1.1	1.1	0.071	10.19	9.918	10.6	9.947
19494-0746	RST4642	1940	1991	269	260	315.237	0.3	0.4	0.081	10.06	9.293	10.08	9.285
12309-4920	RST 598	1929	1991	21	4	308.394	0.5	0.5	0.067	10.84	9.899	10.75	9.869
21591+6400	HU 975 AB	1904	2008	214	210	153.499	0.3	0.3	0.085	9.39	8.791	10.04	8.802
12346-6557	RST 601	1930	1944	272	268	325.375	0.4	0.5	0.088	10.4	9.700	11.5	9.721
20219+7347	HDS2909	1991	1991	238	227	284.789	0.7	0.6	0.082	10.5	9.256	10.77	9.146
08493+3226	COU1743	1979	2008	123	118	175.951	0.3	0.3	0.059	10.81	10.055	11.24	10.041
17120-3337	B 898	1927	1992	112	114	56.023	0.3	0.3	0.079	9.34	8.875	10.01	8.925
22141+5142	TDT3419	1991	1991	118	118	59.481	0.5	0.5	0.099	11.43	10.946	11.56	10.964

Table 9 continues on the next page.

Estimating Visual Magnitudes for Wide Double Stars with Missing or Suspect WDS Values

Table 9 (continued). List of WDS Objects with GAIA DR1 Separation <0.1" (assumed mostly ghosts)

WDS ID	Disc	Obs1	Obs2	WDS PA1	WDS PA2	Gaia PA	WDS Sep1	WDS Sep2	Gaia Sep	WDS M1	Gmag1	WDS M2	Gmag2
18293-5119	RST 988	1930	1991	161	174	115.346	0.6	0.6	0.059	10.5	9.915	10.6	9.725
10507-6630	RST 512	1930	1991	16	23	320.356	0.7	1	0.079	10.92	10.332	11.04	10.432
06219-1611	TDS3776	1991	1991	57	57	353.370	0.7	0.7	0.074	11.08	10.406	11.24	10.411
12368+2014	AG 180	1991	2007	340	355	290.478	0.2	0.3	0.085	7.81	7.402	9.79	7.404
15563-5527	JSP 673	1930	1930	287	287	222.353	0.2	0.2	0.097	10.7	9.857	11.2	9.870
16248+3925	HU 1276	1905	2010	168	270	336.824	0.5	0.4	0.068	9.1	8.695	11.6	8.710
21217-7420	B 2493	1930	1991	171	160	227.961	0.3	0.4	0.069	10.4	9.557	10.43	9.552
18229+1458	HU 581	1902	2008	120	117	48.371	0.3	0.3	0.077	8.8	8.362	9.4	8.361
17184-2952	B 337	1927	1991	202	192	260.996	0.6	0.6	0.093	8.08	7.934	9.75	8.097
19134+2926	COU1157	1974	2007	92	146	76.116	0.2	0.3	0.064	9.8	8.979	9.8	8.966
06310-7044	TDS 253	1991	1991	313	313	25.835	0.9	0.9	0.093	10.89	10.454	11.54	10.346
08570+3715	HU 859	1904	2008	204	181	107.860	0.3	0.4	0.060	8.84	8.543	10.44	8.524
09508-4430	DON 365	1932	1991	81	106	30.158	0.3	0.6	0.061	11.33	10.168	11.22	10.282
23314-4210	I 1471	1926	1991	30	10	86.600	0.5	0.5	0.074	8.45	8.110	10.59	8.103
01443+5732	BU 870 AB	1880	2010	69	332	48.827	1.0	0.6	0.075	6.29	6.197	8.68	6.216
08338-1424	A 2366 BC	1911	1991	47	42	324.224	0.5	0.6	0.094	10.65	10.027	10.69	9.910
19452-4240	HDS2805	1991	2014	357	342	60.508	0.2	0.4	0.076	11.62	10.682	12.22	10.675
16065+7547	HU 916 AB	1904	1995	175	168	247.183	0.5	0.5	0.061	9.75	8.539	9.27	8.541
06538-4307	HDS 955	1991	2015	93	82	2.498	0.5	0.3	0.079	9.61	8.638	9.71	8.641
02437-2240	RST2286	1933	1993	357	12	91.567	0.2	0.1	0.088	9.8	9.243	9.8	9.229
06399-0108	TDS4012	1991	1991	351	351	270.898	0.7	0.7	0.092	11.14	10.238	11.39	10.341
23482+8247	HU 797	1904	1996	132	70	150.683	0.8	0.5	0.069	9.13	8.146	9.2	8.137
14133-7923	RST2890	1934	1971	139	140	58.840	0.4	0.4	0.098	11	9.930	11	9.923
09467+6530	TDS6800	1991	1991	19	19	295.569	0.6	0.6	0.074	11.39	10.387	11.74	10.441
13550-4235	I 401 AB	1902	1989	232	280	4.387	0.4	0.3	0.077	9.3	8.573	9.6	8.831
12519+2647	HDS1805	1991	2012	168	182	97.530	0.5	0.5	0.075	11.71	10.881	12.98	10.906
21460+3626	HDS3100	1991	2009	179	190	274.684	0.5	0.5	0.093	9.15	8.725	11.25	8.736
07274+0650	A 2867	1914	1995	345	348	73.422	0.4	0.5	0.075	10.44	9.690	10.42	9.661
19085-5050	I 1392	1926	1986	35	22	114.118	0.3	0.4	0.091	10.3	9.541	10.8	9.627
02369+5635	TDS 89	1991	1991	352	352	84.225	0.8	0.8	0.080	10.89	10.314	11.44	10.391
00505+2450	LDS3203	1960	2013	315	320	52.709	1.0	1	0.085	12.48	10.996	13.59	10.950
08452-4559	FGS 23	2008	2008	274	274	7.893	0.2	0.2	0.064	11.5	10.816	11.9	10.806
23486+1622	HEI 91	1978	2010	150	153	57.831	0.7	0.7	0.070	10.1	9.818	11.9	9.823
05171+5047	COU2579	1992	2007	36	38	134.283	0.3	0.3	0.061	10.5	9.893	11.2	9.890
10149-2738	RST1492	1933	1951	170	175	271.645	0.4	0.4	0.060	11.1	9.832	11.1	9.843
20066+0928	A 1196	1905	1974	243	240	141.705	0.2	0.3	0.083	10	9.349	10.2	9.315
13190-2536	HDS1866	1991	2007	21	189	287.828	0.2	0.1	0.063	8.52	7.950	9.9	7.951
03213+4809	COU2020	1983	2008	238	233	133.577	0.3	0.3	0.065	10.5	10.038	11	9.994
01317+1506	CHR 198	1972	2007	5	354	252.763	0.5	0.4	0.077	9.11	8.441	10.7	8.444
13194-3957	RST1712	1935	1991	63	355	96.947	0.8	0.5	0.072	10.86	9.743	11.42	9.770
07261-2409	RST4848 AB	1942	1989	210	220	323.581	0.2	0.3	0.062	9.9	9.406	9.9	9.376
12490+3556	COU1426	1976	1996	202	207	311.293	1.1	1.2	0.067	11.22	11.043	12.81	11.073

Table 9 continues on the next page.

Table 9 (continued). List of WDS Objects with GAIA DR1 Separation <0.1" (assumed mostly ghosts)

WDS ID	Disc	Obs1	Obs2	WDS PA1	WDS PA2	Gaia PA	WDS Sep1	WDS Sep2	Gaia Sep	WDS M1	Gmag1	WDS M2	Gmag2
19352+0825	BAG 27 Aa;Ab	2000	2008	46	43	297.241	0.1	0.3	0.078	10.38	9.462	10.5	9.439
13112-5522	FIN 56	1927	1990	196	173	279.309	0.4	0.4	0.072	9.9	9.428	10	9.439
13457-4643	RST 656	1928	1991	88	103	355.106	0.5	0.6	0.080	10.82	9.883	10.79	9.835
11537+2626	HDS1677	1991	2008	67	91	201.221	0.4	0.9	0.076	10.48	10.042	12.43	10.052
15171-5031	HDS2148	1991	1991	193	193	305.183	0.2	0.2	0.067	10.27	9.495	11.01	9.480
07225-1218	TDS 364	1991	1991	334	334	219.174	1.0	1	0.095	10.7	10.570	11.38	10.057
12529+3116	SHN 25	1997	1997	166	166	284.368	0.2	0.2	0.069	14.2	13.497	14.4	13.494
10172-7252	HEI 494 Ca;Cb	2015	2015	153	135	253.802	0.1	0.1	0.061	12.5	9.185	13.4	9.182
13041+5227	MLR 704	1991	2012	200	37	156.108	0.4	0.4	0.061	10.96	8.979	9.43	8.951
04478+5318	HU 612	1902	2014	198	2	122.359	0.2	0.8	0.096	7.06	6.840	8.54	6.860
10330-3956	FIN 26	1926	1991	169	169	289.781	0.2	0.3	0.088	9.21	7.916	8.28	7.912
15271+2355	A 82	1900	2014	323	354	232.824	0.8	0.8	0.073	9.74	9.169	10.48	9.384
11378-8043	I 888	1910	1991	100	104	341.358	0.5	0.4	0.093	9.52	8.628	9.61	8.624
23385-4801	I 1474	1926	1991	170	215	342.147	0.5	0.3	0.089	10.37	9.371	10.65	9.395
03032+7436	MLR 387	1972	1997	94	92	219.453	0.3	0.3	0.063	10.37	9.769	11.55	9.942
04316+3739	BU 789	1881	2014	323	333	100.687	1.3	0.7	0.065	8.7	8.365	9.42	8.438
00465+1558	HEI 19	1978	2016	240	244	114.951	0.5	0.7	0.067	11.01	10.145	11.06	10.088
17003+0106	A 2235	1910	2010	276	268	138.574	0.7	0.8	0.091	10.42	9.764	10.44	9.675
20520+8158	TDT2588	1991	1991	295	295	165.312	0.9	0.9	0.084	11.75	11.242	12.02	11.126
17090-4713	RST 902	1930	1949	340	351	120.884	0.4	0.3	0.090	11.5	10.519	11.5	10.560
16309+3804	STF2059	1829	2009	209	182	51.050	1.2	0.4	0.070	8.75	7.856	8.79	7.895
16201-5315	B 1805	1929	1979	319	326	194.362	0.4	0.3	0.065	9	7.859	9.6	7.814
12111-0633	A 77	1900	2006	60	19	245.343	0.5	0.3	0.079	8.62	8.234	10.43	8.238
23102+3540	COU1198	1973	2009	274	261	126.957	0.5	0.5	0.083	11	10.396	12	10.337
11528-5250	B 1200	1928	1990	96	104	238.048	0.3	0.3	0.063	9.6	9.191	10.6	9.216
06425+7035	MLR 405	1972	1991	241	244	108.983	0.4	0.5	0.063	8.98	8.289	9.57	8.225
03206-8608	HDS 417	1991	2014	271	295	158.668	0.3	0.3	0.059	9.32	8.589	9.97	8.555
01450+2703	COU 750	1972	2009	50	27	167.023	0.2	0.3	0.067	9.7	9.670	9.7	9.664
22282+4204	COU1833	1979	2007	257	288	147.660	0.3	0.4	0.062	11.1	10.141	11.1	10.049
18443+2052	HU 325	1901	2008	13	7	147.751	0.3	0.3	0.062	10.17	9.601	10.85	9.609
09098-2701	RST1418	1931	1967	54	51	268.975	0.3	0.3	0.081	10.3	9.313	10.3	9.318
23288+1512	HU 998	1904	1979	198	186	328.539	0.4	0.3	0.070	10.1	9.529	11.1	9.489
19004-4550	FIN 12	1926	1991	55	37	254.050	0.4	0.5	0.065	9.96	9.284	10.25	9.329
08327-5558	RST 333	1929	1991	123	153	10.030	0.3	0.4	0.060	10.09	9.164	10.21	9.113
22402+3732	HO 188	1885	2008	43	224	80.375	0.4	0.4	0.069	8.68	7.803	9.04	7.829
00241-3941	RST1187	1931	1945	295	295	78.838	0.6	0.6	0.074	9.5	9.694	12.5	9.001
08514-0529	TDS6139	1991	1991	89	89	232.960	0.5	0.5	0.061	11	10.191	11.15	10.178
19460+3717	COU2284	1985	2016	333	331	186.530	0.5	0.6	0.084	8.9	8.645	10.1	8.657
18086+1245	HDS2556	1991	1991	126	126	272.296	0.5	0.5	0.084	9.39	8.657	11.94	8.655
22002+4756	A 778 AB	1904	1994	281	240	27.892	0.3	0.2	0.067	10.1	9.441	10.9	9.421
19306+2817	COU1161 Aa;Ac	1992	2007	111	340	191.736	0.1	0.1	0.069	8.1	8.726	8.8	8.725

Table 9 concludes on the next page.

Estimating Visual Magnitudes for Wide Double Stars with Missing or Suspect WDS Values

Table 9 (conclusion). List of WDS Objects with GAIA DR1 Separation <0.1" (assumed mostly ghosts)

WDS ID	Disc	Obs1	Obs2	WDS PA1	WDS PA2	Gaia PA	WDS Sep1	WDS Sep2	Gaia Sep	WDS M1	Gmag1	WDS M2	Gmag2
10172-7252	HEI 494 AB	1989	2015	102	105	253.802	0.3	0.3	0.061	9.78	9.185	10.59	9.182
18154+5720	HDS2577	1991	2013	139	307	156.233	0.2	0.2	0.084	8.93	8.088	9.56	8.085
20416+3000	COU1174	1974	2009	24	30	180.954	0.4	0.3	0.089	10.3	9.842	11.3	9.851
19585+3553	ROE 146	1919	2013	44	45	196.311	1.5	1.5	0.063	9.85	9.698	11.46	9.761
20333+3323	RBR 30 Ba;Bb	2013	2015	295	299	90.698	0.2	0.2	0.068	9.3	11.512	9.6	11.509
10504-6359	RST3717	1938	1980	39	38	189.911	0.2	0.2	0.096	9.7	8.266	9.8	8.256
04164+3317	HU 816 AB	1902	2007	154	301	93.580	0.3	0.2	0.073	10.2	9.013	11.2	9.006
03305-4534	RST 76	1928	1969	132	125	330.615	0.6	0.5	0.086	11.9	10.845	12.2	10.986
12014-5442	TDS 654	1991	1991	202	202	356.596	1.1	1.1	0.066	10.71	10.246	11.69	10.279
22354-5511	HDS3206	1991	2015	141	158	3.160	0.2	0.3	0.060	8.06	7.352	9.77	7.351
04187+0445	A 1939	1908	2003	247	292	136.699	0.8	0.7	0.087	9.56	8.706	9.6	8.751
13137-6248	HDS1852	1991	2017	154	158	314.208	0.2	0.2	0.073	9.8	8.866	10.36	8.853
19456+4147	FOX 89	1925	1991	213	212	11.957	1.0	1	0.072	10.11	9.815	11.02	9.799
12225-5306	B 1211	1929	1991	51	49	246.054	1.0	0.9	0.059	10.24	9.916	11.04	10.030
18127-3433	RST3162	1933	1986	158	195	30.333	0.2	0.3	0.094	10.7	9.593	10.7	9.577
01286+0009	RST4748	1942	1991	192	236	70.462	0.3	0.5	0.072	10.83	9.621	10.57	9.634
12429+0516	A 1602	1907	2014	178	27	220.768	0.3	0.6	0.082	8.77	8.335	10.12	8.370
00055-1835	RST3340	1935	2001	123	287	120.582	0.3	0.3	0.097	10.4	9.775	10.4	9.749
00339+5316	TDS1523	1991	2007	84	90	256.895	0.5	0.7	0.078	10.62	10.077	10.68	9.738
22371+3712	A 1472	1906	2009	275	263	70.071	0.3	0.3	0.060	9.8	9.001	10.3	8.992
08136+1023	BU 204	1875	2004	302	292	99.459	1.1	0.8	0.062	7.58	7.132	9.36	7.128
18131-0528	RST4582	1938	1950	324	328	160.504	0.3	0.3	0.078	10.7	9.722	11	9.820
18036+3731	COU1147	1974	2016	146	175	344.068	0.7	0.7	0.091	11	10.044	11.34	10.033
23043+5131	HDS3288	1991	1991	311	311	141.119	0.7	0.7	0.081	9.66	9.783	11.73	9.495