Counter-Check of Binaries Reported to be Detected in Gaia DR2 as well as an Equal Mass "Twin" Binary Population

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Abstract: A recent paper (El-Badry et al. 2019, in the following EB19) reports the discovery of a sharp excess of equal mass "twin" binaries based on the data from an earlier paper (El-Badry and Rix 2018, in the following EB18) reporting the construction of a very pure catalog of ~55,000 wide binaries based on Gaia DR2 catalog data.

This report counter-checks both propositions using basically the identical Gaia DR2 catalog data, but with different assessment methods and different quality requirements especially regarding the relative parallax data error and using Gaia DR2 StarHorse catalog data for star masses with the result that both papers seem somewhat questionable in their use of existing data and also in their conclusions.

This report contradicts the EB18 "very pure" claim with the assessment that >50% of the reported binary pairs are, with more stringent data selection and evaluation criteria, most likely optical pairs and not binaries. The culprit for this disappointing record is the allowance for Gaia DR2 objects with an unreasonably large parallax error as well as the questionable method for calculating the likely spatial distance between the components of the assumed physical pairs.

The in EB19 reported discovery of a specific equal mass "twin" binary population seems to be a consequence of a questionable method for estimating star masses and can besides the caveats regarding the EB18 data for this reason not be confirmed. A moderate excess of very similar to equal mass pairs seems simply a consequence of the frequency of star masses in the selected star population – the most frequent masses have for obvious reasons a larger chance to be combined in a pair than other masses.

Introduction

The recently pre-published EB19 paper (26 June 2019, arXiv:1906.10128v1) on the detection of an equal mass binaries population referring to the EB18 catalog data reminded me that in July 2018 Brian Skiff had made me aware of the highly interesting EB18 paper then just pre-published (submitted to arXiv on 16 Jul 2018 and published on 9 Aug 2018 in MNRAS) reporting the identification of over 55,000 physical double stars in the solar neighborhood (less than 200 parsecs distance from the solar system) selected from GAIA DR2, primarily on the basis of common proper motion and common parallax with the claim of an extremely small contamination rate of less than 0.2 percent (means with an extremely small number of false positives). After a first look at this paper and the provided data, mainly for counter-checking with the Knapp and Nanson HPMS3 report including also some newly detected physical pairs based on GAIA DR2 data just submitted to JDSO, it was despite some open questions not checked in detail due to other ongoing projects.

As the recent EB19 paper on the detection of an excess of equal mass "twin" binaries also posed some questions, I decided to give both papers a closer look, starting with EB18 as base for EB19.

The EB18 catalog is mentioned in the report as being available online, but without giving any specific download information. Just a look at the personal El-Badry webpage provides the necessary information for downloading the catalog, which is meanwhile available in a second version from 12 Sep 2018 with one of the selection criteria removed, changing the number of objects from 55,128 to 55,507. The additional objects are not marked as such and spread over the full list, so object numbering is a bit unclear. All these issues raise the question; if this catalog can be considered to be published in a regular way. To get a clear reference, I added to the EB18 catalog, v1, a column with a running ID number up to 55,128, identified then the additional objects in v2 and added them to the list v1 starting with running ID number 55,129 up to 55,507.

This research is done during the summer 2019 with the EB18 objects still not included in the WDS or WDSS catalog. As I had meanwhile published in DSSC27 a list with >4,000 most likely physicals also based on GAIA DR2 data it was also interesting to find out how different methods using the same GAIA DR2 data set worked and why they produced different results (see Appendix B).

Critical Examination of the EB18 Catalog

The criteria for selecting pairs from GAIA DR2 were basically looking for objects with parallax >5 with a parallax error <5% ("We search for companions around stars that are nearby and have precise parallaxes, parallax > 5 and parallax_over_error > 20") with a second object nearby within 50,000 AU using additional cut criteria to eliminate objects with questionable data quality. While all such criteria and cuts are prone to discussion, some details are particularly noticeable:

- Parallax error <5% for the primary - At first look rather restrictive, but in effect far too generous because parallax errors in the dimension near 5% cause a huge spread in the calculated distance with enhanced risk of false positives when looking for likely binaries
- Parallax error <20% for the secondary - Surprisingly the <5% requirement is changed when looking for a potential secondary, allowing for a much larger parallax error thus adding 1,585 highly questionable objects to the EB18 catalog v1 and an additional 195 to EB18 v2 – there are certainly no good reasons to have different requirements for primaries and secondaries. Also, a bit surprisingly, is the fact that 2,332 secondaries have a parallax value below 5 mas. While it might be sensible for primaries with parallax close to 5 mas to look for secondaries with parallax slightly below 5 mas, but certainly not down to 3.23 mas as is the case with the EB18 object with source_id2 453570059955151232
- Projected separation between the components smaller than 50,000 AU or ~0.25 parsec – This seems a rather rigid cut compared to the ~1 parsec distance considered in several papers (Jiang and Tremaine 2010, Knapp 2019, Kamdar et al. 2019) as reasonable cut for potential binaries. But, on the other hand, other authors like Kouwenhoven et al. 2010 also postulate a semi-major axis of less than 0.1 parsec as requirement for an at least moderately stable binary. What at first looks like an effective criterion gets quickly suspect by the crude attempt to calculate the spatial separation between the components of a binary by applying the angular separation in arcseconds θ on the distance of the primary in parsecs as θ x (1/ω) with ω for the parallax. It is very surprising that the Gaia DR2 data is obviously taken very seriously when selecting objects, but is more or less completely neglected for binary assessment by ignoring the parallax for the secondary as well as the given parallax error. This is most obvious in the mentioned cases with parallax values for the secondaries far below 5 mas making the idea that such a pair with a distance delta of 100 parsec or more might be a binary rather absurd (see example mentioned above)
- Proper motion differences within 3σ of the maximum velocity difference expected for a system of total 5 Sun mass with circular orbit – Questionable from the very beginning as common proper motion is no longer to be considered a necessary criterion for physical pairs (Knapp 2019), but oddest is the 5 solar mass assumption, as nearly all objects are reported to be between 0.3 and 1.3 Sun masses. The authors are obviously aware of this oddity and eliminated this criterion for the above mentioned version v2 of the catalog.
- Additional data quality cuts regarding the photometry values for both components are applied as the position on the CMD (color-magnitude diagram) is used to estimate the mass for all objects by interpolating on a grid of isochrones. Surprisingly the parallax of the brighter star is also assigned to the assumed companion, thus ignoring again existing GAIA DR2 data. The reason for such a procedure remains unclear. The EB18 authors themselves state "These mass estimates are crude …" but believe that they are in most cases accurate within 0.1 $M_{\odot}$. The estimated masses are, according to the EB18 paper, also used to declare the component with the larger mass as primary. This claim makes a bit cautious

Obj	source_id1	source_id2	Sep	PA	WDS	Disc	C	WDS Sep	WDS PA
2	2871944820092678144	2871944820092678272	3.34520	54.99	23415+3247	ES 2327		3.35	54.9
5	2872283263515298432	2872283740256668416	112.35477	194.521	23320+3221	UC 4977		112.35	194.5
6	2872384074987802112	2872384281146232064	9.16626	138.009	23336+3234	OSO 199	AB	9.17	138.0
10	2872630399952398848	2872630399952398720	14.43348	62.576	23337+3316	LDS5102		14.40	242.5
14	2872975234286502272	2872974856329379968	36.60679	71.61	23392+3426	KPP3396		36.61	251.6
19	2873177681863201920	2873177681866528384	3.57084	166.619	23372+3439	HO 201		3.57	346.5
21	2847106611901400192	2847106646261138176	9.28754	193.27	00074+2219	CVR 304		9.29	13.2
24	2873451352884905344	2873451357179959680	24.58191	14.896	00033+3103	CRB 24		24.60	194.9
39	2875142745366475264	2875142749661298560	4.79736	243.448	00033+3357	ES 2209		4.80	243.4
52	2876526931721385344	2876526931721384960	10.27108	171.493	00144+3609	LDS3140		10.27	171.4

Content description:
Obj = Running EB18_v1 number
source_id1 = GAIA DR2 source id for primary
source_id2 = GAIA DR2 source id for secondary
Sep = EB18_v1 angular separation
PA = EB18_v1 position angle
WDS = WDS ID
Disc = WDS discoverer code
C = WDS components
WDS Sep = WDS angular separation
WDS PA = WDS position angle

Table 1: Cross-match EB18_v1 with WDS catalog (stub from download file)

because there are too many cases (to be precise 43.7%) with the fainter star as primary, contradicting the general expectation that at similar distance main sequence stars with larger mass should also be brighter

- Usually, the brighter star of a pair is designated as primary based on the assumption that with similar distance the brightness of the components reflects most often also the mass of the stars. – This convention, as already mentioned above, is ignored in the EB18 catalog. This is especially irritating for cross-matching with the WDS catalog (a routine task for double star astronomers but neglected by the EB18 authors), which therefore has to be done twice for the positions of the primary as well as the secondary. Using the WDS catalog per July 2019 as reference, there are more than 20% of the EB18 objects listed as WDS pairs including a few hundred added to the WDS catalog since July 2018. Table 1 lists as stub the first 10 out of 11,202 positively matched objects available for download from the JDSO website as flat text file “WDS X EB18_v1”
- The EB18 catalog is intended to be a pure doubles catalog, so all multiples as well as clusters were eliminated by the authors. Surprisingly the most basic GAIA DR2 data quality check suggested by the GAIA team (Arenou et al. 2018) for “visibility_periods_used” <9 and “duplicated source” =1 was neglected. To ignore the GAIA DR2 field “duplicated_source” means accepting potentially duplicated light sources indicating multiples not resolved by GAIA (see also Appendix B).

Side remarks for Table 1:

- A good part of the matched objects come with reversed PA due to switched components for primary/secondary
- WDS LDS 215 and LDS6215 are ident
- WDS LDS 832 and TVB 18 might be identical with inverse components
- Eliminated objects after initial cross-check result with a 5 arcsecond search radius around the coordinates for primaries and secondaries:
  - ◊ Double matches due to search via primary and secondary with separations smaller than the search radius of 5"
  - ◊ Matches with delta PA >20 compared to the WDS value (considering also reversed components)
  - ◊ Matches with delta in angular separation >25% from the WDS value

An assessment of the EB18 v1 objects with the scheme according to Knapp 2019 results in 32,999 or

Obj	source_id1	source_id2	Sep	PA	BCD_AU_1_2	RCD_AU_1_2	WCD_AU_1_2	PlxS	s_AU
1	2872017143044576896	2872017147341819904	16.42602	115.958	2,796.74	292,559.32	1,059,605.55	20	2,814.80
2	2871944820092678144	2871944820092678272	3.34520	234.990	563,011.53	1,377,568.56	2,190,716.37	1	660.44
3	2846735178834441856	2846735178834442368	6.42001	26.531	882,128.79	3,000,878.16	5,081,478.37	1	1,185.44
4	2846483566765789056	2846485039939110272	23.74313	90.053	4,396.42	230,748.06	1,494,720.43	20	4,443.08
6	2872384074987802112	2872384281146232064	9.16626	318.009	1,670.35	223,020.41	658,351.46	20	1,666.72
7	2872379264624690304	2872379264624690432	5.82210	112.488	804.13	245,794.06	985,230.99	20	811.84
8	2872309033319137792	2872308792800972160	123.26979	118.342	24,179.08	307,841.37	819,985.03	20	24,346.18
11	2872663591459404032	2872663591459403776	20.62646	323.294	305,580.45	701,158.67	1,097,453.20	1	3,002.22
12	2872803057638197120	2872803057638196608	17.92730	46.944	92,699.80	1,099,818.55	2,145,871.87	20	2,894.65
13	2872912184166813440	2872912179872035584	2.15982	89.651	432.92	1,123,801.67	2,763,248.61	20	431.79

Content description:

Obj	=	Running EB18 object number (1-55128 for v1 and 55,129 to 55,507 for additional v2 objects)
source_id1	=	GAIA DR2 source id for the primary
Plx1	=	Plx primary in mas
Plx1_e	=	Plx error for the primary
*Gmag1	=	Gmag primary
source_id2	=	GAIA DR2 source id for the secondary
Plx2	=	Plx secondary in mas
Plx2_e	=	Plx error for the secondary
*Gmag2	=	Gmag secondary
Sep	=	Angular separation in arcseconds
PA	=	Position angle
*BCD_LY_1	=	Best case distance primary from Sun in lightyears calculated from Sep and Plx using +/- 1xPlx_e to minimize the spatial distance between the components within this range
*BCD_LY_2	=	Best case distance secondary from Sun in lightyears calculated from Sep and Plx using +/- 1xPlx_e to minimize the spatial distance between the components within this range
BCD_AU_1_2	=	Best case distance between the components in AU
*RCD_LY_1	=	Realistic case distance primary from Sun in lightyears calculated from Sep and Plx as given
*RCD_LY_2	=	Realistic case distance secondary from Sun in lightyears calculated from Sep and Plx as given
RCD_AU_1_2	=	Realistic case distance between the components in AU
*WCD_LY_1	=	Worst case distance primary from Sun in lightyears calculated from Sep and Plx using +/- 1xPlx_e to maximize the spatial distance between the components within this range
*WCD_LY_2	=	Worst case distance secondary from Sun in lightyears calculated from Sep and Plx using +/- 1xPlx_e to maximize the spatial distance between the components within this range
WCD_AU_1_2	=	Worst case distance between the components in AU
PlxS	=	Parallax score between 0 and 100 depending on best/realistic/worst case distance <200,000 AU and Plx error as estimated likelihood for potential gravitational relationship
s_AU	=	EB18 distance between the components in AU

Values with " * " are not listed in Table 2 but are available in the download file

Table 2: EB18_v1 likely opticals (stub from download file)

~60% of the reported pairs as likely opticals although this scheme accepts similar to EB18 parallax errors up to 5% for a positive rating. Table 2 gives a stub of such objects, the full list is available for download from the JDSO website as flat text file "EB18 likely opticals".

The column "PlxS" gives an indication for the likelihood for a distance between the components smaller than 200,000 AU (~1 parsec) using the angular separation as well as the given Gaia DR2 parallax and parallax error data. A value of 20 suggests a likelihood of ~20% (but certainly far below 50%) for such cases with parallaxes overlapping within the given parallax error – in such cases the spatial distance "s_AU" given in EB18 is quite close to the best case distance "BCD_AU_1_2", but the realistic case distance using the given parallaxes without considering the given errors is larger than 200,000 AU or ~1 parsec. A "PlxS" value of 1 indicates a likelihood of near zero (but certainly below 10%) as the parallaxes do not even overlap within the given error range.

A rather precise likelihood can be derived by a Monte-Carlo simulation using the given GAIA DR2 data for RA, Dec and parallax as mean values and the given error as standard deviation for a normal distribution (see Appendix A). To give an impression such a simulation is done for a few objects in table 2 with a sample size of 120,000:

Obj 1 with PlxS=20: Smallest distance of the simulation results is 2,775 AU, the percentile 16 value is already ~139,000 AU and the median distance is ~455,000 AU. The rather large parallax errors cause a very flat distribution with a huge spread and the likelihood for a distance <200,000 AU is 23%.

Obj 2 with PlxS=1: Smallest distance of the simulation results is 679 AU but already the percentile 16 value is with ~805,000 AU far outside the cut value of 200,000 AU and the median distance is with ~3,917,000 AU quite huge. The rather large parallax errors cause a very flat distribution with a huge spread and the likelihood for a distance <200,000 AU is 2%.

Obj 3 with PlxS=1: Smallest distance of the simulation results is 1,117 AU but median distance is with ~9,317,000 AU more than huge. The very large parallax errors cause an extremely flat distribution with a huge spread and the likelihood for a distance <200,000 AU is again 2%.

Obj 6: with PlxS=20: Smallest distance of the simulation results is 1,665 AU and median distance misses with ~278,000 AU the cut by 40%. The large parallax error for the primary causes a large spread and the likelihood for a distance <200,000 AU is 37%. A case for a might be binary - future GAIA data releases might provide a parallax for the primary with a smaller error allowing for a more conclusive assessment.

Obj 13 with PlxS=20: Smallest distance of the simulation results is 434 AU but median distance is with ~1,197,000 AU rather huge. The large parallax errors cause a very flat distribution with a huge spread and the likelihood for a distance <200,000 AU is 9%.

The simulation examples show very clearly that the EB18 spatial distance values s_AU correspond closely with the smallest simulations results – but these come only with an extremely small likelihood close to zero and the more realistic median distance values are in all these cases far too large to allow for gravitational relationship.

My scheme for assessing assumed binaries (Knapp 2018) works fine with reasonable small parallax errors, but it allows similar to EB18 parallax errors up to 5% for a positive rating. When developing this scheme, my expectation was that combining data with normal distributed error range should result in a normal distribution with the combined mean as average. While this worked out very well with very small relative errors, I had with my first Monte-Carlo simulation runs to realize that even moderately large parallax errors produce a huge spread resulting in very flat distributions with mean/median values; far larger than the spatial distance between the components calculated from parallaxes and angular separation without errors. Meanwhile, it is clear that the cut for parallax errors has to be reduced by a factor ~10 to get reliable results. This means that objects with parallax error up to 0.5%, and with some allowance up to 1%, are correctly assessed with a median simulation distance close to the calculated "realistic case distance" but with larger parallax errors the median distance of the simulation is due to the large spread mostly outside the 200,000 AU range. For this reason it is necessary to have also a closer look at the objects with PlxS value ~80 indicating falsely that the calculated RCD_AU_1_2 values of less than 200,000 AU should be near the median value of a simulation run. Table 3 gives several examples of such seemingly good pairs as a stub, the full list of 3,920 such objects is

Obj	source_id1	source_id2	Sep	PA	BCD_AU_1_2	RCD_AU_1_2	WCD_AU_1_2	PlxS	s_AU	PlxE
14	2872975234286502272	2872974856329379968	36.60679	251.610	3,234.61	132,102.41	590,404.44	80	3,245.96	C
17	2873172974582491904	2873172630984993408	209.33177	238.590	38,912.74	157,914.76	1,043,049.97	80	39,194.29	C
35	2874298805767507328	2874298767112458752	4.50143	158.628	760.33	179,607.34	1,587,385.70	80	769.90	D
51	2876373343690310144	2876373343690310016	3.78342	301.144	508.63	191,584.98	933,052.87	80	513.45	C
57	2876697252944594176	2876697252944594048	2.24872	261.778	299.79	5,457.75	909,993.78	80	303.58	D
64	2877347339194412416	2877347339194412800	7.81695	201.379	1,323.75	184,235.12	911,128.14	80	1,322.95	C
81	2879327112958858880	2879327319119080832	152.73209	23.427	21,719.18	59,375.62	858,334.79	80	21,984.84	C
110	2881998960574720256	2881998956279420288	6.47185	273.745	1,159.71	9,488.82	1,377,482.29	80	1,173.98	D
118	2865994709839871872	2865993232369137920	24.55551	234.106	1,092.73	101,562.63	324,366.40	80	1,097.90	C
123	2866270893416092032	2866270893416091520	13.62311	25.390	1,462.20	185,084.20	837,406.62	80	1,468.76	D

Content description:
Ident with Table 2 plus additional column PlxE with rating for the relative Plx (C for >1% and D for >1.5%)

Table 3: EB18_v1 objects likely optical despite Plx Score 80 rendered questionable by large parallax errors (stub from download file)

Obj	source_id1	source_id2	Sep	PA	BCD_AU_1_2	RCD_AU_1_2	WCD_AU_1_2	PlxS	s_AU
5	2872283263515298432	2872283740256668416	112.35478	14.521	6,167.61	30,794.37	98,604.65	100	6,186.68
9	2872313706243670656	2872313706243670400	13.00470	350.594	1,400.24	69,845.60	266,163.53	80	1,404.81
10	2872630399952398848	2872630399952398720	14.43348	242.576	734.66	43,373.89	115,286.47	100	737.19
19	2873177681863201920	2873177681866528384	3.57084	346.619	407.78	74,333.27	296,233.95	80	409.80
29	2873926105685136640	2873926105685136768	3.04193	218.904	410.99	136,934.46	571,862.18	80	410.70
36	2874596429820987264	2874596429820987520	6.87615	176.107	869.10	137,093.28	441,583.30	80	868.13
37	2874788432038781312	2874788432038781440	3.04745	101.571	544.22	96,712.26	582,079.56	80	545.78
38	2875031527188163072	2875033176455625856	199.25836	37.354	16,400.53	26,040.50	118,477.55	100	16,426.52
40	2874952018753440128	2874952018753440000	2.95796	50.103	450.15	78,981.92	339,651.24	80	450.59
41	2875236719249747712	2875236723545613952	15.44426	318.081	1,173.39	14,156.73	157,550.91	100	1,175.52

Content description identical with Table 2.

Table 4: EB18_v1 objects likely physicals (stub from download file)

available for download from the JDSO website as flat text file “EB18_v1_seemingly_good”. This means also that additional 3,920 or ~7% of the EB18 v1 catalog are also likely optical pairs raising the percentage of most likely EB18 opticals to 67%.

To demonstrate the effect of large parallax errors, I ran the Monte-Carlo simulation for the first 3 objects on this list:

Obj 14: Smallest distance of the simulation results is 3,225 AU but median distance is already ~277,344 AU – more than double the calculated RCD_AU_1_2 distance. The large parallax error for the secondary of ~2.1% causes despite the rather small parallax error for the secondary a large spread and the likelihood for a distance <200,000 AU is 38%.

Obj 17: Smallest distance of the simulation results is 38,487 AU but median distance is already ~471,349 AU – about triple the calculated RCD_AU_1_2 distance. The rather large parallax error for the secondary of ~1.6% causes combined with the median large parallax error of ~0.7% for the primary a corresponding large spread and the likelihood for a distance <200,000 AU is 22%.

Obj 35: Smallest distance of the simulation results is 756 AU but median distance is already ~709,035 AU – about 4 times the calculated RCD_AU_1_2 distance. The rather large parallax error for the secondary of ~2.7% causes combined with the large parallax error of ~1.3% for the primary a huge spread and the likelihood for a distance <200,000 AU is only 15%.

The remaining 18,209 EB18_v1 objects are rated with PlxS 100 or 80 but with parallax error smaller than 1%. Table 4 is a stub of 10 objects from the full list available for download form the JDSO website as flat text file “EB18_v1_likely_physicals”.

To demonstrate the effect of small parallax errors I run the Monte-Carlo simulation for the first 3 objects on this list again with a sample size of 120,000:

Obj 5 with a PLxS value of 100: Smallest spatial distance between the components 6,143 AU and median distance 39,764 AU with 100% likelihood for a distance less than 200,000 AU with the exception of only a few outliers up to ~244,000 AU.

Obj 9 with PlxS 80: Smallest distance of the simulation results is 1,396 AU and median distance is ~109,108 AU – about 50% larger than the calculated RCD_AU_1_2 distance. The moderate parallax errors for both the primary and the secondary cause some spread and the likelihood for a distance <200,000 AU is 79%.

Obj 10 with PlxS 100: Smallest distance of the simulation results is 732 AU and the median distance is ~48,053 AU – quite close to the calculated RCD_AU_1_2 distance. The small parallax errors for both the primary and the secondary of ~0.35 cause a relative small spread and the likelihood for a distance <200,000 AU is 100% with only a few outliers up to ~283,000 AU. Figure 1 shows the distribution of the simulation sample for the spatial distance:

Despite all EB18 efforts to estimate star masses based on their color-magnitude diagram position no

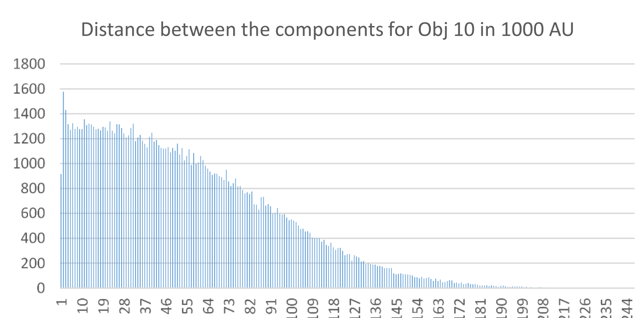

Figure 1. Distance between the components of Obj 10 in 1000 AU according to Monte-Carlo simulation with a sample size of 120,000.

such values are given in the EB18 catalog so it is impossible to repeat the given conclusions. To compensate for this lack of data I looked up the mass50 (means percentile 50 mass) values in the Anders et al. 2019 GAIA DR2 StarHorse (in the following StarHorse) catalog. I would have preferred to cross-match the full EB18 catalog with the StarHorse catalog but the GAIA.AIP query interface hosted by the "Leibniz-Institute for Astrophysics Potsdam" does not offer the possibility to use large object lists (at least I did not find it and the help desk was due to the university holiday season not available) so I had to operate with many queries for small parts of the EB18 catalog of about 250 objects and I decided to restrict my efforts to a representative ~10% sample by selecting by chance 5 bins with 1,000 EB18_v1 objects each and got in total 4,810 matches with values for both components.

A first look made clear that EB18 primaries were often (to be precise >47%) the stars with the smaller StarHorse mass50 value with the latter corresponding very well also with the brightness of the stars (with only a few exceptions mostly for pairs with nearly ident brightness) means larger mass for the brighter stars. Taking in consequence the stars with the larger mass50 value as primaries resulted in a minimum mass of 0.12 $M_\odot$ and a maximum mass of 3.10 $M_\odot$. Average value for the primary is 0.72 $M_\odot$ with standard deviation of 0.33 $M_\odot$. Average value for the secondary is 0.44 $M_\odot$ with standard deviation of 0.22 $M_\odot$ with a minimum mass of 0.11 $M_\odot$ and a maximum mass of 2.31 $M_\odot$. These numbers do not match very well with the EB18-statement "Most of the main-sequence stars have masses $0.3 \leq M/M_\odot \leq 1.3$".

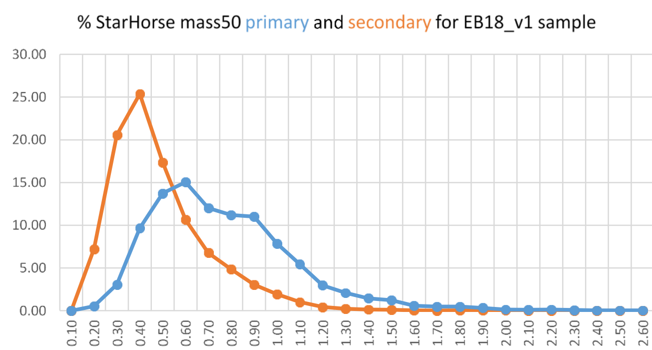

Figure 2. Distribution of StarHorse mass50 for primary and secondary in percent of the EB18_v1 sample.

Table 5 gives a stub for the first 10 of the EB18 objects cross-matched with the StarHorse catalog, the full list is available for download from the JDSO website as flat text file "EB18_v1_mass50":

Most interestingly the distribution of masses for primary and secondary is quite different with a clear peak near the average 0.44 $M_\odot$ value for the secondary compared to a much larger spread for the primary. The distribution for the primary shows a dent in the 0.7 and 0.8 mass50 bin suggesting an irregularity caused may be by a bias in the EB18 object selection process (see Figure 2 and compare with Figure 13).

Figure 5 in EB18 (shown here as Figure 3) shows the mass ratio distribution of the EB18 pairs (black line for main sequence pairs) – steep increase from small

Obj	source_id1	mass50_1	Gmag1	source_id2	mass50_2	Gmag2
1	2872017143044576896	0.79240966	12.119735	2872017147341819904	0.37382376	16.622170
3	2846735178834441856	0.39968893	16.502570	2846735178834442368	0.19929305	17.984964
4	2846483566765789056	1.88280869	8.157404	2846485039939110272	0.30255136	17.368803
5	2872283263515298432	0.32529020	14.360177	2872283740256668416	0.70147246	10.459101
6	2872384074987802112	0.35074097	15.618967	2872384281146232064	0.60082656	13.138443
7	2872379264624690304	0.42372254	15.743548	2872379264624690432	0.27287805	17.105940
8	2872309033319137792	0.79839927	12.309546	2872308792800972160	0.56184644	14.558531
9	2872313706243670656	0.60056657	13.318013	2872313706243670400	0.50094569	14.433413
10	2872630399952398848	0.30996296	14.524491	2872630399952398720	0.30038962	14.604014
11	2872663591459404032	0.63140053	13.939705	2872663591459403776	0.45031360	15.235794

Content description

Obj = Running EB18 object number (1-55128 for v1 and 55,129 to 55,507 for additional v2 objects)
source_id1 = GAIA DR2 source id for the primary
mass50_1 = Mass50 value for the primary from the Anders et al. 2019 GAIA DR2 StarHorse catalog
Gmag1 = GAIA DR2 Gmag for the primary
source_id2 = GAIA DR2 source id for the secondary
mass50_2 = Mass50 value for the secondary from the Anders et al. 2019 GAIA DR2 StarHorse catalog
Gmag2 = GAIA DR2 Gmag for the secondary

Table 5: StarHorse mass50 values for a sample of EB18_v1 objects (stub from download file)

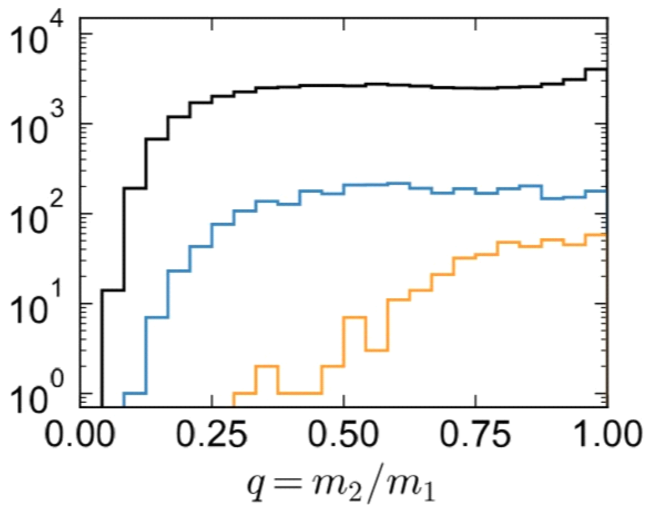

Figure 3. Clipping from EB18 Figure 5: q=m2/m1 cumulated (black line for MS/MS pairs)

ratios with flat distribution for a ratio from 0.25 to 0.95 with a tiny spike in the end towards a ratio of 1.

The reason for such a difference remains unclear – the size of the sample of 4,810 provides a 1.86% margin of error with 99% confidence so sample size cannot be the problem. Another reason would be that the mass50 data from the StarHorse catalog are significantly inferior compared to the EB18 mass estimations – this seems highly unlikely especially with the EB18 issue regarding main sequence brightness/mass relationship already discussed.

Summary of the Critical Examination of the EB18 Paper/Catalog

Overall points of concern are

- The allowed parallax error for selecting objects from the GAIA DR2 catalog is far too generous to meet the "very pure" claim
- The method for calculating the spatial distance between the components of pairs provides consistently completely unrealistic best case result by ignoring the GAIA DR2 parallax value of the secondary as well as the parallax errors for primary and secondary
- Star masses are estimated by their position in a color-magnitude diagram but the absolute magnitude for the companions is calculated with the same parallax value as for the brighter component ignoring again existing precise GAIA DR2 data
- The stars with the larger mass in a pair are selected as primaries but a very high percentage of the primaries are fainter than the assumed secondaries – rather not to expect for main sequence pairs. This puts an overall question mark on the star mass estimation process
- No star mass values are provided making it impossible to counter-check the reported results.

Resulting issues are:

- Heavy contamination of the EB18 catalog with false positives – even if we concede that about 25% of the 67% as likely opticals assessed EB18 objects might be very well binaries there remains a contamination rate of >50%
- Spatial distance s_AU between the components far too optimistic to the degree that these values can be considered generally wrong
- Estimated star mass values are not only not provided but by the given evidence highly questionable.

Critical Examination of the EB19 Paper

EB19 reports the discovery of an equal mass "twin" binary population based on the EB18 catalog data with some additional cuts which seems to confirm "A puz-

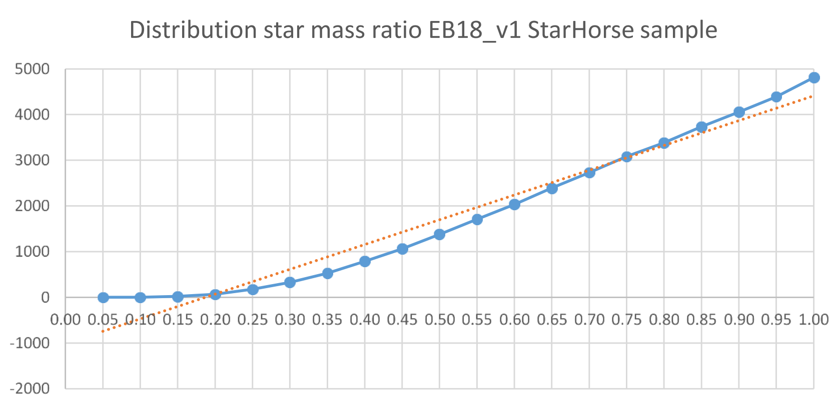

Figure 4. Distribution star mass ratio EB18_v1 StarHorse sample in 0.05 bins

Counter-Check of Binaries Reported to be Detected in Gaia DR2 as well as an Equal Mass "Twin" Binary ...

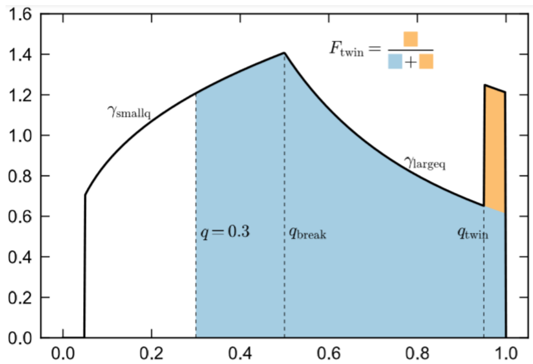

Figure 5. Clipping from EB19 Figure 7 suggesting a huge excess of equal mass binaries

zling feature of the mass ratio distribution identified by previous works … the so called 'twin' phenomenon … a purported statistical excess of nearly equal-mass binaries with mass ratios 0.95 ≲ q < 1". The most important additional quality cuts are as follows:

- Restriction to main sequence pairs
- Restriction to pairs with parallax error size <5% also for the secondary
- Restriction to a mass range up to 2.5M$_\odot$

While the restriction to assumed main sequence pairs looks reasonable the decision to eliminate the pairs with secondaries not meeting the criteria applied for the primaries looks like a late acknowledgement that it was from the very beginning questionable to apply different selection criteria for primaries and secondaries in EB18.

Figure 7 from the EB19 paper (shown here in Figure 5) suggests a noticeable excess of equal-mass pairs after applying the additional quality cuts on the EB18 data but again no mass data values are provided, only several graphs with color-magnitude diagrams. This figure is by the way very similar to figure 2 from Moe and Di Stefano 2017.

As no star mass data is published the EB19 results cannot be repeated independently so I had again to take resort with the StarHorse catalog this time including the EB18_v2 data as this release is obviously the base used for EB19. This added 49 v2 objects to the list but the application of the additional EB19 cuts mentioned above reduced the total number of the sample to 4,432 means a sample size still >10% of the EB19 data.

As the data for the first 10 objects is identical with Table 5 no stub is given here but the full list is available for download from the JDSO website as flat text file "EB18_v2_mass50_ex_cuts". In the following this data set is referred to as EB19 StarHorse sample.

The mass ratio distribution based on this data sample using the higher mass50 value as primary is shown in Figure 6 using 1% bins.

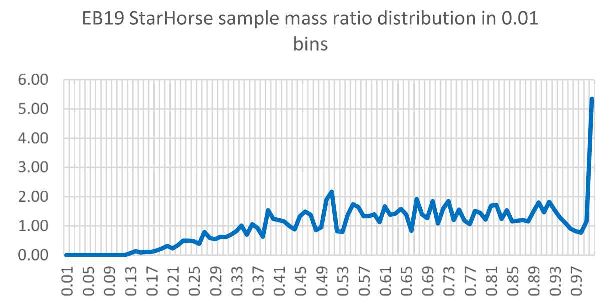

Figure 6. Distribution of mass ratios for EB19 StarHorse sample in 0.01 bins

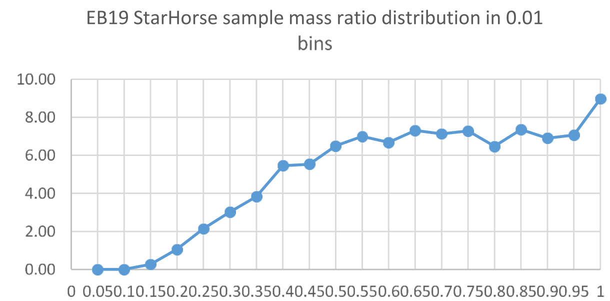

Figure 7. Distribution of mass ratios for EB19 StarHorse sample in 0.05 bins

The same data presented in 0.05 bins is likely better to compare with EB19 Figure 7.

This distribution of mass ratios is definitely very different from the distribution suggested in EB19 Figure 7. There is no steep increase but beginning with a mass ratio of ~0.15 this looks similar to the EB18_v1 StarHorse sample rather like a linear increase of star mass ratios with a small spike at the end. But can this spike considered to be a significant excess of "twin" pairs with similar mass?

In my opinion not because if the star masses of the components of pairs are considered to be determined by a random process then we get the same statistical effect. When merging two random processes with a given mean value then masses near the mean value occur depending on the given standard deviation more often than masses very different form the mean value and for this reason a spike of "twins" is purely the expected result of such a random process.

If we combine the EB19 StarHorse sample data for an overall star population we get an average mass of 0.59M$_\odot$ with a standard deviation of 0.31 (see Figure 8).

Using this data set for a random selection of ~4,500

Counter-Check of Binaries Reported to be Detected in Gaia DR2 as well as an Equal Mass "Twin" Binary ...

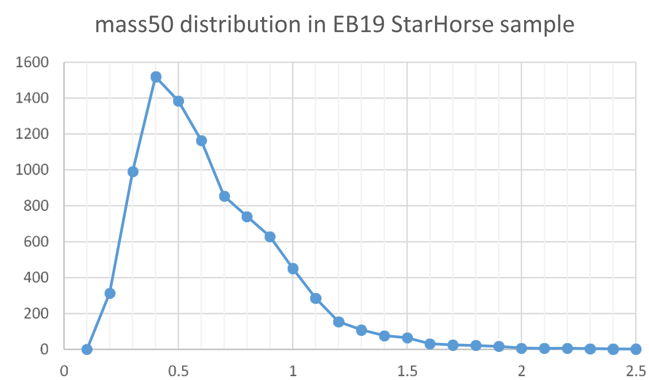

Figure 8. mass50 distribution in EB19 StarHorse sample

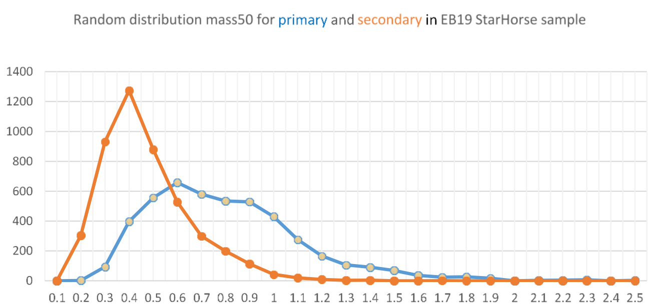

Figure 9. Random pair mass50 distribution for primary and secondary based on EB19 StarHorse star population

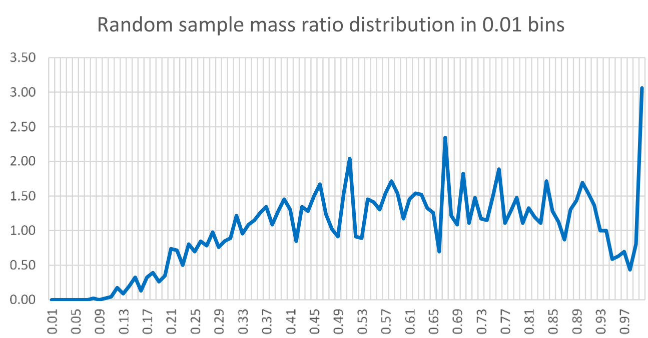

Figure 10. Random sample mass ratio distribution in 0.01 bins (based on EB19 StarHorse sample star population)

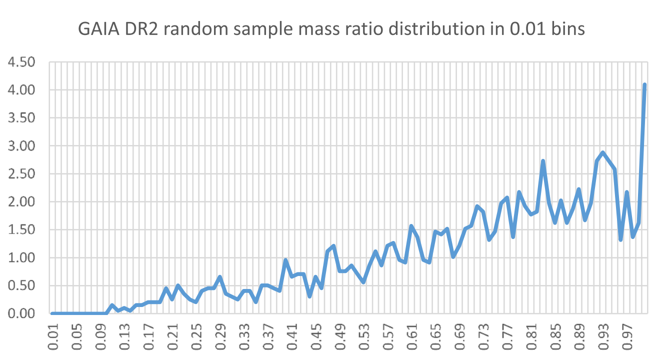

Figure 11: GAIA DR2 random sample mass ratio distribution in 0.01 bins

pairs we get the following distribution very similar to the pattern shown in Figure 2 for the EB18_v1 StarHorse mass50 sample. Interestingly even the dent for the masses 0.7 and 0.8 $M_\odot$ is replicated if a bit weaker.

This results in a mass ratio distribution for random pairs based on the EB19 star population as shown in Figure 10.

The spike at the end of Figure 10 with the random sample might be less pronounced than in Figure 6 with the EB19 StarHorse data set but it seems highly questionable if this difference is statistically significant enough to allow for the conclusion that there is such a thing as an equal-mass "twin" population. The 99% confidence interval for the 5.39% spike in Figure 6 is 0.88% and the 99% confidence interval for the 3.06% spike in graph 9 is 0.67%. While this means that both spikes do not overlap even within their 99% confidence intervals with a gap of 0.74% remaining, such a tiny gap seems to me not significant enough for serious conclusions.

To eliminate any misgivings about using the given EB19 StarHorse mass50 distribution, I drew a random sample of an arbitrary number of 1,977 GAIA DR2 star pairs using the GAIA random index, matched with the corresponding StarHorse mass50 values, made the larger mass star the primary and calculated the mass ratio for each pair. What I got is shown in Figure 11.

This time the peak value is 4.1% with a 99% confidence interval of 1.15% covering the EB19 StarHorse sample as well as the random sample based on EB19 StarHorse data pool. No data set is given for this example as it can be easily reproduced with existing tools publicly available.

I consider these random results as proof that the EB19 mass ratio distribution corresponds with the distribution in random samples and that there is no such thing as an excess in "twin" binaries with other than pure statistical reason – at least when the mass50 StarHorse catalog data is considered to be more reliable than the not publicly available EB18 mass estimations.

So far the results by just looking at the numbers - another question is the EB19 mass data quality based on the EB18 data catalog. Despite the "enhancements" of EB18 data by applying additional quality cuts it remains still an unresolved riddle why it was considered appropriate to use an obviously highly contaminated date source for extensive statistical processing. Highly contaminated not only due to the huge part of false binary positives but also for the following reasons:

- The EB18 authors themselves consider their mass estimations as "crude"
- The parallax for the secondaries was intentionally falsely – by ignoring existing GAIA DR2 data

Counter-Check of Binaries Reported to be Detected in Gaia DR2 as well as an Equal Mass "Twin" Binary ...

KPP+	source_id1	mass50_1	source_id2	mass50_2	q
1	2341739525536269568	0.54917818	2341739525536269440	0.54917598	0.99999599
2	4922504834475892480	0.49068627	4922504834475011072	0.25059149	0.51069595
3	420485136603049088	0.78688747	420485136593782912	0.74453515	0.94617741
4	2746869015880925824	0.78168672	2746869015880925696	0.59936732	0.76676155
5	2306711382881486208	0.65043151	2306711181018700800	0.44966626	0.69133530
6	4923573765936638208	0.69848222	4923573765936638464	0.64902496	0.92919324
10	396259489527418368	0.70071042	396259459468383744	0.69816643	0.99636941
11	4689746567995853952	0.85447359	4689746537932710656	0.55178142	0.64575597
12	4922464805380607360	0.44927859	4922464805379529600	0.20058107	0.44645143
14	4901424344713245184	0.89591235	4901424344713244928	0.60024953	0.66998689

Content description:
KPP+ = Running object number from Knapp 2019/DSSC 27
source_id1 = GAIA DR2 source id for primary
mass50_1 = GAIA DR2 StarHorse mass50 for primary
source_id2 = GAIA DR2 source id for secondary
mass50_2 = GAIA DR2 StarHorse mass50 for secondary
q = Mass ratio

Table 6: KPP objects sample

– considered ident with the parallax for the primaries to calculate the absolute magnitude for their position on the color-magnitude diagram used for estimating the masses of stars.

At least to some degree the authors of EB19 seem to be aware that some caution is appropriate by stating "In modeling the mass ratio distribution, it is not critical that the mass ratio of any binary be measured accurately, but rather that the distribution of magnitude difference be predicted self-consistently" – in simple words this means that it is for the authors not important if the data is questionable but that the results seem reasonable. I am not sure if I can subscribe to such an approach – more appropriate to me seems the concept that flawed input data produces most likely flawed output (garbage in, garbage out).

Finally there remains the scenario that the EB19 mass ration distribution is similar to a random sample only because of the high contamination rate of the EB18 catalog despite the additional cuts and that a "twin" binaries excess exists very well in a pure binaries data set.

To check this scenario I have a look at a GAIA DR2 binaries set I trust to show very little contamination – this means a counter-check with KPP objects from Knapp 2019/DSSC 27 based on GAIA DR2 objects with a parallax error of less than 0.5%. After elimination of all (visible) multiples as well as all objects with potential duplicity issues and with less than 9 visibility_periods_used 3,270 most likely physical pairs remaining considered being (despite a large overlap with the EB18 catalog, see Appendix B) without contamination with false positives and potentially unresolved multiples. For all objects the 50 percentile mass value from the GAIA DR2 StarHorse catalog was matched if available with remaining 2,842 pairs with mass50 values for both components and the mass ratio was calculated. Table 6 gives the data for the first 10 objects as stub, the full data set is available for download from the JDSO website as flat text file "KPP_objects_sample".

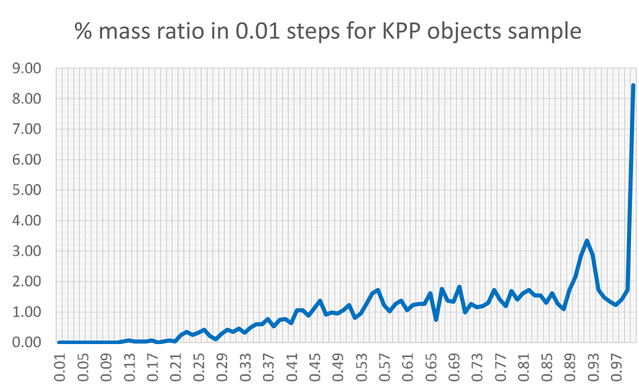

Figure 12. Distribution mass ratio in 0.01 steps for a pure binaries data set

A first look at the mass ratio of these objects seems to support the impression of an excess of pairs with similar mass this time even with a peak value of 8.43% (see Figure 12).

A closer look at the frequency of component masses shows a peak for the primaries at 0.68 $M_{\odot}$ with a standard deviation of 0.24 and for the secondaries at 0.47 and 0.16 (see Figures 13 and 14) suggesting an overlap of corresponding distribution of masses between 0.5 and 0.6 $M_{\odot}$. The comparison with the corresponding values from the EB18_v1 data set (see Figure 2) with an average value for the primary of 0.72 $M_{\odot}$ with standard deviation of 0.33 $M_{\odot}$ and an average value for the secondary is 0.44 $M_{\odot}$ with standard deviation of 0.22 $M_{\odot}$ indicates not only closer mean values but especially also a significantly smaller standard deviation leading unavoidable to a larger number of nearly equal mass pairs.

This clearly confirms again that the cause for an exponential trend towards similar mass pairs is simply a function of the mass frequency of the components in the given star population– values around the mean value simply occur significantly more often than other mass values so the probability of two components having similar mass in this range is accordingly higher than for other combinations.

Summary

This report shows that the EB18 catalog has besides some other discussed shortcomings a huge contamination rate of likely >50% with false positives. The data quality cut for the GAIA DR2 parallax values applied for the EB18 catalog with parallax error up to 5% is most likely the main reason for a noticeable ratio of questionable pairs reported far beyond the contamination rate estimated by the authors themselves. The cause is simply the massive spread in possible distances between the components caused by large parallax errors (see Appendix A). Looking up objects with a parallax near 5 and parallax_over_error near 20 in the CDS I/347 "Distances to 1.33 billion stars in Gaia DR2" catalog results in a spread up to +/- 10 parsecs – obviously such objects are of little significance when looking for binaries.

The use of the likely highly contaminated EB18 catalog for EB19 seems despite additional data quality cuts not such a good idea especially as the star mass estimation method applied seems also rather suspect as well. As no mass data are given I had to resort to a sample of mass data from Anders et al. 2019 GAIA DR2 StarHorse catalog with the result that the EB19 result of an assumed "twin" binaries excess can be explained as simple statistical consequence when selecting star pairs by random from a given star population.

Acknowledgements:

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

- Washington Double Star Catalog
- CDS VizieR
- GAIA DR2 catalog
- Distances to 1.33 billion stars in Gaia DR2 catalog
- DSS and Pan-STARRS (PS1) images
- Aladin Sky Atlas
- CDS TAP-VizieR and X-Match
- GAIA DR2 StarHorse catalog
- Gaia@AIP Services hosted by the Leibniz-Institute for Astrophysics Potsdam (AIP)

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F. Arenou, et al., 2018, "Gaia Data Release 2: Catalogue validation", *Astronomy & Astrophysics*, **616**, A17.

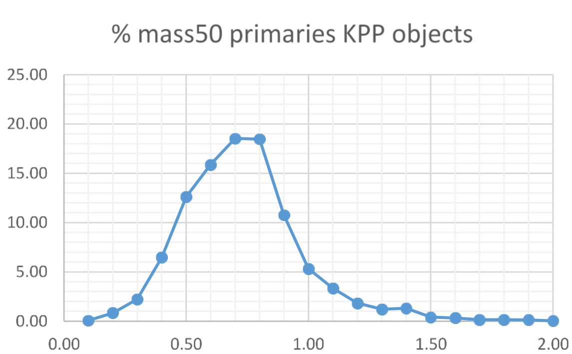


Figure 13. Mass50 distribution for the primaries in the KPP objects sample

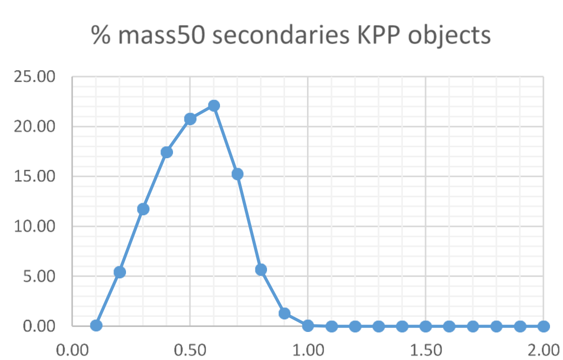


Figure 14. Mass50 distribution for the secondaries in the KPP objects sample

Kareem El-Badry, et al., 2019, "Discovery of an equal-mass "twin" binary population reaching 1000+ AU separations", arXiv:1906.10128v1.

Kareem El-Badry and Hans-Walter Rix, 2018, "Imprints of white dwarf recoil in the separation distribution of Gaia wide binaries", *Monthly Notices of the Royal Astronomical Society*, Advance Article Aug 9, 2018.

Moe, Maxwell & Di Stefano, Rosanne, 2017, "Mind Your Ps and Qs: The Interrelation between Period (P) and Mass-ratio (Q) Distributions of Binary Stars", *The Astrophysical Journal Supplement Series*, **230**:15 (55p).

Knapp, Wilfried R.A., 2018, "A New Concept for Counter-Checking of Assumed Binaries", *Journal of Double Star Observations*, **14** (3), 487-491.

Knapp, W. and Nanson, J., 2019, "A Catalog of High Proper Motion Stars in the Southern Sky (HPMS3 Catalog)", *Journal of Double Star Observations*, **15** (1), 21-41.

Knapp, Wilfried R. A., 2019, "The 'True' Movement of Double Stars in Space", *Journal of Double Star Observations*, **15** (3), 464-488.

Kouwenhoven, M.B.N, et al., 2010, "The formation of very wide binaries during the star cluster dissolution phase", *Monthly Notices of the Royal Astronomical Society*, **404**, 1835–1848.

Appendix A

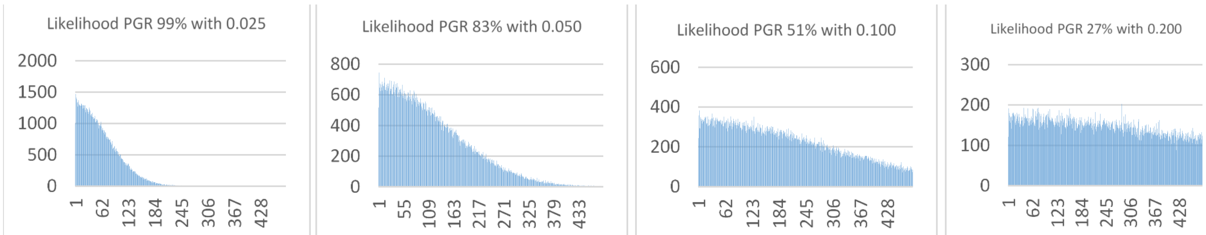
Description of the binary assessment scheme (according to Knapp 2018):

Based on the given GAIA DR2 values for parallax and parallax error the following scenarios for the distance between the components of a pair of stars in AU are calculated:

- Best case distance: Smallest possible distance between the components using the given parallax values +/- given error range
- Realistic case distance: Distance between the components using the given parallax values without considering the error range
- Worst case distance: Largest possible distance between the components using the given parallax values +/- given error range
- Next comes a letter based rating for the distance: "A" for worst case distance, "B" for realistic case distance and "C" for best case distance less than 200,000 AU and "D" for above
- Next comes a letter based rating for the parallax error size "A" for Plx error less than 5% of Plx, "B" for less than 10%, "C" for less than 15% and "D" for above
- The letter based scoring is then transformed into an estimated likelihood for a potential gravitational relationship (PGR)

Meanwhile it became clear that the expectation that the "realistic case distance" should correspond with the mean value of the distance after combining the parallax values as normal distributions with the given errors as standard deviation works only for parallax errors smaller by a factor 10 as given above. This means that the proposed assessment scheme works fine with parallax errors up to 0.5% and acceptable good up to 1%. Any error size above 1% leads to an increasing spread in the distance distribution making the "realistic case distance" value obsolete.

In the following figures this effect is shown in units of 1,000 AU for a pair with 6.42" angular separation and parallax 10 mas for both components with parallax errors 0.025/0.050/0.100/0.200.



Figures A1 to A4: Distance distribution with parallax errors 0.025/0.050/0.100/0.200

Description of the potential gravitational relationship assessment procedure based on Monte Carlo simulation (according to Knapp 2019):

While the assessment scheme described above can be easily used for huge objects lists the following much more precise scheme needs to be applied step by step per single object:

- GAIA DR2 values for RA/Dec and Plx are used for a Monte Carlo simulation assuming a normal distribution for these parameters with the given error range as standard deviation. The distance between the components is calculated from the inverted simulated parallax data and the simulated angular separation using the law of cosines

  with a and b = distance vectors for the stars A and B in lightyears calculated as (1000/Plx)*3.261631 and γ = angular separation in degrees calculated as
- The likelihood for potential gravitational relationship (PGR) is the percentage of simulation results

$$\sqrt{a^2 - 2ab\cos(\gamma) + b^2}$$

  <200,000 AU (~1 parsec) out of the simulation sample with a size of 120,000
- The smallest, median and largest distance is the smallest, median and largest result of the simulation sample,

$$\gamma = \arccos\left[\sin(DE1)\sin(DE2) + \cos(DE1)\cos(DE2)\cos\left(\left|RA1 - RA2\right|\right)\right]$$

  also percentile 16 or 84 or any other percentiles are easily to determine if required
- The smallest/median/largest etc. distance might also used as estimation for the minimum value for the semi-major axis of a potential orbit allowing for the calculation of a smallest/median/largest etc. possible orbit period assuming zero inclination using the available star masses of primary and secondary (for example GAIA DR2 StarHorse mass16/50/84 values).

Appendix B

Cross-match EB18 catalog with "Physical pairs found in GAIA DR2" (Knapp 2019)

In autumn 2018 (with the EB18 paper long forgotten) I worked on a paper "Physical pairs found in GAIA DR2" submitted to Bob Argyle end of November 2018 and published in DSSC27 in spring 2019. The objects were selected from GAIA DR2 with a parallax value >5mas and an angular separation up to 60 arcseconds. Final result were 4,217 objects found to be most likely physical by applying the assessment scheme described in Appendix A. Basically it is to expect that all these objects are already covered with the EB18 catalog but to be sure I cross-matched my list with the EB18_v2 catalog and got a positive match for 3,173 objects with about 50% of them with reversed primary/secondary. Table B1 lists the first 10 such objects as stub with the full list available for download from the JDSO website as flat text file "KPP_XX_EB18_v2".

KPP+	Obj	source_id1	source_id2	Sep	PA	Plx1	e_Plx1	Plx2	e_Plx2	BCD AU	RCD AU	WCD AU	PlxS
1	42492	2341739525536269568	2341739525536269440	4.61684	24.778	9.2362	0.0417	9.1584	0.0456	501.62	189715.33	402791.34	80
4	48938	2746869015880925824	2746869015880925696	4.84969	270.613	10.6021	0.0490	10.6156	0.0489	455.33	24746.04	204173.78	80
5	42567	2306711382881486208	2306711181018700800	9.48859	56.226	8.9474	0.0374	8.9395	0.0367	1057.11	20400.43	211455.28	80
6	7377	4923573765936638208	4923573765936638464	6.80564	166.112	9.3457	0.0244	9.3191	0.0426	726.98	63002.70	222118.16	80
10	35449	396259489527418368	396259459468383744	18.61237	177.283	7.3463	0.0301	7.3641	0.0306	2523.28	67915.30	299304.53	80
13	53174	4991245614249699456	4991245614249699584	5.09070	234.828	7.9640	0.0387	7.9396	0.0310	638.70	79599.12	306682.27	80
14	7395	4901424344713245184	4901424344713244928	2.84072	60.447	6.9153	0.0281	6.9360	0.0177	409.13	89020.31	286416.27	80
16	37772	420291656914875008	420290901000634112	38.68582	125.738	8.1796	0.0304	8.2113	0.0365	4712.14	97467.42	302629.22	80
17	7417	4904558330809468416	4904558330809468288	7.50102	39.693	5.6652	0.0274	5.6376	0.0228	1325.20	178256.70	502077.08	80
18	165	2849801721059508096	2849801721059507968	2.85337	356.977	11.7827	0.0382	11.7856	0.0582	241.39	4314.40	147251.08	100

Content description

KPP+	=	Running object number
*Comp	=	Components (blank = AB)
Obj	=	EB18 object number
*WDS ID	=	WDS object ID in case of an overlap with WDS catalog
*Disc Ref	=	Discoverer ID in case of an overlap with WDS catalog
source_id1	=	GAIA DR2 source id for primary
source_id2	=	GAIA DR2 source id for secondary
Sep	=	Separation in arcseconds epoch 2015.5
*e_Sep	=	Error separation
PA	=	Position angle epoch 2015.5
*e_PA	=	Error position angle
Plx1	=	Parallax value primary in mas
e_Plx1	=	Error parallax value primary
Plx2	=	Parallax value secondary in mas
e_Plx2	=	Error parallax value secondary
BCD AU	=	Best case distance between components in AU
RCD AU	=	Realistic case distance between components in AU
WCD AU	=	Worst case distance between components in AU
PlxS	=	Parallax score, estimated likelihood for potential gravitational relationship
*v1	=	GAIA DR2 visibility_periods_used primary
*d1	=	GAIA DR2 duplicated_source primary
*v2	=	GAIA DR2 visibility_periods_used secondary
*d2	=	GAIA DR2 duplicated_source secondary

* value given only in download file

Table B1: KPP objects cross-matched with EB18_v2 (stub from download file)

The number of 4,217 newly found KPP objects seems even with the restriction to the angular separation of 60" rather modest compared to the >55,000 objects in the EB18 catalog, but the main reasons for this difference are obviously:

- Aiming for most reliable GAIA DR2 parallaxes I selected only objects with <0.5% parallax error (means compared to EB18 more rigid to a factor of 10)
- Cross-matching with the WDS catalog to eliminate all already known double stars
- Calculating the distance between the components using the given GAIA DR2 data for the secondary instead of assuming the parallax for the secondary being ident with the parallax for the primary.

The remaining >1,000 KPP objects not covered by EB18 are to be explained as follows:

- Multiples were not excluded but considered of special interest
- Common proper motion was considered not relevant for assessing a pair as likely physical (see Knapp 2019

on "True movement …") so the KPP data set includes many objects with rather different proper motion values.

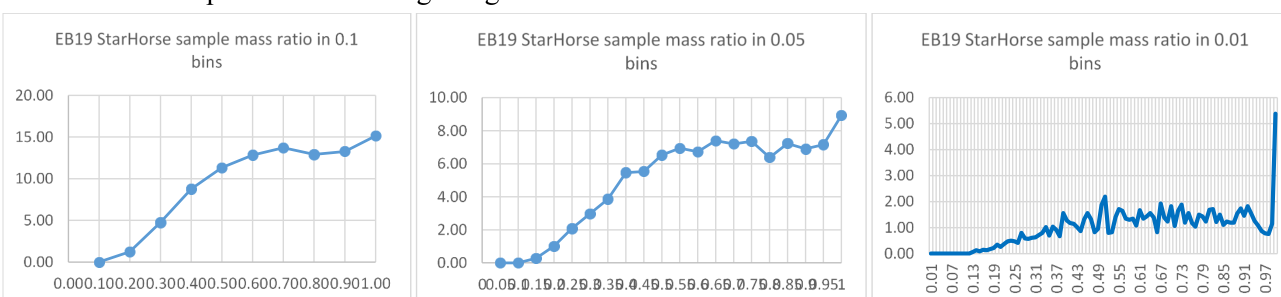
Side result: The EB18 catalog was designed to include only binary pairs by eliminating suspected multiples – this did not completely work out. 57 of the positively matched KPP objects refer to components of multiples with components given in the "Comp" column. Additionally there are 16 objects overlapping with one component indicating a corresponding number of multiples with an additional component outside the KPP objects 60" search radius. Finally there are 551 objects with GAIA DR1 field "duplicated_source" = 1 for at least one component which means that these components are potentially doubles themselves. In total this means a significant contamination of the EB18 catalog with multiples even if a part of these multiples might not be physical but just optical. Why the authors of EB18 did not exclude objects with "duplicated_source" = 1 remains unclear.

Appendix C

Effects of presenting data in graphs

Presenting results with estimated values in graphs has some caveats. The very same EB19 data set with StarHorse mass50 can be presented in graphs with different bin size allowing for different conclusions showing that this kind of data presentation is close to manipulating results:

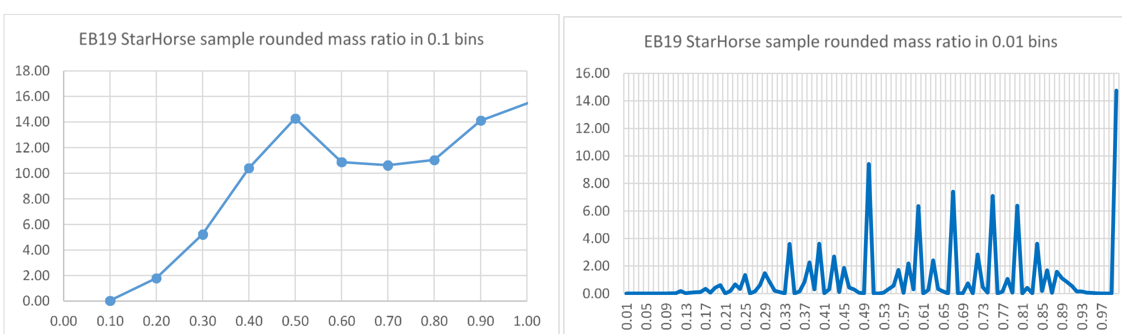
Just another experiment with single digit rounded mass50 values as substitute for "estimated" masses shows



Graph C1 to C3: Presenting identical data with different bin sizes

that selecting bin size combined with crude estimated values might result in undesired distortions delivering quite different conclusions:

Same data as above but with single digit rounded EB19 StarHorse mass50 values with a bin size of 0.1: Compared with graph C1 there is suddenly a peak at q = 0.5.



Graphs C4 and C5: Presenting ident but rounded data with different bin sizes

The ident result in bins of 0.01: The equal mass spike is compared to graph 3 with 14.76% suddenly truly significant enough to draw conclusions for an excess in "twin" pairs.

I certainly do not want to impute to the EB19 authors the intention to tamper with their data to get a desired result but I wanted to demonstrate that limited precision of data (by rounding or estimating) and selecting bin size for presentation of the ratio of such data in graphs can lead to unexpected distortions of the results.