

# Counter-Check of CBL Double Stars for being Physical Pairs

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**Abstract:** This report counter-checks a random sample of CBL objects for the probability of being physical pairs using TGAS proper motion and parallax data finding most of them common proper motion pairs indeed but only in one case with some probability for gravitational relationship

## Introduction

The WDS catalog contains (starting with the first Caballero JDSO report in 2009) per August 2017 about 600 CBL objects – most of them V-coded as assumed physical pairs by means of common proper motion. The TGAS subset of GAIA provides PM and Plx data for stars already covered in the Tycho and Hipparcos catalogs (Michalik et al. 2015) with some overlap for a part of the CBL objects. As a random CBL objects sample, I selected 23 objects with  $\sim 12$  mag secondaries. Next step was then to identify these objects in the 2MASS images and load the GAIA DR1 data to check the PM values for common proper motion using the CPM assessment model from Knapp and Nanson 2017. The results for the selected CBL objects are given in Table 1.

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

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

lated approximately using Pythagoras.

The assessment of a potential gravitational relationship between the components is then based on a quite simple approach assuming average means Sun like star mass with a then assumed gravitational “border” at the outer rim of the Oort cloud at  $\sim 100,000$  AU. If the “realistic” distance between the components is therefore less than 200,000 AU then a potential gravitational relationship is assumed to be present with a high probability because of the overlapping Oort clouds (for details see Appendix B).

## Summary

From 23 total objects, only 2 are to be considered probably not CPM pairs, confirming the assumed high quality of the CBL objects. Eleven objects did not allow for an assessment of gravitational relationship due to missing GAIA DR1 Plx data for at least one component. From the remaining 12 objects, only one can be considered physical in terms of at least some probability of gravitational relationship. All other pairs save 2, have a very small probability of being physical. And 2 objects are, with the given measurements, outside of any possibility of gravitational relationship (however, this does not exclude the possibility of common origin from the same molecular cloud).

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Table 1. CPM Rating for the selected CBL objects

Description of table contents:  
 - Header line: Gives the WDS catalog data available for the selected object with year of last observation in the Date column, for one object without WDS data the Tycho II data is given  
 - Data line:  
 -- RA and Dec give the coordinates from the used catalog in decimal degrees format as these values are directly usable for calculating Sep and PA (Buchheim 2008)  
 -- Sep gives separation in arcseconds calculated from the coordinates of both components as  $\text{SQRT}(((\text{RA2}-\text{RA1}) \cdot \cos(\text{Decl1}))^2 + (\text{Dec2}-\text{Decl1})^2)$  in radians  
 -- PA gives position angle in degrees calculated from the coordinates of both components as  $\text{arctan}((\text{RA2}-\text{RA1}) \cdot \cos(\text{Decl1})) / (\text{Dec2}-\text{Decl1})$  in radians depending on quadrant (Buchheim 2008)  
 -- M1 and M2 give GAIA DR1 Gmags or in case of URAT1 Vmags if available  
 -- pmRA1 and pmDE1 with e\_pm1 give the proper motion data for A and pmRA2, pmDE2 and e\_pm2 for B  
 -- Ap indicates in the aperture used (calculated circular surface diameter)  
 -- Me indicates the WDS code for the used observation method  
 -- Date is the Julian observation epoch  
 -- CPM Rat gives the rating of the CPM assessment based on comparison of the given PM data (description see Appendix A)  
 -- Source/Notes finally indicates the used catalog and gives additional comments and explanations if considered necessary

Name	RA	Dec	Sep	PA	M1	M2	pmRA1	pmDec1	e_pm1	pmRA2	pmDec2	e_pm2	Ap	Me	Date	CPM Rat	Source/Notes
CBL 130	07:08:55.240	-11:23:29.6	48.0	31	11.29	12.27	-7	-73							2010		WDS07089-1123
	107.2301783	-11.39187011	48.002	31.114	11.096	11.988	-3.60	-74.25	1.909	-4.76	-71.55	1.963	0.96	Hg	2015.0	AAAB	GAIA DR1. PM data from GAIA DR1 catalog. Solid CPM candidate
CBL 114	00:32:19.100	-21:50:33.7	49.7	209	11.62	12.26	60	-1							2010		WDS00323-2151
	8.079834197	-21.84265497	49.714	208.503	11.436	12.032	60.57	-0.09	1.724	63.13	4.89	1.127	0.96	Hg	2015.0	CBAB	GAIA DR1. PM data from GAIA DR1 catalog. Rather optical
CBL 47	10:59:33.138	+23:15:47.1	19.9	183	11.08	12.22	44	-38							2013		WDS10596+2316
	164.8882947	23.2628989	19.808	182.982	10.602	11.750	42.40	-40.30	1.414	41.70	-39.50	1.414	0.96	Hg	2015.000	AAAB	GAIA DR1. PM data from UCAC5 catalog. Solid CPM candidate
CBL 112	05:55:36.199	+45:01:15.7	8.1	74	11.44	12.11	17	-68							2002		WDS05556+4501
	88.9009386	45.0207906	8.064	73.531			17.34	-68.64	5.75	17.67	-72.04	5.75	0.2	Eu	2013.603	AAAB	URAT1. PM data calculated from position comparison with 2MASS. Solid CPM candidate
CBL 170	18:27:24.763	+21:51:53.4	26.6	160	10.31	12.08									2010		WDS18274+2152
	276.8531292	21.8650538	26.596	160.014	10.027	11.532	-14.24	54.36	1.265	-15.78	53.82	1.338	0.96	Hg	2015.0	AAAB	GAIA DR1. PM data from GAIA DR1 catalog. Solid CPM candidate
CBL 56	13:21:51.651	+55:54:04.2	25.1	77	9.33	12.05	-66	-4							2010		WDS13219+5554
	200.4647731	55.9011578	25.068	76.646			12.051	-73.07	6.68	-71.28	-2.22	5.87	0.2	Eu	2013.697	CABB	URAT1. PM data calculated from position comparison with 2MASS. Rather optical
CBL 178	20:33:53.247	-27:10:17.3	52.0	40	9.46	12.05									2010		WDS20339-2710
	308.4722226	-27.17186331	52.047	39.939	9.117	11.355	70.39	-85.20	0.088	70.84	-86.59	2.456	0.96	Hg	2015.0	AAAB	GAIA DR1. PM data from GAIA DR1 catalog. Solid CPM candidate
CBL 147	13:17:35.429	-11:57:01.3	24.1	345	11.23	12.02	-82	36							2013		WDS13176-1157
	199.3972222	-11.9501914	24.296	344.748	10.917	11.586	-85.20	35.40	1.628	-84.80	36.10	1.628	0.96	Hg	2015.000	AAAB	GAIA DR1. PM data from UCAC5 catalog. Solid CPM candidate
CBL 185	21:54:22.589	-44:09:46.4	18.0	74	10.97	12.01	20	-92							2010		WDS21544-4410
	328.5942328	-44.1632639	17.990	73.727	10.621	11.490	18.40	-88.90	1.273	18.20	-88.10	1.414	0.96	Hg	2015.000	AAAB	GAIA DR1. PM data from UCAC5 catalog. Solid CPM candidate

Table 1 concludes on the next page.

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

Name	RA	Dec	Sep	PA	M1	M2	pmRA1	pmDec1	e_pm1	pmRA2	pmDec2	e_pm2	Ap	Me	Date	CPM Rat	Source/Notes
CBL 130	07:08:55.240	-11:23:29.6	48.0	31	11.29	12.27	-7	-73							2010		WDS07089-1123
CBL 115	00:55:33.210	-43:16:11.7	28.2	135	12.04	11.96	13	-86							2010		WDS00556-4316
CBL 150	13:89617105	-43:2758229	28.193	314.525	11.681	11.812	14.08	-84.16	0.530	13.03	-85.10	0.531	0.96	Hg	2015.0	BBAB	GAIADR1. PM data from GAIADR1 catalog. Good CPM candidate
CBL 150	14:12:31.781	-30:06:17.7	31.3	217	11.32	11.95	-65	-16							2010		WDS14125-3006
CBL 57	213.1320539	-30.1049925	31.264	216.472	11.002	11.743	-67.50	-19.40	1.556	-65.80	-18.80	1.556	0.96	Hg	2015.000	AAAB	GAIADR1. PM data from UCAC5 catalog. Solid CPM candidate
CBL 57	13:54:51.370	+51:22:49.9	27.0	110	11.21	11.94	-55	22							2010		WDS13549+5123
CBL 125	208.7136953	51.3805889	26.987	109.713	11.074	11.798	-53.90	18.80	1.980	-54.10	20.90	1.980	0.96	Hg	2015.000	AAAB	GAIADR1. PM data from UCAC5 catalog. Solid CPM candidate
CBL 125	05:23:39.979	-38:18:48.1	24.0	194	11.98	11.93	30	39							2010		WDS05237-3819
CBL 129	80.91474483	-38.31966402	24.023	13.465	11.691	11.749	26.58	41.91	1.602	26.97	40.75	1.250	0.96	Hg	2015.0	AAAB	GAIADR1. PM data from GAIADR1 catalog. Solid CPM candidate
CBL 129	07:03:08.450	-73:50:13.9	51.4	140	11.18	11.90	-3	59							2010		WDS07031-7350
CBL 136	105.7851094	-73.8369683	51.334	140.088	10.969	11.614	-6.30	60.10	1.273	-5.10	60.70	1.273	0.96	Hg	2015.000	AAAB	GAIADR1. PM data from UCAC5 catalog. Solid CPM candidate
CBL 136	10:32:03.301	-30:28:05.5	14.5	30	11.52	11.87	34	-38							2010		WDS10321-3028
CBL 172	158.0139037	-30.46835253	14.484	29.584	11.276	11.465	34.30	-39.37	1.387	34.01	-38.97	1.026	0.96	Hg	2015.0	AAAB	GAIADR1. PM data from GAIADR1 catalog. Solid CPM candidate
CBL 172	18:41:25.437	-44:32:30.6	36.4	53	10.92	11.84	15	-46							2010		WDS18414-4433
CBL 139	11:35:52.050	-40:40:36.4	20.0	247	11.92	11.82	-89	14							2010		GAIADR1. M1 and M2 are G-band. PM data calculated from position comparison with 2MASS. Difference in PMVL too large to be considered a good CPM candidate
CBL 139	173.9595911	-40.67886858	20.052	67.312	11.634	11.667	-87.41	13.80	1.153	-88.12	14.09	1.293	0.96	Hg	2015.0	AAAB	GAIADR1. PM data from GAIADR1 catalog. Solid CPM candidate
CBL 140	11:53:22.089	-67:07:05.6	36.1	119	10.63	11.77	-9	-55							2010		WDS11534-6707
CBL 140	178.341913	-67.11842477	36.105	119.261	10.371	11.317	-8.94	-54.66	0.772	-8.67	-56.34	0.914	0.96	Hg	2015.0	ABAB	GAIADR1. PM data from GAIADR1 catalog. Good CPM candidate, difference in PMVL might indicate an orbit
CBL 177	20:06:03.950	-41:37:36.5	23.7	9	11.56	11.77	56	-51							2010		WDS20061-4138
CBL 165	17:59:53.978	-45:17:20.7	14.3	193	11.12	11.77	8	-46							2010		WDS17599-4517
CBL 165	301.5167418	-41.62699058	23.727	8.935	11.205	11.595	52.05	-51.90	1.397	51.63	-50.36	2.046	0.96	Hg	2015.0	AAAB	GAIADR1. PM data from GAIADR1 catalog. Solid CPM candidate
CBL 182	21:16:13.423	-40:40:51.9	31.3	152	11.28	11.74	43	-24							2010		WDS21162-4041
CBL 182	269.9749319	-45.28932788	14.246	192.908	10.865	11.389	6.30	-55.50	3.989	7.09	-51.25	8.377	0.96	Hg	2015.0	ABCB	GAIADR1. PM data from GAIADR1 catalog. Rather large PM error range, difference in PMVL might indicate an orbit
CBL 134	10:15:08.030	-65:26:11.0	31.2	305	11.32	11.72	-59	15							2010		WDS10151-6526
CBL 134	319.0561483	-40.68119	31.279	151.653	11.214	11.608	43.80	-23.30	1.414	44.20	-23.30	1.414	0.96	Hg	2015.000	AAAB	GAIADR1. PM data from UCAC5 catalog. Solid CPM candidate
CBL 128	06:38:17.670	+18:28:24.6	55.8	64	11.46	11.71	-74	-71							2010		WDS06383+1828
CBL 128	99.5732433	18.4733886	55.816	63.628	10.878	11.055	-76.10	-22.40	1.697	-75.70	-21.60	1.697	0.96	Hg	2015.000	AAAB	GAIADR1. PM data from UCAC5 catalog. Solid CPM candidate

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

Description of the table content:  
 - Name: Object WDS discoverer ID or Tycho catalog ID  
 - PMVD: Proper motion vector direction in degrees for A and B and delta AB  
 - PMVL: Proper motion vector length for A and B and delta AB derived from GAIA DR1 pm values  
 - Plx: Parallax A and B end parallax error A and B from GAIA DR1  
 - Dist AB min: "Best case" distance between the components in AU assuming largest possible equal Plx  
 - Dist AB Plx: "Realistic case" approx. distance between the components in AU according to the given GAIA DR1 parallax values  
 - Dist AB max: "Worst case" approx. maximum distance between the components in AU according to the given GAIA DR1 Plx values with full error range applied in opposite directions  
 - Plx Rating for potential gravitational relationship (see Appendix B):  
 -- "A" for a "realistic" distance less than 200,000 AU (assuming average mass stars like our sun with then overlapping Oort clouds), "B" for less than 300,000 AU (with some probability for a smaller distance within the given Plx error range), "C" for above but with still less than 200,000 AU in "best case" and "D" for larger even in "best case"  
 -- For relation Plx error to Plx value with "A" for less than 5%, "B" for less than 10%, "C" for less than 15% and "D" above

Name	PMVD A	PMVD B	ΔPMVD	PMVL A	PMVL B	ΔPMVL	Plx A	Plx B	e_Plx A	e_Plx B	Dist AB min	Dist AB Plx	Dist AB max	Plx Rat	Notes
CBL 130	182.78	183.80	1.03	74.33	71.71	2.62	4.10	4.46	0.41	0.38	10,644	4,060,874	13,281,909	CB	Probability for gravitational relationship very small to near zero
CBL 114	90.08	85.57	4.51	60.57	63.32	2.74	3.79	2.57	0.51	0.33	8,240,356	25,835,793	44,114,870	DC	Zero probability for gravitational relationship
CBL 47															No Plx data for B available
CBL 112															No Plx data for A available
CBL 170	345.32	343.66	1.67	56.19	56.08	0.11	6.16	6.35	0.27	0.25	4,136	1,001,930	3,767,330	CA	Probability for gravitational relationship rather small
CBL 56															No Plx data for A available
CBL 178	140.43	140.71	0.28	110.52	111.87	1.35	11.69	11.82	0.55	0.74	4,252	194,111	2,093,383	AB	Good probability for gravitational relationship
CBL 147															No GAIA DR1 Plx data for A and B
CBL 185															No GAIA DR1 Plx data for B
CBL 115	170.50	171.30	0.79	85.33	86.09	0.76	4.11	4.23	0.23	0.23	6,496	1,423,763	6,913,466	CB	Probability for gravitational relationship rather small
CBL 150															No GAIA DR1 Plx data for A
CBL 57															No GAIA DR1 Plx data for A and B
CBL 125	32.39	33.50	1.11	49.63	48.87	0.76	3.97	4.06	0.22	0.23	5,734	1,151,770	6,923,721	CB	Probability for gravitational relationship rather small
CBL 129															No GAIA DR1 Plx data for A and B
CBL 136	138.94	138.89	0.05	52.21	51.72	0.49	4.26	4.61	0.48	0.42	3,056	3,676,139	13,560,774	CC	Probability for gravitational relationship very small
CBL 172															No GAIA DR1 Plx data for A
CBL 139	278.97	279.08	0.11	88.49	89.24	0.74	4.04	3.05	0.34	0.53	1,868,662	16,677,527	34,809,614	DC	Zero probability for gravitational relationship
CBL 140	189.29	188.75	0.53	55.39	57.00	1.61	11.79	11.52	0.25	0.29	3,057	410,057	1,235,704	CA	Very small but some probability for gravitational relationship
CBL 177	134.91	134.29	0.63	73.50	72.12	1.38	4.74	4.90	0.58	0.81	4,460	1,420,960	13,459,735	CC	Probability for gravitational relationship very small
CBL 165	173.52	172.13	1.39	55.86	51.74	4.12	5.45	5.75	0.30	0.24	2,478	1,974,656	5,616,678	CA	Probability for gravitational relationship very small
CBL 182															No GAIA DR1 Plx data for B
CBL 134	282.47	280.92	1.55	61.18	62.15	0.97	6.48	6.21	0.28	0.30	4,775	1,383,993	4,388,532	CA	Probability for gravitational relationship very small
CBL 128															No GAIA DR1 Plx data for B

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### References

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- Washington Double Star Catalog
- GAIA DR1 Catalog including TGAS
- UCAC5 catalog
- Aladin Sky Atlas v9.010
- VizieR
- AstroPlanner v2.2

### Appendix A - Description of the CPM rating procedure:

- Four rating factors are used: Proper motion vector direction, proper motion vector length, size of position error in relation to proper motion vector length according to Knapp and Nanson 2017 with extension for relation separation to proper motion speed
- Proper motion vector direction ratings: “A” for identical direction within the error range (given by assuming the worst case of the position error pointing in right angle to the PM vector), “B” for similar direction within the double error range, and “C” for outside
- Proper motion vector length ratings: “A” for identical length within the error range (given by assuming the worst case of the position error pointing in the direction of the PM vector), “B” for similar length within the double error range, and C for outside
- Error size ratings: “A” for error size of less than 5% of the proper motion vector length, “B” for less than 10%, and “C” for a larger error size
- Relation separation to proper motion speed: "A" for less than 100 years, "B" for less than 1000 years and "C" for above
- To compensate for excessively large position errors resulting in an “A” rating despite rather high deviations an absolute upper limit is applied regardless of calculated error size:
- Proper motion vector direction: Max. 2.86° difference for an “A” and 5.72° for a “B”
- Proper motion vector length: Max. 5% difference for an “A” and 10% for a “B”
- To compensate for any overly small error “allowance” (result of a combination of very small position error with large PM vector length) the following exceptions are applied:
- If the PM vector direction difference is larger than this calculated “allowed” error but still less than 0.5° then an “A” is given, a “B” is given for larger than 0.5 but less than 1 degree, and a “C” is given if above
- If the PM vector length difference is larger than this calculated “allowed” error but still less than 0.5% then an “A” is given, a “B” is given for larger than 0.5 but less than 1 percent, and a “C” is given if above

### Appendix B - Description of the Plx rating procedure:

- Two rating factors are used: Distance between the components calculated from the given Plx data and relationship of given Plx error in comparison with the given Plx data
- Distance rating: “A” for distance less than 200,000 AU assuming average star mass means Sun like and an assumed gravitational relationship border with Oort cloud distance, “B” for a distance of less than 300,000 AU, “C” for distance larger than 300,000 AU but best case scenario less than 200,000 AU and “D” if distance larger 300,000 AU even in best case
- Plx error rating: “A” less than 5%, “B” less than 10%, “C” less than 15% and “D” larger than 15% PM error size in relation to the given PM data