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A survey of double stars for Hipparcos

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Astronomia. — *A survey of double stars for Hipparcos.* Nota (*) del Corrisp. MARIO GIROLAMO FRACASTORO.

RIASSUNTO. — Sono stati analizzati il Catalogo delle Stelle Brillanti di D. Hoffleit e il Catalogo delle Stelle Vicine di W. Gliese, al fine di esaminare l'incidenza delle coppie di stelle in vista della missione del satellite astrometrico Hipparcos, con alcune considerazioni sulla natura e la frequenza dei sistemi binari.

Le stelle che formano una coppia sono in genere di tipo spettrale molto vicino e inoltre la differenza di magnitudine fra le due componenti cresce in media con la loro separazione, ben oltre le limitazioni poste dal potere separatore del telescopio.

Il numero di coppie osservato supera quello previsto teoricamente mediante la formula di Poisson per una vicinanza casuale, fino a separazioni di circa 10″.

Almeno per quanto concerne le coppie formate da stelle di media–bassa sequenza principale, si può prevedere infine che anche per stelle più lontane, aventi magnitudini più deboli di quelle contenute nel Catalogo delle Stelle Brillanti, la separazione risulterà inferiore a quella casuale.

The *Catalogue of Bright Stars* (BS, 1964 Edition) contains 9093 entries, namely all stars up to the 6th magnitude and a few fainter ones, over the entire sky. The information concerning these stars is expected to be the most complete available, as a consequence of the great amount of light we receive from them.

The BS has been analysed at first with the purpose of evaluating the impact of composite signals given by pairs of stars, when observed by the astrometric satellite Hipparcos. Consequently, the physical natuıe of the couples has been disregarded, and spectroscopic binaries have been neglected.

A pair of stars is recorded in the BS in two ways:

a) A single entry concerning a star A of magnitude V_1 refers in columns 12 *a* and 12 *b* to the difference of magnitude Δm and the separation s of an existing companion of magnitude V_2 not occupying an entry in the BS.

b) Two consecutive entries of BS are concerned with two stars N and N + 1, having as a rule the same coordinates. In this case, columns 12 *a* and 12 *b* report equal values for Δm and s.

The Δm's range from 0 to 10 magnitudes, or even more. Similarly, the separations range from $0''.1$ to some hundred arcseconds. The greatest Δm's are observed for companions of brighter stars. When stars with $V_1 \leq 2.99$ are only considered (see Fig. 1 *a*), the Δm's are almost uniformly distributed from 0 to 12 magnitudes; while, for V_1 ranging from 6.00 to 6.99 (Fig. 1 *b*), the small Δm's are prevailing, even if values up to $\Delta m = 10$ are found. This

(*) Presentata nella seduta dell'11 dicembre 1982.

fact might be due to the threshold of visibility or the resolving power of the observer, who might be particularly eager when searching companions of very bright stars.

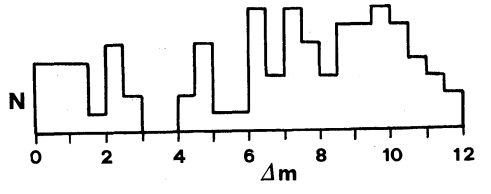

Fig. 1 *a*.

Table 1 *a* reports the fraction of stars having a companion (couples). Altogether: 4548 entries, 1073 pairs, namely 23.6 percent. This fraction remains roughly constant within the range of Right Ascensions examined ($0\text{–}12^h$). Tables 1 *b* and 1 *c* report the frequency distribution of Δm's and separations s.

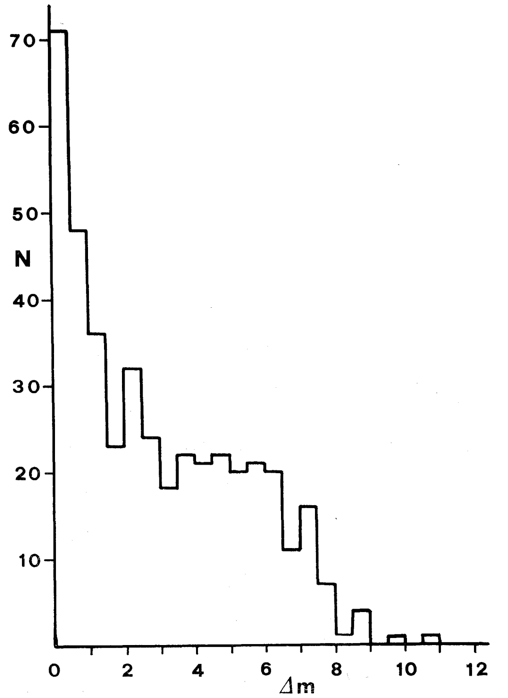

Fig. 1 *b*.

The distribution according to the spectral type of the brighter companion has also been considered. This distribution varies strongly with the Right Ascension with a prevalence of B-type stars when a galactic region is found. 23.6 percent of pairs have an OB-type star as brighter companion; 26.3 percent an A-type star; 18.6 percent an F-type star; 12.7 percent a G-type star; 15.1 percent a K-type star and finally 3.7 percent an M-type star.

A preliminary indication concerning the spectral coupling can be obtained examining the pairs which occupy two entries in the whole BS. The most common coupling clearly appears to be between stars of the same spectral type (see Table 2).

As shown in Figure 2, the average Δm increases steadily up to large values of s. This might be due to observational reasons (in fact, it is easier to detect a faint companion when its separation is large enough). However, it is rather surprising that Δm still increases for $s > 5''$, a separation well outside the minimums of any observer and any professional telescope. The observed trend of the relationship $(\Delta m, s)$ might support the hypothesis that, during the formation of stellar systems, the smaller masses and correspondingly the fainter stars are preferably put on hyperbolic orbits.

TABLE 1

a				*b*		*c*	
RA	Entries	Couples	%	Δm	N	s	N
0– 1	306	72	23.5	0.0–0.9	217	0″.1–0″.9	159
1– 2	296	72	24.3	1.0–1.9	127	1.0–1.9	108
2– 3	313	56	17.9	2.0–2.9	128	2.0–2.9	69
3– 4	339	75	22.1	3.0–3.9	116	3.0–4.9	101
4– 5	375	94	25.1	4.0–4.9	108	5.0–9.9	138
5– 6	492	130	26.4	5.0–5.9	99	10–16	106
6– 7	510	116	22.7	6.0–6.9	115	16–32	167
7– 8	490	105	21.4	7.0–7.9	79	32–64	139
8– 9	436	121	27.8	8.0–8.9	51	64–128	62
9–10	355	80	22.5	9.0–9.9	23	≥ 128	29
10–11	339	82	24.2	≥ 10	15		
11–12	297	71	23.9				

The histogram of the V_2's has been examined for this purpose, and also in order to evaluate how much these companions may affect the signal of their primaries, when observed with the telescope installed on the Hipparcos.

Clearly, this will reach much fainter stars than those listed in the BS. Therefore we may try to sketch a model of a region of the sky, containing the same amount of information as the BS, but extended to fainter stars.

Table 2

	Spectral type of the brighter component							
	O	B	A	F	G	K	M	Spectral type of the fainter component
N	1	4	—	—	—	—	—	O
$\overline{\Delta m}$	1.90	2.70	—	—	—	—	—	
N	—	20	3	1	—	1	—	B
$\overline{\Delta m}$	—	0.73	0.63	0.12	—	0.13	—	
N	—	7	31	—	4	1	1	A
$\overline{\Delta m}$	—	0.79	0.58	—	1.46	2.42	4.79	
N	—	1	6	23	2	3	—	F
$\overline{\Delta m}$	—	2.71	2.07	0.43	1.01	1.31	—	
N	—	—	1	4	9	1	2	G
$\overline{\Delta m}$	—	—	0.08	1.23	0.44	1.19	2.01	
N	—	—	—	1	2	3	1	K
$\overline{\Delta m}$	—	—	—	2.55	1.28	6.30	0.60	
N	—	—	—	—	—	—	—	M
$\overline{\Delta m}$	—	—	—	—	—	—	—	

It is well known that the total number N (m) of stars increases with m at a slower rate than foreseen from a uniform and indefinite distribution of stars and in absence of interstellar absorption. This is due to the limited size of our Galaxy, for intrinsically bright stars, and to the contribution of intrinsically faint and relatively nearby stars, which become visible when fainter magnitudes are attained. Table 3 gives, for visual magnitudes V ranging from 4 to 20, the corresponding values of log N (m)/K, where K is the number of square degrees covering the whole sphere. Table 3 also gives the average angular distance d on the sky between two stars of magnitude V. It results that, within the range of magnitudes explored by Hipparcos, log N (m) increases roughly by 0.43 per magnitude, instead of 0.6. This means that a Catalogue containing the same amount of information as BS but extended, say, to 11.5 (i.e. 5 magnitudes farther than the actual BS), would contain in general more distant stars; but their average distance would be significantly smaller than 10 r, if r is the actual distance of the stars listed in BS. Consequently, the average separation between the components of a couple would decrease by a factor $f \leq 10$. However, within the pur-

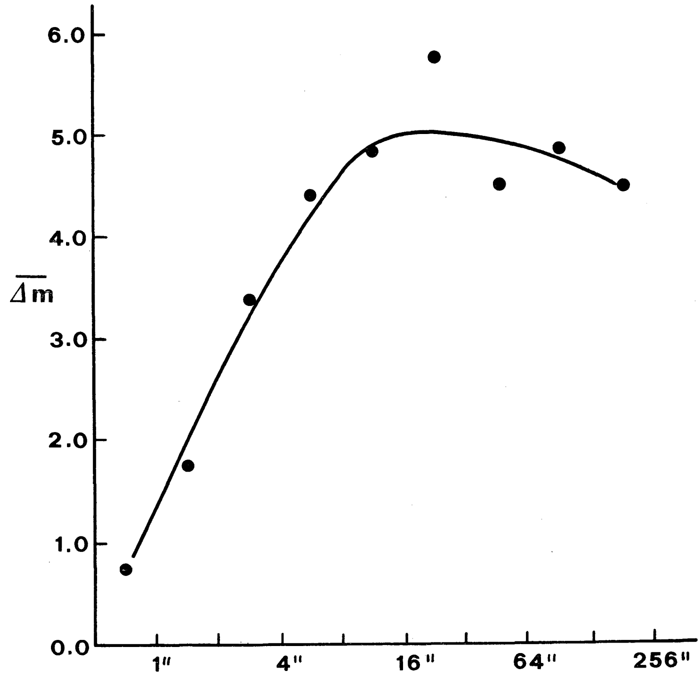

Fig. 2.

poses of this study, we may adopt as an upper limit $f = 10$. This adoption corresponds to neglecting the contribution of very luminous stars and assigning the increased number of stars only to main sequence low luminosity objects [1].

(1) The BS, for RA $\leq 12^h$, lists 199 pairs having a primary with spectrum F, G or K, and luminosity class V. None is listed with M-type spectrum and luminosity class V, as expected in view of the low intrinsic luminosity of these stars.

146 pairs have an F-type primary, 44 a G-type and 9 a K-type. However, adopting for dF-type stars an absolute magnitude $M_F = 4$, for dG-type stars $M_G = 5.5$ and for dK-type stars $M_K = 7$, and assuming $V_1 = 6$ for all primary stars regardless of their spectral type, we obtain an average parallax $\pi_F = 0''.040$, $\pi_G = 0''.079$ and $\pi_K = 0''.158$ and consequently the number of pairs per cubic parsec results:

F pairs: $N_F = 0.00446$

G pairs: $N_G = 0.0105$

K pairs: $N_K = 0.0172$

The contribution from 178 A dwarf pairs (average values: $V_1 = 6$, $M_A = +2$, $\pi_A = 0''.016$) results 0.00034 pairs per cubic parsec.

Finally, the BS lists 131 couples having a B5–type or hotter primary. Assuming $M_B = -3.5$, their contribution results practically negligible (0.000000125 couples per cubic parsec). In this case, however, the space distribution is far from being uniform.

Altogether we obtain 0.0325 pairs per cubic parsec, namely 41.1 percent of the whole population resulting in the vicinity of our sun (0.079 stars, single, double or multiple, within 5.1 parsec).

Considering the average Δm's in terms of separations, different trends are obtained for low-temperature dwarfs and for hot stars. In particular, for dwarf F, G, K pairs, We now come to our model. The same number of stars and pairs, contained in a region of $30 \times 30 = 900$ square degrees of BS, will be condensed in a region of $3 \times 3 = 9$ square degrees (see Table 4), all magnitudes having been increased by 5 units and all separations by a factor $f = 10$. V'_1 and V'_2 are the hypothetical magnitudes and s' the corresponding separations, d being again the average distance on the sky between two stars of magnitude V'_2.

TABLE 3

V	log N/K	d	V	log N/K	d
4.00– 4.99	—1.59	6°.24	12.00–12.99	+2.03	5′.8
5.00– 5.99	—1.07	3.45	13.00–13.99	+2.42	3.7
6.00– 6.99	—0.51	1.81	14.00–14.99	+2.79	2.4
7.00– 7.99	—0.07	1.09	15.00–15.99	+3.15	1.6
8.00– 8.99	+0.37	40′	16.00–16.99	+3.49	1.08
9.00– 9.99	+0.80	24	17.00–17.99	+3.81	45″
10.00–10.99	+1.22	14.7	18.00–18.99	+4.12	31
11.00–11.99	+1.63	9.2	19.00–19.99	+4.40	23

One can see that *d* is always much larger than the adopted separations. For instance, the pair ex 4580 has $V'_1 = 11.3$ and $V'_2 = 19.0$, $s' = 1''42$, $d = 27''$. It follows that even in this model a pair would still be considered as such, because the two components would appear much closer than the average distance between stars as faint as V'_2. In two cases, however, namely ex 4419 and ex 4937, the separation would fall below the resolving limit of Hipparcos, and the ascertainment of their duplicity would be dubious.

It should be pointed out that the region of the sky which has been examined (that included between 11^h and 13^h of Right Ascension and $+15$ and $-15°$ of Declination) is anomalously poor of stars, due to its high galactic latitude ($\sim +60°$). However, the percentage of pairs (24.5) is not significantly different

to small separations correspond frequently small differences of magnitude between the two components ($\Delta m < 1$ in 33 over 42 cases); whereas, under the same circumstances, this happens only 7 out of 14 times for B-type stars. For all separations, we have 60 small Δm's over 199 cases for F, G, K dwarf pairs, and only 18 small Δm's over 131 cases for B-type stars.

This might suggest that a balanced distribution of masses helps dynamically the survival of couples. On the other hand, young pairs, as those containing a B-type star, are probably showing the primeval mass distribution law.

from that found examining the BS up to 12^h of Right Ascension. A similar analysis, made on a different area of the sky ($18^h \div 19^h$; $+15^o \div -15^o$) at low galactic latitude ($\sim +4^o$) shows a larger fraction of pairs ($31/101 = 30.7$) mostly due to four B–type pairs instead of none.

TABLE 4

exBS	V'_1	V'_2	s'	d	exBS	V'_1	V'_2	s'	d
4319	10.5	16.5	0.23	1'.08	4547	11.3	18.5	3.07	31"
4358	10.7	16.2	2.19	1.2	4580	11.3	19.0	1.42	27
4369	11.1	13.6	6.71	3.5	4677/8	11.6	12.0	2.03	7'.5
4399	8.9	12.1	0.32	8.2	4708	11.4	14.2	2.03	2.8
4414	11.0	12.0	3.05	7.5	4758	11.4	15.2	0.18	1.8
4416	10.9	17.9	2.80	40"	4821/2	11.0	11.1	0.57	11.8
4419	11.3	12.8	0.04	6'.8	4825/6	8.7	8.7	0.66	35'
4437	11.0	13.0	1.59	4.6	4828	10.4	16.2	0.41	1.1
4484	11.2	15.4	0.56	1.5	4856	11.3	17.5	1.65	45"
4488	10.6	16.1	0.17	1.2	4877	11.5	17.5	3.36	45
4490	11.4	17.3	0.82	50"	4921	10.9	16.1	2.13	1'.2
4531	10.9	15.1	0.13	2'.0	4925	11.1	16.1	0.13	1.2
4543	11.3	16.1	1.50	1.2	4937	11.5	11.8	0.07	8.5

The *Catalogue of Nearby Stars* by Gliese, 1969 (GL), also contains a great amount of information. A preliminary analysis has been made for a part of it, namely for 645 stars having RA $\leq 11^h\,21^m\,19^s$. The fraction of stars having an optical companion (157) is now 21.9%. The occurrence of Δm's, when compared with BS, favours the small values, as shown in Table 5, where the ratios GL/BS have been reduced to the same number of pairs and the GL last five values are smoothed. Balanced pairs occur more frequently in GL; for Δm ranging from 2 to 10, instead, the occurrence favours the BS. However, still larger Δm's are found in GL.

Figure 3 tries to give a tri-dimensional picture of the situation. Magnitudes m and separations s, in a logarithmic scale, are the horizontal coordinates. Vertically is given the average Δm's resulting for each square. Brighter stars and wider separations are clearly associated with larger Δm's. Single values of Δm have been taken from BS, with the exception of α UMa, where the adopted

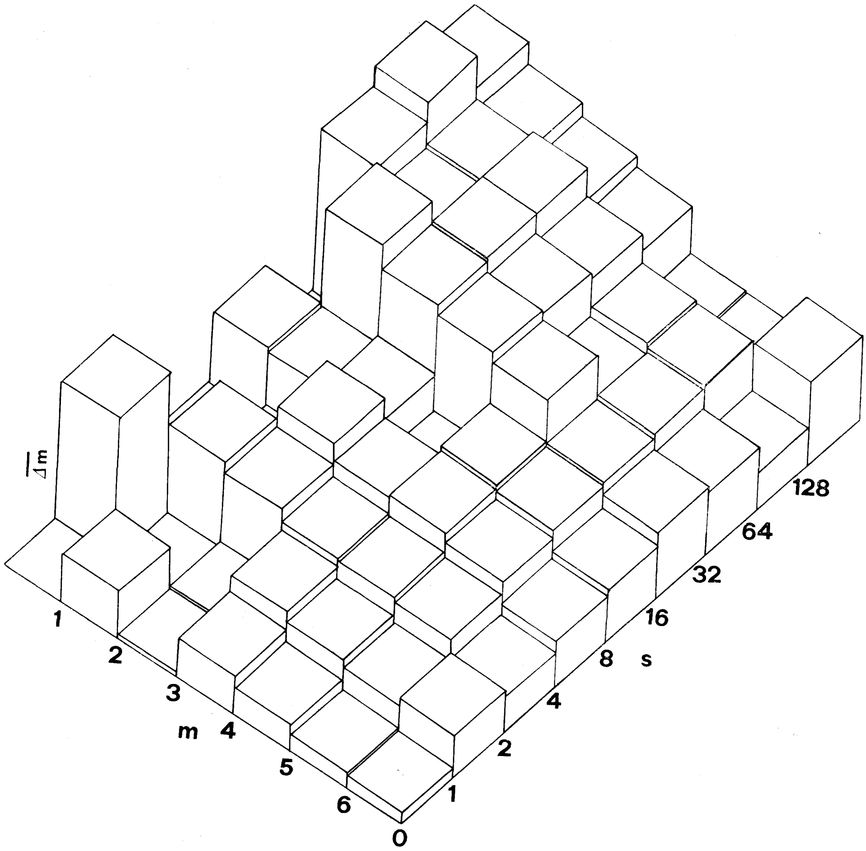

Fig. 3.

Δm has been 2.4, instead of 9.1 as given in BS. For stars brighter than 3.00, all pairs of BS have been examined; for fainter stars, only the data corresponding to the first part of BS have been used.

TABLE 5

Δm	GL	GL/BS	Δm	GL	GL/BS	Δm	GL	GL/BS
0 ÷ 1	47	1.57	4 ÷ 5	14	0.68	8 ÷ 9	3	0.69
1 ÷ 2	21	1.35	5 ÷ 6	9	0.68	9 ÷ 10	1	0.79
2 ÷ 3	25	0.98	6 ÷ 7	9	0.67	10 ÷ 11	3	1.38
3 ÷ 4	11	0.90	7 ÷ 8	10	0.64	11 ÷ 12	1	3.65
						12 ÷ 13	2	—

TABLE 6

s″	3÷4	4÷5	5÷6	6÷7	7÷8	8÷9	9÷10	10÷11	11÷12	12÷13	13÷14	14÷15	N_{obs}	N_{exp}
0.1– 0.9	1 7×10^{-6}	8 2×10^{-5}	29 7×10^{-5}	82 3×10^{-4}	19 8×10^{-4}	8 2×10^{-3}	5 6×10^{-3}	3 2×10^{-2}	0 4×10^{-2}	0 9×10^{-2}	0 0.23	0 0.54	155	1
1.0– 1.9	1 2×10^{-5}	1 8×10^{-5}	7 3×10^{-4}	23 9×10^{-4}	22 3×10^{-3}	15 7×10^{-3}	10 2×10^{-2}	11 0.05	6 0.13	6 0.32	2 0.80	0 1.9	104	3
2.0– 3.9	0 1×10^{-4}	2 4×10^{-4}	4 1×10^{-3}	15 4×10^{-3}	26 1×10^{-2}	18 3×10^{-2}	15 0.08	5 0.21	17 0.55	8 1.41	2 3.4	1 7.8	114	13
4.0– 7.9	2 4×10^{-4}	0 1×10^{-3}	2 4×10^{-3}	13 2×10^{-2}	19 4×10^{-2}	24 0.12	16 0.33	7 0.85	20 2.2	8 5.5	11 14.1	4 31	128	54
8.0–15.9	0 2×10^{-3}	4 5×10^{-3}	4 2×10^{-2}	13 6×10^{-2}	20 0.15	12 0.49	15 1.3	22 3.5	13 8.9	16 22	13 55	10 126	144	217
16–32	0 7×10^{-3}	0 2×10^{-2}	1 7×10^{-2}	9 0.26	15 0.71	18 2.0	16 5.2	14 14.1	24 35	34 87	25 211	8 479	165	832
32–64	0 3×10^{-2}	2 0.09	1 0.29	10 1.02	7 2.8	26 7.8	28 20.9	18 54	24 139	13 339	5 789	2 1636	137	2934
64–128	0 0.11	0 0.34	2 1.14	2 4.1	10 11.3	10 31	13 83	10 215	12 530	3 1215	3 2418	1 3742	76	all
128–256	0 0.43	0 1.4	2 4.6	4 16	4 45	3 122	5 322	10 801	2 1773	0 3208	0 4256	0 all	30	all

TABLE 7

The table reports $\log \overline{N}_{obs}/N_{exp}$, *where* $\overline{N}_{obs}$ *is the smoothed number of couples observed having a companion in the magnitude range given in abscissa and the separation given in ordinate.* N_{exp} *is the number expected according to the Poisson's formula. The line inside the table separates the areas where the* N_{obs} *is larger than expected (prevalence of physical couples) from the area where* N_{obs} *is smaller (incompleteness of observations).*

3÷4	4÷5	5÷6	6÷7	7÷8	8÷9	9÷10	10÷11	11÷12	12÷13	13÷14	14÷15	← V_2
												s″
+5.62	+5.67	+5.73	+5.16	+4.66	+3.73	+2.95	+2.25	+1.40	.	.	.	0.1– 0.9
+4.79	+4.56	+4.58	+4.27	+3.88	+3.34	+2.80	+2.25	+1.77	+1.16	+0.53	—0.45	1.0– 1.9
.	+3.76	+3.82	+3.59	+3.25	+2.81	+2.20	+1.77	+1.26	+0.80	+0.03	—0.76	2.0– 3.9
+3.38	+3.02	+3.06	+2.84	+2.63	+2.21	+1.67	+1.23	+0.73	+0.37	—0.27	—0.74	4.0– 7.9
.	+2.67	+2.59	+2.28	+2.00	+1.50	+1.10	+0.68	+0.28	—0.19	—0.63	—1.18	8.0–15.9
.	+2.11	+1.66	+1.50	+1.30	+0.91	+0.48	+0.11	—0.16	—0.50	—0.97	—1.63	16– 32
.	+1.04	+1.18	+0.77	+0.71	+0.42	+0.06	—0.37	—0.89	—1.38	—2.08	—2.78	32– 64
.	+0.26	+0.06	+0.06	—0.19	—0.45	—0.88	—1.26	—1.80	—2.37	—3.01	—3.44	64–128
.	—0.36	—0.37	—0.68	—1.09	—1.49	—1.73	—2.15	—2.65	—3.69	.	.	128–256

Finally, Table 6 has been obtained comparing the expected number of companions of magnitude V_2 at different separations from a primary star, as deduced from Poisson's formula, with the observed number of companions. The figures give the $\log \overline{N}_{obs}/N_{exp}$ obtained from smoothing the original values of N_{obs}, which are reported in Table 7. The line inside the Table separates the areas where the N_{obs} are larger than expected (prevalence of physical pairs), from the area where the N_{obs} are smaller (incompleteness of observational data). The trend of this line suggests that several pairs, even with large separation, can be interpreted as physical pairs.

A further analysis should take into account the contribution and statistical behavior of further members, beside the second one.