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A COMPARISON OF THE AVERAGE VELOCITY OF BINARIES WITH THAT OF SINGLE STARS,

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It has recently been suggested that some kind of equipartition of energy may exist in our stellar system, the earlier type stars having at the same time greater masses and lower velocities than those of later spectrum.[1] Moreover, the existence of a correlation between mass and velocity within the same spectral-type has been made probable by the fact that there seems to be a relation between absolute magnitude and average velocity. In this connection it seems interesting to inquire whether or not a difference in velocity exists between double stars and single stars.

It is possible to prove that, within each spectral-type, the visual binaries have nearly twice the mass of single stars. PANNEKOEK[2] has shown that a close correlation exists between the mass and the ratio of spectroscopic parallax to trigonometric parallax, in the sense that stars with large masses give high values of this ratio. From the list of binaries used in the present paper, I took the stars for which spectroscopic as well as trigonometric parallaxes are given in *Mount Wilson Contributions*, No. 199, and I compared the two parallaxes for the brighter components. Stars for which the trigonometric parallaxes are founded only on older and inaccurate results have been omitted.

As the spectroscopic parallaxes have been made to agree with the trigonometric ones for a material principally consisting of single stars, it is evident that any systematic difference in mass between brighter components of binaries and single stars of the same absolute magnitude will be borne out by the above comparison.

The computed average ratios between the spectroscopic parallax of the brighter component and the trigonometric parallax are given below; four stars in which one of the parallaxes is larger than 0″.200 were excluded.

Spectrum	Mean ratio	Number of stars
F	0.90	43
G	1.10	27
K	1.07	14
All	0.99	84

The conclusion seems justified that there is no appreciable difference in mass between the brighter components of double stars and single stars of the same absolute magnitude. It is true that part of these stars may have been selected on account of large orbital motion so that there might be a slight selection of more massive stars. This objection may be removed by excluding from the eighty-four stars all those occurring in JACKSON and FURNER's list of binaries with appreciable orbital motion.[3] The total mean ratio then becomes 1.05 (57 stars).

Knowing the mean mass of the brighter components we can form an estimate of the mass of the whole system with the help of the relation between mass and luminosity recently published by HERTZSPRUNG.[4]

For the material used in what follows the mean magnitude differences between the two components are about 2.0 for the *A*- and *F*- type stars, and 2.8 for the *G* and *K* stars. From HERTZSPRUNG's formula (1):

$$m + 5 \log p = -\frac{\log \text{Mass}}{0.084}$$

we find the corresponding ratios of the mass of the fainter component to that of the brighter one as 0.68 and 0.58 respectively. (For the *G* and *K* stars with later type companions, used on page 144, the mass ratio is 0.79.) Therefore, in comparing the average velocities of double stars with those of single stars

[1]See, for instance, HALM, *Monthly Notices*, 71, 634, 1911, and SEARES, *Mount Wilson Contributions* No. 226, 1921.

[2]*Bulletin of the Astronomical Institutes of the Netherlands*, No. 19, 1922.

[3]*Monthly Notices R. A. S.*, 81, 30, 1920.

[4]*Bull. Astr. Neth.* No. 43, 1923.

having the same absolute magnitude as the brighter components of the double stars, the average mass of the former will be about 1.7 or 1.6 times that of the latter stars. Some uncertainty remains, however, as the above mass ratios were found from a material consisting wholly of dwarf stars, whereas the stars considered in the following investigation are, in considerable part, absolutely bright stars.

A list of double stars with known radial velocities was selected from a manuscript *Catalogue of Bright Stars* prepared by Dr. Schlesinger. This catalogue contains all the stars of the *Revised Harvard Photometry*, and among other information contains notes about double stars and all radial velocities published up to June, 1923. Very nearly all stars from Burnham's and Innes' catalogues have been noted in the *Bright Star Catalogue*, unless the difference in magnitude between the two components is unusually large.

I took all pairs of spectra *A*, *F*, *G* and *K* in which the magnitude difference is smaller than 6.0, excluding those in which the companion is at the same time fainter than the 9th magnitude and more than 30″ distant from the main star (unless a common motion shows that they are physically connected). It is easy to prove that the percentage of optical doubles among the remaining stars is too small to have any influence on the results. The *B*-type stars were omitted because of the large number of moving clusters among them, which will tend to obscure every difference in mean velocity between two groups of stars as the same cluster velocities are added to both. Part of the same difficulty holds for the *A*-type stars.

In order to avoid all possible influences that might make the double-star velocities too large I made sure that the material is complete and is not affected by the selection of large common motions; this was done by taking only the Northern pairs with combined magnitude brighter than 5.9 and the Southern pairs brighter than 5.0 from the list mentioned above.

The average absolute magnitude of the brighter components of the double stars with spectra *F*, *G* and *K* was computed with the help of spectroscopic parallaxes in the following way. Spectroscopic absolute magnitudes have been determined for about two-thirds of the stars; for the remaining binaries I computed the average proper motion and apparent magnitude and selected from the binaries with known absolute magnitude a set having the same average proper motion and magnitude. The mean absolute magnitude of these stars was then accepted as that of the binaries with unknown parallaxes. The total means of the absolute magnitudes thus computed are given in column 3 of table 1. Nearly all the *G* and *K* binaries used are *giants*, only 11 being found to be fainter than absolute magnitude +3.0.

The material used to compare single stars with the binaries consists exclusively of stars with known spectroscopic parallaxes thus making it possible to exclude stars within certain limits of absolute magnitude in order to get the same average absolute magnitude as the brighter components of the binaries. This was effected by excluding all stars brighter than +1.0 in the spectral class *F*, 50 percent of the stars brighter than 0.0 in class *G*, and all stars brighter than 0.0 in class *K* (see table 1, column 5, for the average absolute magnitudes). The recent Mount Wilson radial velocities[5] have not been included in the case of the single stars. All stars fainter than 6.5 apparent magnitude have been excluded.

The average radial velocities freed from solar motion (accepting a velocity of 20 km, apex 18^h 0^m; +30°) are compared in the following table.

Table 1

Spectrum of brighter component	Double Stars, brighter than $5^m.9$ for + declinations and brighter than $5^m.0$ for −declinations.		Single Stars, brighter than $6^m.5$.	
	Aver. vel.	Abs. magn.	Aver. vel.	Abs. magn.
*A*0−*A*9	10.4 km (67)	.....	11.0 km (177)	.....
*F*0−*F*9	15.3 km (52)	$+2^M.5$	14.6 km (89)	$+2^M.7$
*G*0−*G*9	11.2 km (26)	+1 .7	15.8 km (88)	+1 .8
*K*0−*K*9	12.8 km (38)	+1 .0	15.0 km (254)	+1 .2

The number of stars on which the averages rest are given between brackets.

A few remarks may accompany the table:

For the spectral class *A* no effort has been made to equalize the absolute magnitudes of double and single stars, and the average velocity for the latter is that given by Campbell.[6]

In the fourth column all doubles with magnitude differences smaller than 6.0 have been excluded.

For a binary the radial velocity of the brighter star has been used throughout, but the difference from that of the center of gravity must be so small that it cannot have any influence on the results.

All stars with peculiar radial velocities of 50 km or higher have been excluded from the comparison for two reasons. In the first place there are indications that the stars with space velocities higher than 66 km

[5] *Mount Wilson Contributions*, No. 258, 1923.

[6] *Lick Observatory Bulletin*, 6, 127, 1911.

form a group by themselves and can be sharply distinguished from the rest of the stars;[7] their velocities may have arisen from a different cause and they should not, therefore, be mixed with the ordinary stars if we want to determine the connection between velocity and mass or velocity and absolute magnitude. In the second place the omission of a few stars with exceptional velocities will increase the accuracy of our results and in this case the gain will be greater than the loss due to the decrease of the differences in mean velocity between two groups of stars.

The binaries are grouped according to the spectrum of the brighter component as in the great majority of cases this is the only one known. No attention was paid to stream-motion, the average distance from the vertices being supposed approximately the same in both cases. It appears from the table, that for the spectra *A* and *F* there does not seem to be any difference between the two average velocities although the binaries have a mass 1.7 times that of the single stars with which they are compared.

For the *G* and *K* stars the binaries seem to have lower velocities. This result can, however, be interpreted in different ways. Professor Hertzsprung has drawn my attention to the fact that a relatively high percentage of the *G* and *K* double stars have *B* or *A* companions and that it might be questioned whether these stars should not have been classified among the *B*- and *A*-type stars. To investigate this point I made a list of all *G* and *K* stars that are known to have *B*- or *A*-type companions, a total of 42 stars. After the exclusion of the high velocity star o^2 *Eridani* there are 16 stars[8] with known radial velocities, giving a mean peculiar velocity of 7.2 km. The same exceptionally low velocity is obtained from the proper motions of these stars: considering only the 24 stars for which proper motions occur in Boss's Catalogue we get an average secular parallax of 0″.036 and an average proper motion in a direction at right angles to the great circle through the apex (average τ-component) of 0″.015; accordingly the average linear velocity in that direction is 8.3 km. Correcting for a probable error of 0″.005 in the proper motions, this value becomes 7.8 km.

As far as the evidence from this small number of stars goes it looks as though these stars with blue companions should according to their velocities be classified among types *A* and *B* rather than among types *G* and *K*, although the *G* and *K* stars are 2.5 magnitudes brighter than their companions on the average, this value being found from the 17 binaries in which the brighter component is brighter than apparent magnitude 6.0.[9]

This becomes the more surprising by the fact that in practically all binaries, visual as well as spectroscopic, where the mass-ratio is known, the brighter star has the largest mass.[10]

It is not only in their motions, but also in their positions relative to the galaxy that these later type binaries more closely resemble *B*- and *A*-type stars than stars of the spectrum of their brighter components, as shown in table 2.[11] The first four lines of the table give the percentage of all stars of the 6th magnitude between 0° and ±20°, ±20° and ±40°, ±40° and ±90° galactic latitude respectively. They were computed from table 11, *Groningen Publications* No. 30, for apparent magnitude 6.0, which is the average magnitude of the 41 binaries mentioned above. The last two lines give the corresponding percentages for these binaries; the last line, in which only stars with Northern declination are used, is added to show that the strong galactic condensation cannot be explained by a selection in the observing program.

Table 2

Spectrum	Percentage of stars between galactic latitudes			Number of stars
	0° and ±20°	±20° and ±40°	±40° and ±90°	
*B*0 − *B*9	67%	24%	9%	917
*A*0 − *A*9	49	26	25	1343
*G*0 − *G*9	41	29	30	671
*K*0 − *K*9	41	28	31	1425
Binaries	66	29	5	41
Northern declinations only	64	29	7	28
Area Unit 10.000 sq. degrees	1.41	1.24	1.47	4.13

[7] See *Bull. Astr. Neth.* No. 23, 1922.

[8] Including one *Ma* star having a blue companion, namely *α Scorpii*.

[9] So far as I know there is within this limit only one binary in which the brightness of the *G* or *K* component is less than that of the *A* or *B* component.

[10] It should be mentioned, however, that Pannekoek, in estimating the mass-ratio of three binaries where the fainter companion was of earlier spectral type, came to the conclusion that in all three cases the fainter star was the most massive (*Bull. Astr. Neth.*, No. 19, page 117.)

[11] Perrine, in *Astrophysical Journal* 47, 293, noticed that these stars show a decided preference for the galaxy.

The total numbers of stars used in each line is given in the last column.

The binaries show a galactic condensation practically as strong as that of *B* stars of the same apparent magntude. This is not a perspective effect arising from the large average distance of these absolutely bright stars (for the most distant *single* *K* giants exhibit hardly any preference for the galaxy), but it shows that their *linear* distance from the galactic plane is on the average very much smaller than that of single *K* stars.[12]

That this erroneous classification of the *G* and *K* stars with blue companions may well account for the differences in the two last lines of table 1 appears plausible if we remark that in 37% of the cases in which the spectrum of the companion has been determined it appears to be of Class *A* or *B*. If we consider only those pairs in which the spectrum of the companion is known to be later than *A*9 we find 26 *G* and *K* stars with an average velocity of 15.8 km.[13] while the average velocity of single stars of the same absolute magnitude and spectrum is 16.7 km (79 stars).

For the stars about which we are sure as to the spectrum according to which they should be classified the ratios of the mean velocity of single stars to that of binaries (with the approximate probable errors) come out as follows:

A stars	1.06 ±0.07
F stars	0.95 ±0.09
G and *K* stars	1.06 ±0.12

The average is 1.02 ±0.05 (p.e.) whereas the factor expected in the case of equipartition would be 1.27.[14]

The material used is almost too scant to permit any conclusions, but, so far as the indications go, it seems that there is no appreciable difference between the two average velocities, and that therefore if a kind of equipartition does exist among stars of different mass then binary stars must somehow have been affected just as though the mass of the system were equal to that of the more massive component alone. It would also follow that the motions of the stars have not been influenced to a considerable extent by transfer of energy from one star to another, as this transfer would have resulted in higher velocities for the single stars than for the binaries. It would be of interest to get more information about radial velocities of a homogeneous list of double stars; for instance, all BURNHAM stars brighter than apparent magnitude 8.0 in which the components differ by less than three magnitudes and are far enough apart to allow color determinations of both components.

In the above note I have dealt with visual binaries only, because in the case of spectroscopic binaries a comparison of the mass of the systems with that of single stars could not well be made. It may, however, be of interest to add a preliminary comparison for these binaries as in this case again there does not seem to be any difference in mean velocity.

In order to avoid a larger difference in mean magnitude between the two groups of stars compared, the average velocities computed by CAMPBELL (*loc. cit.*) were used for the single stars, and in the case of the spectroscopic binaries I took only stars brighter than 5.5 apparent magnitude.

The mean velocities, with the number of stars between brackets, are given in table 3. Stars with velocities higher than 50 km. and a few stars for which the velocity of the center of gravity is uncertain, have been excluded. The average probable error of the velocities of the binaries considered is not larger than that of CAMPBELL's velocities.

Table 3

Spectrum	Spectrosc. Bin. brighter than $5^m.5$	Single Stars (CAMPBELL)
*B*0–*B*9	6.6 km (43)	6.5 km (225)
*A*0–*A*9	12.0 km (30)	11.0 km (177)
*F*0–*F*9	12.4 km (20)	14.1 km (184)
*G*0–*K*9	16.0 km (18)	13.6 km (492)

The ratio of the average radial velocity of the single stars to that of the binaries is in this case 1.03 ±0.05 (p.e.).

Summary:

Evidence has been brought forward that the average mass of the brighter component of a visual binary is about equal to that of a single star of the same spectrum and absolute brightness.

There are no indications of a difference in mean velocity between single stars and binaries (both visual and spectroscopic), but for the spectra *G* and *K* the material is insufficient for any definite conclusion.

It seems probable that the *G*- and *K*-type binaries with blue companions should, according to their motions as well as to their galactic condensation, be classified among the spectra *B* and *A* rather than among *G* and *K*.

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[12]The same characteristics; low velocity and strong condensation towards the Galaxy; are shown by the so-called *c*-stars, and it may be that we are dealing with this kind of star here. It must be observed, however, that even the spectroscopically brightest *K* giants do not show a galactic condensation comparable with that of the binaries.

[13]If we take only the brighter stars, as was done for table 2 (to avoid possible selection for large proper motion), there remain 14 stars with an average velocity of 16.6 km.

[14]In the computation of this theoretical factor account has been taken of the fact that velocities higher than 50 km were excluded, which, supposing a Gaussian distribution in the velocities, diminishes the factor from 1.30 to 1.27.