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COMMUNICATIONS FROM THE OBSERVATORY AT LEIDEN.

The estimated number of high velocities among stars selected according to proper motion,
by *J. H. Oort.*

The following computations are the outcome of a question, which Professor HERTZSPRUNG had put to me, concerning the probable percentage of high velocity stars among faint stars of considerable proper motion.

The computations, made with the help of Mr. KRIEST, have been limited to stars occurring in SCHLESINGER's parallax catalogue (1924 edition). It was assumed that in this catalogue there had been no direct or indirect selection with respect to velocity except for the obvious selection according to magnitude and proper motion. The stars selected have originally been divided into three categories:

a) m between 3·0 and 5·9, $\mu \geq 0''\cdot251$,

b) m between 4·0 and 5·9, μ between $0''\cdot100$ and $0''\cdot250$,

c) m between 6·0 and 8·9, $\mu \geq 0''\cdot251$,

where m is the visual magnitude, μ the annual proper motion.

So far as possible space velocities have been computed for these stars and have been corrected for the motion of the sun (assumed to be 20 km/sec towards 18^h0^m; $+30°$). The stars with corrected velocities larger than or equal to 63 km/sec have been called high velocity stars [1]).

For stars with parallaxes larger than $0''\cdot050$ the space velocities were computed with the aid of trigonometric parallaxes if well determined values were available and if the velocity was not so near the limit of 63 km/sec that it was difficult to decide whether it should be counted as high or as low. For the remaining stars spectroscopic parallaxes were used. These were taken from the Mt Wilson [2]) and Victoria [3]) catalogues, tentatively corrected for systematic error [4]). If two spectroscopic values were available the simple mean was taken and if the trigonometric parallax was larger than 5 times its probable error this was also used in forming the mean parallax.

Especially in the fainter group there are many stars of which no good parallax or radial velocity has been determined. These stars have been omitted. Proceeding in this way there is, however, a slight danger of preference for certain spectral types, and because of the correlation between spectrum and velocity some selection according to velocity might ensue. In the first category only 10 stars out of the total of 159 had to be omitted. These 10 stars do not differ from the others in average spectrum, so that their omission does no harm. In the (*b*) group (from which the members of the Hyades cluster were omitted from the start) 26 out of the 138 stars could not be used for the computation of space velocities. Among these 26 there is a much higher proportion of stars with types F0 and earlier than among the remaining stars. To avoid systematic effects of selection I have, somewhat arbitrarily, marked as low velocities 16 of the early type stars among these 26. The remaining 10 were omitted. In category (*c*) there are 120 stars among the total of 359 for which no sufficient data are available for computing the space velocity. The distribution of the remaining stars over the various spectral types differs a little from that of all stars in this category, but it is easily made to agree by excluding 36 additional stars, the total number remaining for the following discussion being 203.

Because of the accidental errors in the parallaxes a number of stars whose actual velocities are below 63 km/sec will appear to be high, and vice versa. In general it may be expected that, except for the stars with very large values of $m + 5 \log \mu$, there will be a systematic effect in the sense that the percentage of *apparent* velocities higher than 63 km/sec will be a little larger than the percentage would be if it could

[1]) Compare *B.A.N.* No. 23, 1922 and *Groningen Publ.*, No. 40, p. 4, 1926.

[2]) *Astrophysical Journal*, **53**, 13, 1921 and **56**, 242, 1922; *Mt Wilson Contr.* Nos. 199 and 244.

[3]) *Victoria Publ.*, **3**, 3, 1924.

[4]) *Groningen Publ.* No. 40, Table 4.

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have been computed from the *true* velocities. The percentage found from the computed space velocities would therefore require correction by a factor smaller than 1. However, it appears rather difficult to determine this factor. For this purpose I have only considered the stars for which spectroscopic parallaxes were used ("spectroscopic group"), it being assumed that for the stars with large trigonometric parallaxes the division into low and high velocities had been unambiguous (as mentioned above all stars whose velocities were found to be near 63 km/sec were included in the spectroscopic group). Plots were made showing the distribution of the space velocities in the spectroscopic group and from these I have tried to get an idea of what the effect of the accidental errors would amount to. The correction factor adopted for the numbers of high velocities in the "spectroscopic group" is 0·9 for stars with $H \equiv m + 5 \log \mu \leq + 6$, no correction being made in the case of stars with $H > + 6$. The factor is admittedly uncertain but this is not very serious, since in any case the final result of this note can only be of the nature of a rough indication of what will happen to the velocity distribution when small proper motions are excluded.

TABLE 1. Total numbers of stars and numbers of high velocities.

m \ H	−1·0	0·0	+1·0	+2·0	+3·0	+4·0	+5·0	+6·0	+7·0	+8·0
μ	0″·100 to 0·157	0″·158 to 0·250	0″·251 to 0·397	0″·398 to 0·630	0″·631 to 0·999	1″·000 to 1·584	1″·585 to 2·511	2″·512 to 3·979	3″·980 to 6·309	6″·310 to 9·999
3·0 to 3·9	. . . . .	. . . . .	5 0	7 0·9	10 3·7	3 1·9	1 0	0 0	0 0	0 0
4·0 to 4·9	33 4·5	32 4·5	18 4·6	12 0	4 1·0	4 1·0	2 1	1 1	1 1	0 0
5·0 to 5·9	30 4·5	29 5·5	42 8·1	17 2·7	11 4·7	7 3·8	4 2	1 1	0 0	0 0
6·0 to 6·9	. . . . .	. . . . .	21 7·4	26 4·6	16 11·2	7 5	0 0	0 0	0 0	1 1
7·0 to 7·9	. . . . .	. . . . .	10 3·8	25 11·8	16 11	4 3	0 0	0 0	1 1	1 1
8·0 to 8·9	. . . . .	. . . . .	6 3·6	39 23	18 12	4 4	4 3	1 0	2 2	0 0

Table 1 shows the results arranged according to visual magnitude and proper motion. The limits of proper motion have been chosen in such a way that $5 \log \mu$ increases with a unit for each following column. In each division the first number gives the total number of stars investigated, whereas the second number shows the quantity of high velocities among this total, corrected as indicated in the preceding paragraph.

The average values of $H = m + 5 \log \mu$ given in the heading correspond to the numbers in the first line of the table ($3^{m}·0$ to $3^{m}·9$). If we proceed downwards and to the left by equal steps the value of H remains constant.

As HERTZSPRUNG has remarked it can easily be seen that, as long as over the whole volume of space considered the star density is constant, the distribution of velocities and luminosities must be the same for groups of stars that have the same value of $m + 5 \log \mu$. The condition of constant density will certainly be fulfilled for the stars with proper motions exceeding 0″·200 annually and it has been verified from Table 1 that there are indeed no indications of systematic differences between bright and faint stars with the same value of $m + 5 \log \mu$. Some care should however be taken in extrapolating the percentages to still fainter apparent magnitudes, where the decrease in density will begin to be felt. The extrapolation would then give too large a percentage of high velocities. In the present note this effect will be neglected.

The stars with the same value of H have now been combined; the total numbers of stars and the derived percentages of high velocities are shown in Table 3.

Before proceeding to discuss these results in detail it may be of interest to check the general order of magnitude of the percentages found with those that can be inferred solely from a study of the *radial* velocities of these stars. For this purpose the stars were combined into four groups:

I from $H = + 0·5$ to $H = + 3·5$,
II from $H = + 3·5$ to $H = + 6·5$,
III from $H = + 6·5$ to $H = + 8·5$,
IV $H \geq + 8·5$.

For all stars used in the present paper and which fell within these groups the radial velocities, corrected for solar motion, were tabulated. The frequency curves of the corrected radial velocities could in each group be perfectly represented by a double Gaussian function

$$\alpha \frac{h_1}{\sqrt{\pi}} e^{-h_1^2 v^2} + (1 - \alpha) \frac{h_2}{\sqrt{\pi}} e^{-h_2^2 v^2} .$$

The constants representing the observed distribu-

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tions are shown in Table 2. The unit of velocity is 1 km/sec.

TABLE 2. Distribution of radial velocities and percentage of high velocities.

Group	n	h_1	h_2	α	Percentage of high space velocities		
					From rad. vel. (1)	From rad. vel. (2)	From space vel.
I	185	0·038	0·015	0·69	20 %	25 %	17 %
II	153	·028	·011	·82	23	31	38
III	91	·024	·011	·66	41	53	65
IV	14	·024	·007	·36	68	74	87

If there had been no selection the frequency of space velocities higher than 63 km/sec could have been computed directly from these constants. For, if we assume that each Gaussian distribution of radial velocities corresponds to a "Maxwellian" distribution of space motions, the frequency of high space velocities is given by

$$\frac{2}{\sqrt{\pi}}\, 63\, h\, e^{-(63\, h)^2} + \left(1 - \frac{2}{\sqrt{\pi}}\right) \int_0^{63\, h} e^{-z^2}\, dz.$$

The proportions computed with the various moduli in Table 2 are:

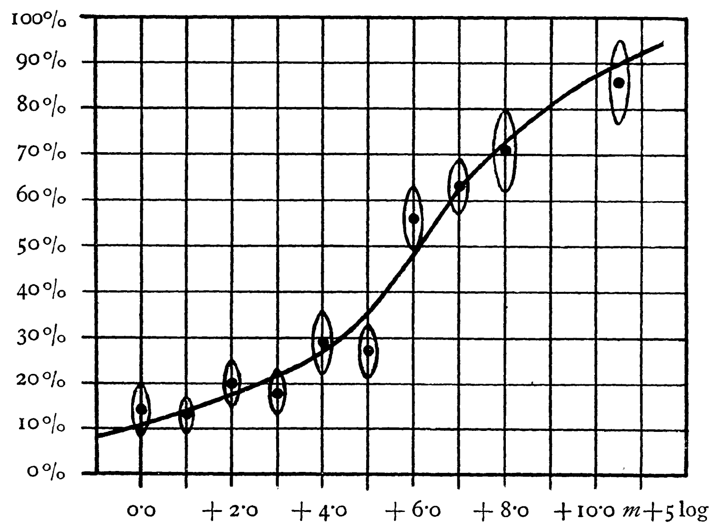
h	
0·038	0·010
·028	·102
·024	·207
·015	·618
·011	·812
·007	·943

The percentages of high space velocities computed with these numbers are shown in the sixth column of Table 2. There has been, however, a selection with regard to transverse velocity and accordingly it is to be expected that the true proportions of high space velocities for each Gaussian distribution are higher than the values just computed. It is hard to estimate what the exact effect of the selection will have been. I have recomputed the proportions of high velocities on the assumption that in each Gaussian distribution the real ratio between the number of high space velocities and that of low velocities is twice that computed on the assumption of no selection. The percentages of high space velocities found in this manner are given in the seventh column of Table 2, under the heading "From rad. vel. (2)". The percentages in the sixth and seventh columns are to be compared with those in the last column, which were derived from the space velocities themselves (that is from the numbers in Table 3). As was expected the numbers in the 6th column appear to be too low. Those in the 7th column agree roughly with the percentages derived from the space velocities. In the following discussion I shall restrict myself to the latter.

Table 3 shows the percentages of high velocities among stars with different values of $m + 5 \log \mu$. The total number of stars in each group is given under n; n_h denotes the number of high velocities, p the percentage of the total number which have high velocities and ε_p the mean error of this percentage. In computing these mean errors no account has been taken of possible systematic errors. The percentages are plotted against $m + 5 \log \mu$ in the accompanying diagram, the lengths of the major axes of the ellipses drawn round each point being equal to twice the mean errors of the plotted percentages.

TABLE 3. Percentages of high velocities for different values of $m + 5 \log \mu$.

$m + 5 \log \mu$	n	n_h	p	ε_p
0·0	33	4·5	14 %	± 6 %
+ 1·0	67	9·0	13	± 4
+ 2·0	54	11·0	20	± 5
+ 3·0	64	11·8	18	± 5
+ 4·0	45	13·0	29	± 7
+ 5·0	52	14·1	27	± 6
+ 6·0	56	31·4	56	± 7
+ 7·0	67	42	63	± 6
+ 8·0	24	17	71	± 9
+ 10·5	14	12	86	± 9



Percentage of high velocities.

It will be remarked that the percentages of high velocities among stars with considerable proper motion are quite high; at $m + 5 \log \mu = + 6$ about half of the stars appear to have high velocities.

By a consideration of the mean parallax of stars with proper motions larger than 0″·500 annually LUYTEN previously found that the geometrical mean of the transverse velocities in his catalogue was 62 km/sec,

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