



Universiteit  
Leiden  
The Netherlands

## Some peculiarities in the motion of stars of high velocity

Oort, J.H.

### Citation

Oort, J. H. (1922). Some peculiarities in the motion of stars of high velocity. *Bulletin Of The Astronomical Institutes Of The Netherlands*, 1, 133. Retrieved from <https://hdl.handle.net/1887/6013>

Version: Not Applicable (or Unknown)

License: [Leiden University Non-exclusive license](#)

Downloaded from: <https://hdl.handle.net/1887/6013>

**Note:** To cite this publication please use the final published version (if applicable).

# BULLETIN OF THE ASTRONOMICAL INSTITUTES OF THE NETHERLANDS.

1922 September 1

No. 23.

## COMMUNICATION FROM THE KAPTEYN ASTRONOMICAL LABORATORY AT GRONINGEN.

### Some peculiarities in the motion of stars of high velocity, by *J. H. Oort.*

Among the stars observed for radial velocity a greater number occur of large speed than are to be expected with a Maxwellian distribution. There are at least 16 stars whose radial velocity surpasses 150 *km/sec* whereas according to Maxwell's law with a mean radial velocity of 20 *km/sec* we do not find an average of one of that speed in a million.

The velocities of those stars, when freed from solar motion, are not found to be distributed at random, nor do they show a preference that might originate from either of the two star streams: they are all moving towards one hemisphere of the sky, as has already been demonstrated by W. S. ADAMS and A. H. JOY\*).

The principal aim of the present article is to test this result for other stars and to prove that a *sharply defined limit* exists, above which all velocities are directed towards the above mentioned hemisphere, whereas for inferior velocities no preference seems to exist.

#### *The systematic motion.*

*a. Radial velocities.* The stars were selected from J. VOÛTE'S *First Catalogue of Radial Velocities* and from the motions published afterwards, specially from the extensive list of Boss stars, which J. S. PLASKETT most kindly sent to the Kapteyn Astronomical Laboratory in advance of publication. All stars that, *after having been freed from the sun's motion*, (Sun's velocity 20 *km/sec*, apex 18<sup>h</sup> 0<sup>m</sup>; + 30°) proved to have a peculiar velocity  $\geq 75$  *km/sec* were taken.

On calculating the galactic coordinates (galactic pole 1900: 12<sup>h</sup> 42<sup>m</sup> 33<sup>s</sup>; + 27° 13') of the 47 stars which we found, it appears that the 16 situated between the galactic longitudes 162°—310° all have positive velocities, whereas each of the 19 stars whose longitudes are situated in the opposite segment 342° to 130°, shows a negative velocity.\*\*)

\*) *Proc. Nat. Ac. V. 239 or Mt. Wilson Contr. 163 (1919).*

\*\*) There is one Md-variable with gal. longit. 114° that has a velocity = + 96 *km/sec*.

The directions of the radial motions of these 47 stars are consequently concentrated within the galactic longitudes 130° and 342° or within a sector of 212° (see figure 3). The average longitude of the radial velocity vectors\*) is 230° and the average latitude —5°.

At first sight we should be inclined to think that the systematic motion of the stars just described is caused by the selection of the observational material. It is undoubtedly true that the fainter stars have been selected on account of their large p. m. and high declination; but it is difficult to imagine how this can have influenced the *sign* of the rad. vel. Also the following arguments may be advanced:

1. Without exception the stars brighter than 4<sup>m</sup>. 6 Harv. have been observed for rad. vel. Among these occur 9 with a velocity > 65 *km/sec*; they all show the systematic motion very distinctly.

2. If it were a consequence of selection the same phenomenon should show itself in velocities between say 50 and 60 *km/sec* which also have been selected on account of the magnitude of their motions. Further on it will be shown that the velocities of these stars do not show a preference for any hemisphere.

*b. Transverse velocities.* The parallax stars being for the greater part observed on account of their large p. m. it is quite natural that many of these stars have a velocity > 75 *km/sec*. From a catalogue of trigonometrical parallaxes composed by Prof. P. J. VAN RHIJN I selected 61 stars of which, taking into consideration the errors in the parallax, it can be ascertained with tolerable precision that they have a transverse velocity > 80 *km/sec*. Out of these three groups were formed\*\*):

\*) These vectors are proportional to the rad. vel. and are drawn in the direction from the centre of the celestial sphere towards the star when the velocity is positive and in the inverse direction when it is negative.

\*\*) In what follows  $\mu$  represents the proper motion,  $\pi$  the parallax and  $r_\pi$  the probable error of the parallax.

1°. those of which the transv. vel.:  $4.74 \frac{\mu}{\pi} > 140$   
 $km/sec$  and  $\frac{r\pi}{\pi} < \frac{1}{3}$ .

2°. those with  $4.74 \frac{\mu}{\pi} > 80$  and  $\frac{r\pi}{\pi} < \frac{1}{6}$ .

3°. those with  $4.74 \frac{\mu}{\pi + r\pi} > 140$  and  $r\pi < 0''.025$ .

In the first two groups the parallax was large enough to allow a fairly accurate computation of the value of the transverse velocity and afterwards to free it from reflected solar motion. Projected on the plane of the galaxy the directions of the resultant velocities all lie between  $145^\circ$  and  $325^\circ$  galactic longitude, a sector which, but for a small difference in extension, corresponds exactly with that found from the radial velocities. (See dotted lines in fig. 3).

Of the 36 stars contained in the last group it can only be said that the transv. vel. very probably are larger than  $75 km/sec$  and only their *directions* can be calculated. After projection on the galaxy these fell inside a segment of  $150^\circ$  between longitudes  $160^\circ$  and  $310^\circ$ .

The dispersion in galactic latitude is much less than that in longitude: among the 61 stars investigated there are only 4 for which the direction of the transv. vel. lies more than  $40^\circ$  outside the galaxy.

*A priori* a preference for motions towards the solar antapex would have been expected because the large p. m. of these stars are mainly found in this direction. But the solar motion is not large enough to cause a large number of velocities  $> 100 km/sec$  to be directed towards one hemisphere, whereas above  $60 km/sec$  not a single one in the inverse direction occurs.

Thus the results both from radial and transverse velocities agree in indicating that the direction of motion of stars with a total peculiar velocity  $> 80 km/sec$  is limited to one hemisphere, the centre of which lies at  $\lambda = 230^\circ \pm 5^\circ$  (mean error);  $\beta = -5^\circ \pm 4^\circ$  (m. e.) [ $\alpha = 8^h 20^m$ ;  $\delta = -44^\circ$ ].

There can, therefore, be no doubt about the reality of the phenomenon.

When calculating the mean apex of this group of stars by averaging the galactic longitudes and latitudes of the velocity-vectors\*) we find:

\*) Objection may be raised to this method, if the vectors are not arranged symmetrically with respect to the true apex. The objection is met by the fact that the total velocities, calculated from a number of parallax stars, produce very nearly the same position of the apex.

aver. long aver. lat.

a) 47 stars with high radial velocities	230°	— 5°
$b_1$ and $b_2$ ) 25 transv. vel. freed from solar motion	230°	— 4°
$b_3$ ) 36 <i>other</i> transv. vel., <i>not</i> freed from solar motion	225°	— 7°
9 rad. vel. of globular clusters	231°	— 11°

The result from the velocities of 9 clusters measured by SLIPHER, which also move towards one hemisphere and which velocities are of about the same order of magnitude, is added for comparison.

#### *The inferior limit.*

The question now arises where the inferior limit of this group of „high velocity” stars lies. I have tried to find a solution by selecting all those stars that have peculiar radial velocities between 50 and 90  $km/sec$ . In order to secure these rad. vel. being as representative as possible of the *total* velocities I only considered the 42 stars that had an annual p. m.  $< 0''.300$ . Twentythree of these stars, for which a parallax was available, give a mean transverse speed of  $35 km/sec$ ; as the 19 remaining stars show smaller p. m.'s we may estimate the mean transv. vel. for all 42 stars at about 25 or 30  $km/sec$ , therefore much smaller than the rad. vel.

After arranging the stars according to the value of their velocity it appears that the first star with inverse motion is found at  $61 km/sec$  and at the same time that this number forms a sharp limit between the „ordinary” stars and the „high velocity” stars.

If we draw the radial velocities of the 42 stars as vectors from one point, and imagine them, for the sake of convenience, projected on the plane of the galaxy (as is done in the three figures, the length of each arrow being proportional to the magnitude of the total rad. vel., *not* to its projection) the 16 vectors of the stars with velocities between 62 and 90  $km/sec$  lie inside a sector of  $137^\circ$ ; (fig. 1) whereas those of the velocities between 50 and  $61 km/sec$  are evenly distributed over the galactic longitudes without showing the least preference for the above sector (fig. 2).

The figures 1 and 2 are drawn on the same scale, the radius of the circle representing a velocity of  $62 km/sec$ .

In figure 3 all known peculiar rad. vel.  $> 90 km/sec$  are drawn, the scale being 2 times smaller than that in the preceding figures.

FIGURE 1.

Peculiar radial velocities between 62 and 90  $km/sec$ ,  
in the galactic plane:  $P. M. < 0''.300$ .

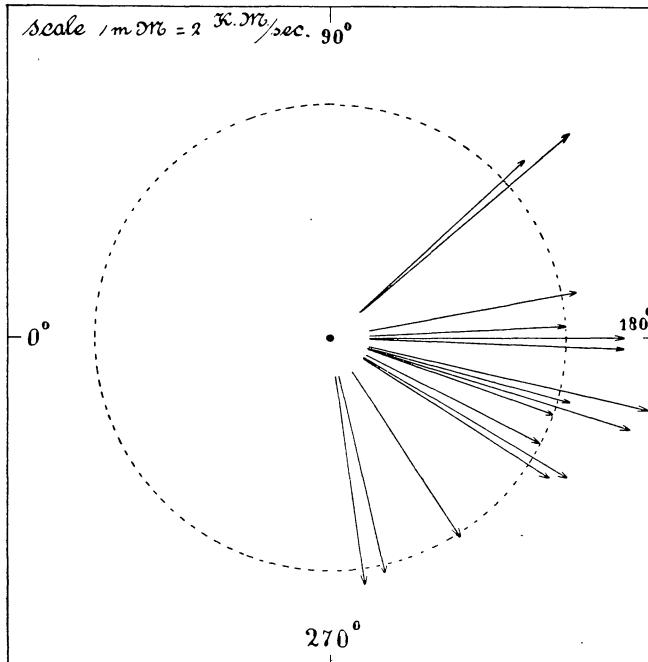
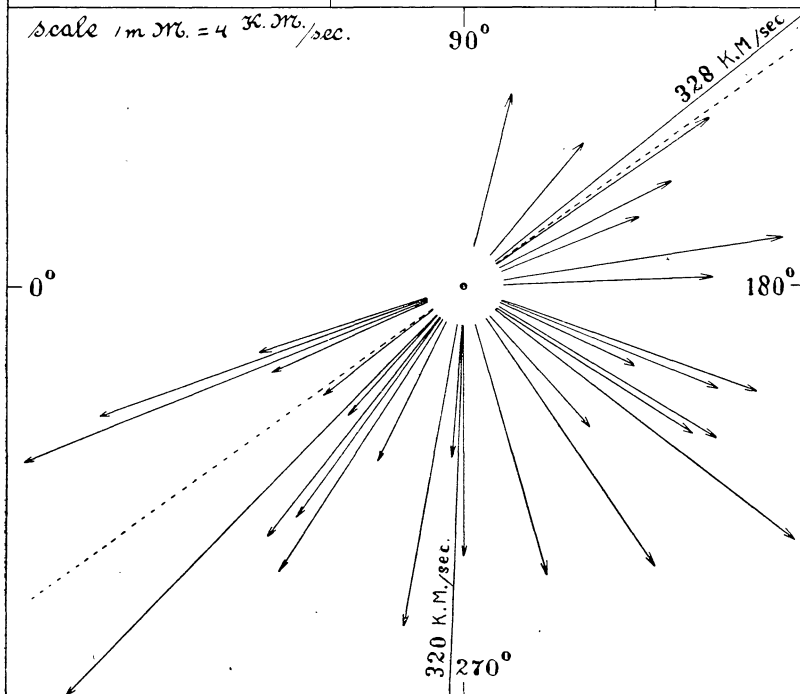
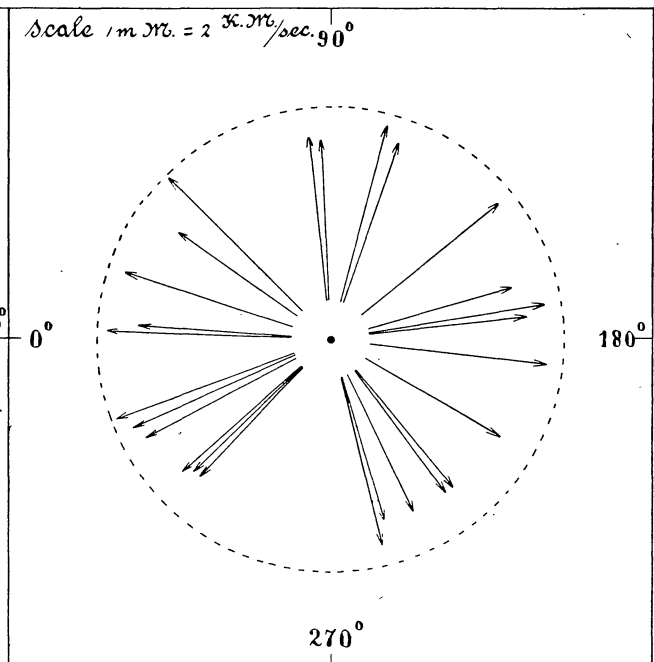


FIGURE 2.

Peculiar radial velocities between 50 and 61  $km/sec$ ,  
in the galactic plane:  $P. M. < 0''.300$ .



G. H. M.

FIGURE 3.

Peculiar radial velocities larger than 90  $km/sec$ , in the galactic plane.  
The dotted lines in longitudes 145° and 325° are the limits beyond which  
no peculiar transverse velocities larger than 90  $km/sec$  occur.

We can also find the demarcation between the „high velocity” and „ordinary” stars independently of the preceding considerations, by means of the

the accurately determined total velocities. Neither do the proper motions pass through one point as would be the case with parallel motion.

galactic latitudes of the rad. vel. vectors:

The vectors of stars with a velocity between 64 and 90  $km/sec$  are all situated between  $-40^\circ$  and  $+40^\circ$  gal. lat. At 63  $km/sec$  we find the first one with a higher latitude (viz:  $-73^\circ$ ) and of the 30 stars with vel. from 50 to 63  $km/sec$  no less than 9 have a gal. lat. larger than  $40^\circ$ .

The limits 61 and 63 found from the galactic longitudes and latitudes respectively are in excellent agreement. Probably the limit of the total velocities will be somewhat higher because the total vel. of the stars here considered is a little higher than their radial speed. If we assume an average transv. vel. of 25  $km/sec$  the limit in the total vel. is raised to about 66  $km/sec$ .

Although the „high velocity” stars show a strong preference in direction we can by no means assert that they form a group moving in parallel directions and with equal speeds. This becomes evident when we compare the directions and magnitudes of some of

The speed relative to the sun of the centroid of 56 stars whose total velocity could be accurately calculated and exceeded  $65 \text{ km/sec}$ , amounts to  $74 \text{ km/sec}$  in galactic longitude  $236^\circ$ , latitude  $-7^\circ$  [ $\alpha = 8^{\text{h}} 20^{\text{m}}$ ;  $\delta = -50^\circ$ ].

Two stars were found moving in an inverse direction. The first of these is  $\sigma \text{ Draconis}$  ( $19^{\text{h}} 33^{\text{m}}$ ;  $+69^\circ.5$ )  $\pi = 0''.192$ , total vel.  $67 \text{ km/sec}$ . A modification of the parallax to  $0''.200$  would suffice to diminish the tot. vel. to  $65 \text{ km/sec}$ .

Of more importance is the exceptional star *Groombr.* 990 ( $5^{\text{h}} 30^{\text{m}}$ ;  $+51^\circ.4$ ) which with the given parallax of  $0''.035$  appears to have a tot. vel. of  $96 \text{ km/sec}$ . In order to reduce this velocity to below  $65 \text{ km/sec}$  the parallax ought to be  $>0''.065$ . It would be interesting if this parallax, which has been measured at Allegheny and Mc Cormick, amongst others, were determined over again.

#### *Influence on the determination of the sun's velocity.*

The average apex of the group of „high velocity” stars ( $8^{\text{h}} 20^{\text{m}}$ ;  $-44^\circ$ ) deviates only  $31^\circ$  from the ant-apex of the solar motion.

For this reason the percentage of „high velocity” stars found in a given material of rad. vel. will have a noticeable influence on the sun's velocity, calculated from that material. This is illustrated by the three results ( $17.8^*$ ;  $19.5^{**}$ ) and  $21.5^{***}$ )  $\text{km/sec}$ , the first of which was obtained by CAMPBELL after having excluded 26 stars with pec. rad. vel.  $>60 \text{ km/sec}$ , the second without excluding any star and the third by G. STRÖMBERG with the aid of Mt. Wilson rad. vel., where the percentage of great velocities is much higher. Not only does the uncertainty as to the sun's velocity evidently thereby become much greater, but the serious danger arises of systematic errors in the mean parallaxes of faint stars:

In order to reduce the secular parallaxes to annual ones we must suppose, as long as no rad. vel. are known, that the sun's velocity relative to these faint stars is equal to that which holds for the brighter stars with the aid of which it was determined. At present it is impossible to find an accurate value of the solar vel. relative to stars fainter than the  $7^{\text{th}}$  magn. For stars fainter than apparent magn. 8 the rad. vel. of only 16 stars have been published, which have all a big p. m. Among these 16 we find 11 with a velocity larger than  $65 \text{ km/sec}$ .

It is a well known fact that the mean velocity

increases with decreasing brightness. Therefore the percentage of „high vel.” stars will be higher among the fainter ones and the sun's velocity will increase accordingly.

This may be supported by the following numerical computation, which shows the large change in the sun's velocity for the absolutely faint stars:

If for a list of nearest stars, as given by Prof. E. HERTZSPRUNG\*), we calculate the total velocities, it appears that 8 of the 21 given stars with parallaxes  $>0''.200$  belong to the group of „high vel.” stars.\*\*)

If in the way indicated by EDDINGTON\*\*\*) we make an estimate of the number of stars brighter than  $10^{\text{m}}.0$  which are wanting in such a list (chiefly stars with small p. m. and consequently smaller velocities) we arrive at a total number of  $31 \pm 5.6$  (m. e.), \*\*\*\*) among which are  $10 \pm 3.2$  (m. e.) stars with velocities  $>65 \text{ km/sec}$ , or  $32\%$ . Perhaps this percentage is still too small, as EDDINGTON most probably has made too high an estimate of the number of stars with smaller p. m. by assuming a Maxwellian distribution of velocities.

It may prove accidental that in this space there are so many „high vel.” stars, but in the case of the mean percentage being only  $15\%$  the chance of a value  $\geq 32\%$  in a given sphere would not exceed  $8/1000$ .

If now we suppose that the velocity of the sun relative to the 21 „ordinary” stars is  $20 \text{ km/sec}$ , the sun's velocity relative to the total number of stars in this sphere (brighter than the apparent magnitude 10.0) is found to be:  $V_0 = -45 \text{ km/sec}$  in  $\alpha = 19^{\text{h}}$   $\delta = +25^\circ$ .

These considerations refer to absolutely very faint stars; in general such high percentages will not be found with stars of the  $9^{\text{th}}$  and  $10^{\text{th}}$  magn. I only wanted to show that it would be very desirable to determine rad. vel. for faint stars not selected according to p. m.

As long as this has not been done one should be very careful in using the generally adopted value for the sun's velocity when computing the mean parallax of a group of faint stars, especially if this group is known to contain a large number of high velocities as is the case with the cluster-type variables, for instance.

For a determination of the systematic and peculiar motions of the stars, it will doubtless be better to treat separately the „high vel.” stars and the „ordi-

\*) B. A. N. 5, 1922.

\*\*\*) In what follows we have accepted the name „high velocity star” for all stars with velocities superior to  $66 \text{ km/sec}$ .

\*\*\*\*) *Stellar Movements* p. 43, 1910.

\*\*\*\*\*) In *Mt Wilson Contr.* 188 (1920) KAPTEYN and VAN RHIJN find 24 as the total number of stars (the faintest included) in the same space.

\*) CAMPBELL *Stellar Motions* p. 188, 1913.

\*\*\*) *Lick Obs. Bull.* VI p. 127, 1911.

\*\*\*\*) *Proc. Nat. Ac.* IV p. 36, 1918.

nary" stars, which have been shown to behave so very differently. \*)

The stars with high radial velocities belong for the greater part to the spectral types *F* and *G*, whereas among 78 stars with rad. vel.  $> 62 \text{ km/sec}$  only one *B*- and three *A*-spectra occur. The average apex of the group appears to agree very well for the different types. The mean galactic longitudes are: for spectrum *F*  $230^\circ$ , for *G*  $229^\circ$  for *K*  $225^\circ$  and for *M*  $228^\circ$ . (These numbers were obtained by taking the average longitude of the rad. vel. vectors, leaving out the stars with the largest p. m.).

The apex seems in gal. long. to depend on the magnitude of the velocities as shown in the following table: \*\*)

Velocity	aver. long. from rad. vel.	Number	aver. long. from transv. vel.	Number
$> 200 \text{ km/sec}$	$270^\circ \pm 20^\circ$ (p. e.)	6	$253^\circ \pm 7^\circ$ (p. e.)	6
100—200 »	$244 \pm 10$ »	18	$234 \pm 15$ »	9
62—100 »	$212 \pm 6$ »	21	$211 \pm 13$ »	19

In the second and fourth columns are given the mean galactic longitudes from radial and transverse velocities respectively. Although the probable errors are large, the results confirm each other in indicating a higher average longitude for the higher speeds. The latitude does not vary perceptibly.

*Remark. The total attraction of the Milky Way system.*

According to KAPTEYN, the total attraction of

\*) In this connection an investigation by G. STRÖMBERG (*Proc. Nat. Ac. IV* p. 36, 1918) may be mentioned, dealing with the stream motion of stars of the 2<sup>nd</sup> and 3<sup>rd</sup> spectral types. I am sure that the greater part of the asymmetry of his velocity curves (pag. 40) is caused by the systematic motion of the „high vel.” stars which were of great influence on his averages. The curves thus represent a somewhat arbitrary combination of two different phenomena: the star-streaming of the „ordinary” stars and the preferential motion of the „high vel.” stars with which this paper deals.

\*\*) See footnote on page 134.

the galactic system is such that the final velocity ( $V_c$ ) of a star falling from infinity towards the centre would be about  $81 \text{ km/sec}$  \*). If we accept this number, or even suppose it *twice* as large, the stars with velocities  $> 150 \text{ km/sec}$  form a group of „foreigners” coming from immense distances outside the galactic system. For example with  $V_c = 81 \text{ km/sec}$  a star with a velocity of  $100 \text{ km/sec}$  must have been at a distance of about 240.000 parsec  $3 \times 10^9$  years ago. \*\*)

It is evident that for these stars there must be a minimum of velocity viz: the vel. acquired by falling from the above mentioned great distances to the neighbourhood of the sun. Moreover it is clear that so absolute an avoidance of one hemisphere as displayed by the „high velocity” stars would be impossible for stars with vel. smaller than  $V_c$ . The attractive power of the system would oblige them after some time to move in the opposite direction.

It seems difficult to explain the sharp limit of this group if we take the velocity of escape to be considerably larger than  $66 \text{ km/sec}$ . The  $81 \text{ km/sec}$  found by Kapteyn was calculated assuming that the mean mass of the stars is equal to that of the sun, whereas with an average of 0.65 of the sun's mass  $65 \text{ km/sec}$  is found, in near agreement with the  $66 \text{ km/sec}$  found for the „high velocity” stars.

Thus the result indicates that the mean mass of the stars in general is smaller than that of the sun, which is not in discordance with the observations, the average luminosity of all the stars of the system being about 16 times smaller than that of the sun. \*\*\*)

\*) This value has not been published. In the *Astrophys. Journ.* May 1922 page 319 (*Mt. Wilson Contr.* 230)  $V_c$  is found to be about  $100 \text{ km/sec}$ ; this value has been found adopting for  $n$   $7.5 \times 10^{-30}$  or mean mass of the stars 1.5 times the sun's mass. whereas the above value of  $81 \text{ km/sec}$  represents the same velocity computed with a mean star mass equal to the sun's mass.

\*\*) According to the researches on radioactive minerals, made by RUTHERFORD and others, this represents about the inferior limit of the age of the earth.

\*\*\*) KAPTEYN and VAN RHIJN, *Mt. Wilson Contr.* 188, page 11.