Astronomy. — *Researches on the distribution of the stars in space.* By Prof. A. PANNEKOEK.

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1. The problem of the distribution of the stars in space is the problem of finding the distances, when they are so large that a direct determination of parallaxes is impossible. We can find the distance of a star from its apparent magnitude, if we know its absolute magnitude (for which we will take here the magnitude at distance 1 parsec). Then

$$m = M + 5 \log r$$

or, designating $5 \log r$ by ϱ, the modulus of distance, we have simply

$$\varrho = m - M.$$

KAPTEYN has shown first that for stars of the spectral classes B and A the dispersion in absolute magnitude is so small that without a large error we may find the distance by assuming for each star the mean absolute magnitude of the spectral subclass to which it belongs. The completion of the HENRY DRAPER Catalogue, containing spectrum and magnitude of all stars down to the 8—9th magnitude makes it possible to apply this method to the stars at large. In this paper we shall give the chief results of an investigation which will be published in extenso in the Publications of the Astronomical Institute of the University of Amsterdam.

The mean absolute magnitude is greatly variable with the spectral class; the brightness decreases from $B0$ regularly to A and F. From different sources we have adopted the following values

$B0$	$B1$	$B2$	$B3$	$B5$	$B8$	$B9$	$A0$	$A2$	$A3$
-8.1	-7.5	-6.8	-6.2	-5.8	-4.9	-4.6	-4.1	-3.4	$-2.8.$

Usually the subclasses $B8$—$A3$ have been combined into one class A, for which a mean absolute magnitude -4.1 was found; in a discussion of the B stars the subclasses $B0$—$B5$ were treated at the same time. For spectra designated simply A or B the magnitudes of the mean and most numerous subclasses $A0$ and $B3$ were assumed, of course with greater uncertainty. The stars of class K were also included in our research. These stars consist of dwarfs with an absolute magnitude $+2$, and giants with a mean absolute magnitude -4.3; though the number of dwarfs in a volume of space far exceeds the number of giants, the stars of a certain apparent magnitude, on the contrary, are almost entirely giants, and their distribution shows us the distribution of the K giants in space.

The HENRY DRAPER Catalogue is complete to 8.3 on the Northern, to 9.3 on the Southern Hemisphere. These limiting magnitudes correspond to $\varrho = 14.5$ and $\varrho = 15.5$ (i.e. $r = 800$ and 1250 parsecs) for $B3$, to $\varrho = 12.4$ and $\varrho = 13.4$ ($r = 300$ and 480 parsecs) for A. Thus we can study the distribution of the stars in space around us for the B stars as far as 1000 parsecs distance, for the A stars (and also for the K giants) to circa 400 parsecs. For some special regions the "HENRY DRAPER Extension", of which only a few parts have been published so far now, pushes the limit of magnitude 2 magn. fainter, and the limit of distance 2.5 times farther.

2. The stars of type B show a strong tendency to cluster into groups separated by spaces almost devoid of these stars. For such groups the use of the formula $\varrho = m - M$ in the manner indicated above must give erroneous results as to the character of the space distribution. Such groups, occupying only a small area in the sky, contain B stars of very different apparent magnitudes; subtracting the same mean M for this class we find values of ϱ as much different as the values of m themselves. So e.g. in the Orion group of B stars which is clearly connected with the Orion nebula, and which stands at a rather high galactic latitude (-17°) as a dense group very distinctly apart from other groups and streams, we find B stars from the 2^d down to the 9^th magnitude, from which distances from $r = 100$ to $r = 1000$ are computed. Even if we should admit the extreme values to be due to chance coincidences of some very near and very remote stars, the main mass of these Orion stars would extend from 200 to 600 parsecs in the line of sight, whereas the lateral extension (apparent extension in galactic longitude 12°) is only 0.2 times the distance. Unless we should be forced to the quite unadmissible conception of a universe composed of conical condensations all exactly directed to our sun, we have to admit that the stars of the same spectral subclass in such a group are very different in absolute magnitude. Since it cannot be admitted that our sun occupies a quite exceptional place, determining a radial structure of the starsystem around, the extension in depth for the visible condensations must be of the same order of magnitude as the lateral extension. Hence for condensations of small apparent extent the modulus of distance of its different stars will be almost the same; in such groups the distribution of apparent magnitude will correspond to the frequency curve of absolute magnitude. In this way groups of B stars which are sufficiently isolated to eliminate the influence of foreground and background stars, may be used to find the dispersion and the figure of the luminosity curve for this class of stars. By this luminosity curve we mean the average curve for each of the subclasses; it is given by the distribution of the values of $\varrho = m - M$, where for each subclass its proper mean M is used.

3. To study the apparent distribution and the situation of the groups

charts were prepared for different values of ϱ: < 11, 11—12, 12—13, 13—14, 14—15, 15—16. If the dispersion in M was negligible, each group would appear only on the chart which contains its distance. Now by the appreciable dispersion each group appears on several consecutive charts, and its real distance must correspond to some mean value of ϱ where it is most prominent.

On the first chart, with $\varrho < 11$, the most important group is the so-called Centaurus-Lupus-Scorpio cluster of B stars, in Scorpio and Lupus far N. of the galactic axis, crossing it at $l = 270°$, and continuing less dense at the S. side to Orion, forming GOULD's inclined belt of bright stars. Further we have here the Pleiades and a small group near δ Persei, EDDINGTON's moving cluster in Perseus.

On the charts 11 and 12 a region of great density extends along the S. side of the Galaxy from $l = 200°$ to $260°$, showing three marked condensations in Canis major, Puppis and Vela. On charts 11, 12, 13 the Orion group strikes the eye; on charts 13 and 14 a small dense group near ζ Scorpii is visible. On charts 14 and 15 we find three regions with dense groups; the most important in Carina, with a strong condensation around the nebula η Carinae, agrees with the Milky Way features in Carina and Crux; two dense groups are seen in Sagittarius at $l = 335°$ and $l = 341°$; and a distinct cluster extends 6° in longitude around P Cygni, in which the HENRY DRAPER Extension shows a large number of faint B stars with $\varrho = 16$ and 17. A small, less distinct group of B stars extends around the double cluster χh Persei. Moreover on each of these charts we find evenly dispersed stars, sometimes forming large groups of small density, e.g. on chart 12—13 a thin group in Cygnus, on chart 14 a long streak following the Galaxy in Monoceros.

In all these groups and regions the frequency according to magnitude was determined. The only groups that are sufficiently small, isolated, rich and complete, to give a reliable luminosity curve, are the Orion group and the P Cygni group. Both show a composite curve of large dispersion, consisting of at least two separate tops (fig. 1). In Orion their number of stars is equal, in Cygnus, where they are less clearly separated, the top of the smaller stars is more numerous; their brightness is 0.8^m below and 0.8^m above the mean magnitude. This mean magnitude corresponds to distance $\varrho = 13.0$ (400 parsecs) for the Orion group, $\varrho = 15{,}9$ (1500 parsecs) for the P Cygni group. A less numerous group of still brighter stars, 2^m above the mean, seems to be present in both. This does not mean that every subclass has exactly the same form of luminosity curve relative to its mean absolute magnitude. This irregular dispersion of the absolute magnitudes is chiefly a quality of the most numerous subclasses $B3$ and $B5$; but the rich condensations in Carina-Centaurus, the $B3$ and $B5$ stars of which are for a large part beyond the limit of the D.C., show for the subclass $B0$ also a dispersion with two maxima, 0.7^m brighter and 0.5^m fainter than the average value. It will be interesting to investigate whether spectral differences within each spectral subclass accompany these considerable differences in absolute

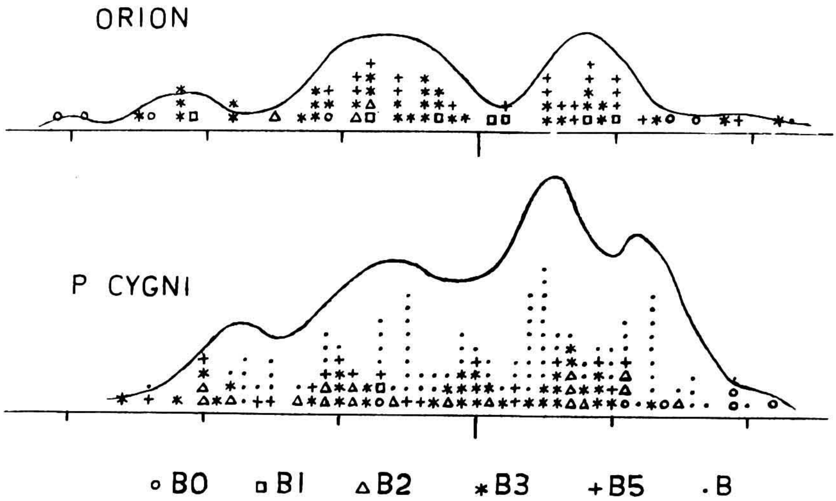

Fig. 1. Luminosity curves for the *B* stars.

brightness. Part of these differences may be caused by external influences, e.g. the absorption through the nebulae surrounding many of these stars; but it is not probable that the whole phenomenon and its systematic character can be explained in this way.

4. The derivation of the distance of groups of *B* stars is made much more difficult by this great and irregular dispersion of their luminosity curve. Where the frequency curve in small groups exhibits two maxima, they may be identified with the maxima of the luminosity curve; where for extended groups only one broad maximum is found, it is taken for the strongly smoothed mean of the two tops. In some cases it could be made probable that a single maximum observed corresponds to one of the tops; thus the members of the Scorpio-Lupus-Centaurus cluster are nearly all small stars, and the other top belonging to the large stars is hardly indicated. For the *B*-stars surrounding the χh Persei cluster the same may be deduced from the distance found by PARVULESCO. For the dense clusters of faint stars in Carina and surroundings and in Sagittarius only the large stars are contained in the D.C. and the small stars fall below its limit; here the brightest subclass *B*0 must be used to find the distance. The results for some of the chief groups are contained in the following table; when there is some doubt which of two values for ϱ should be chosen, both are given.

The two most brilliant irregular nebulae of the sky are connected with two of these groups, the Orion group and the Carina group. Their distances are determined therefore at the same time: 400 parsecs for the Orion nebula, 1700 parsecs for the η Car. nebula.

TABLE 1. Distance of groups of *B* stars.

Group	Galactic Longitude	Galactic Latitude	Number of stars	ϱ	Distance in parsecs
Scorpio-Lupus	281°—322°	+13°	30	10.5	125
α Persi	116	−6°	11	10.7; 11.1	140; 170
ϑ Carinae	257	−4°	9	11.7	220
δ-η Canis major	201—213	−7°	43	11.5; 12.3	200; 290
ζ Puppis	220	−7°	12	11.9	240
γ Velorum	225—233	−7°	46	12.4	300
S. Border [1])	200—245	−8°	120	12.4	300
Orion	165—178	−17°	71	13.0	400
Cygnus	34—52	+1°	40	13.3	460
χ h Persei	103	−3°	53	14.0	630
Monoceros	172—204	0°	180	13.9; 15.0	600; 1000
ζ Scorpii	312	+1°	31	14.4	760
Carina (η, x, y)	253°—259°	0°	223	16.2	1700
λ Centauri	261—267	−1°	80	16.2	1700
m Centauri	272—277	−1°	87	17.2	2700
9 Sagittarii	332—338	−2°	54	15.3	1150
N of μ Sagittarii	338—344	−1°	99	16.2	1700
P Cygni	40—47	+1°	171	15.9	1500

[1]) In this group the 3 preceding ones are partly included.

A diagram representing the relative situation of these and other more dispersed groups, projected on the galactic plane, is given Fig. 2, p. 7. In the space between them also some *B* stars will be dispersed which are not included in our groups; the method used here to find the distance of groups cannot be applied to single stars. Before the publication of the Draper Catalogue the *B* stars were thought to form a system of some 600 parsecs diameter with its centre at 100 or 150 parsecs in the direction of Puppis ($l = 230°$). This centre corresponds to the groups in Canis major, Puppis, Vela, which extend over the whole southern border of the galactic zone. We now see that this is the most important group only among the *B* stars at small distance; several groups of the same or greater richness and importance are shown at larger distance, and they gradually merge into the groups, formed by the nearest galactic clouds.

Is the clustering tendency a peculiarity of the *B* type stars which separates them from the more evenly distributed bulk of the other stars,

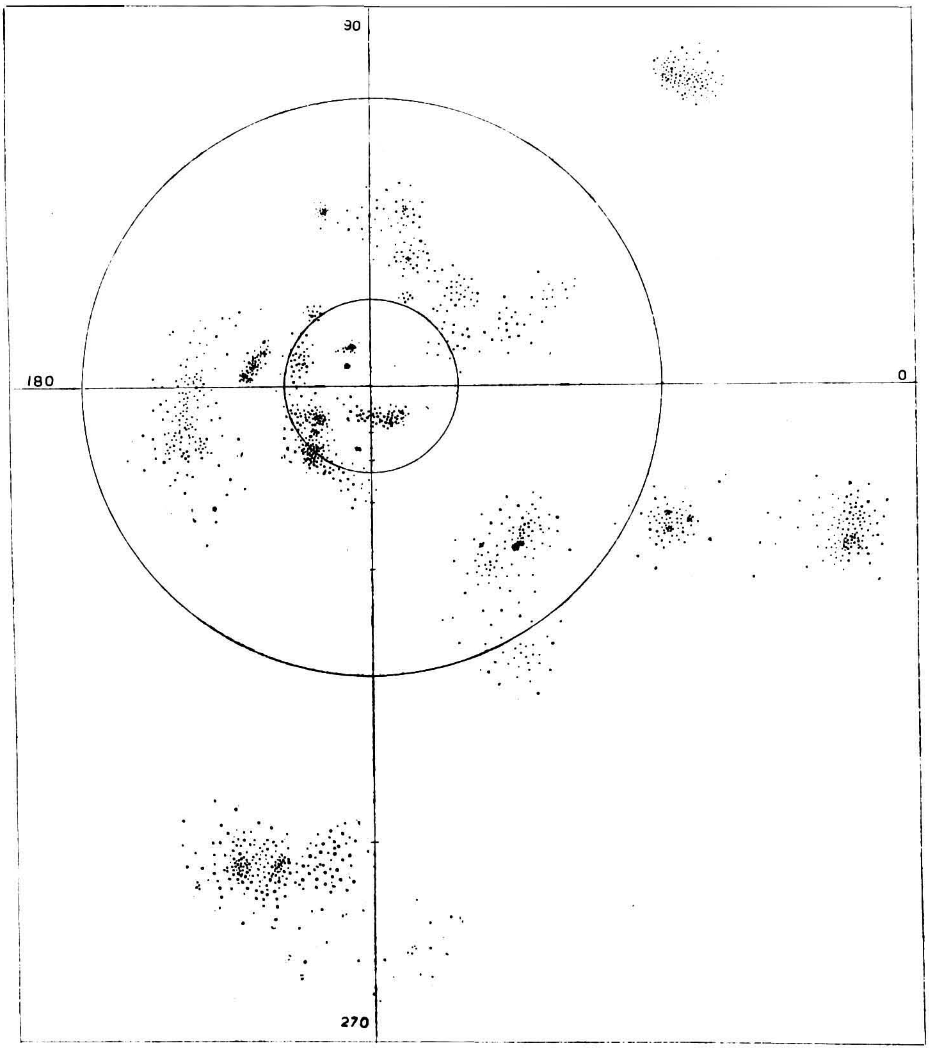

Fig. 2. Diagram of the groups of *B* stars, projected on the galactic plane. (The circles have a radius of 300 and 1000 parsecs).

or must the *B* stars be considered as the giant-star skeleton governing also the distribution of the other stars? From such clusters as the Pleiades we know that they consist of *B* stars, *A* stars and further *G* dwarfs, belonging together and in this sequence decreasing in absolute and apparent magnitude. Some "moving clusters" as the Scorpio-Centaurus group and that in Perseus (called δ Pers. group above) are known to consist partly of *B*0—*B*5, partly of *B*8—*A*5 stars. An answer to this question may be found by studying the distribution of the *A* type stars in space.

5. The two charts Fig. 3 p. 8 represent the region between 5^h and 6^h Rectascension, $+10^\circ$ and -10° Declination, the first with the Orion

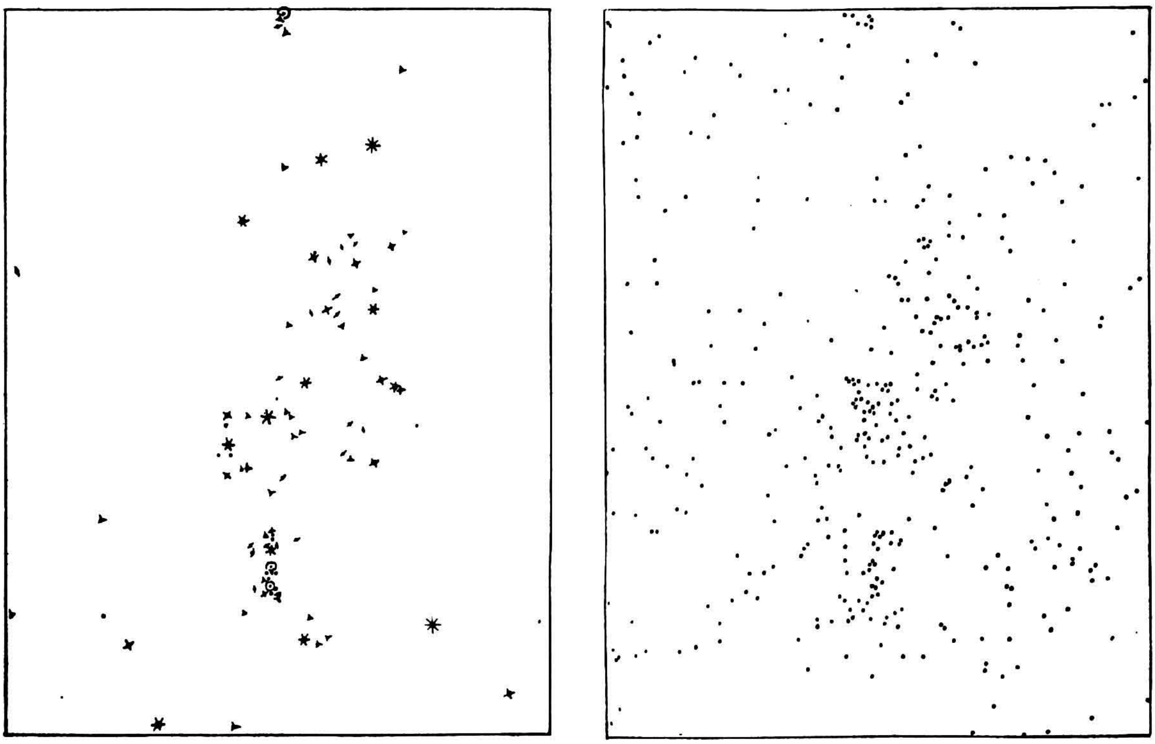

Fig. 3. Chart of the group of *B* stars (left) and of the *A* stars between 8.75^m and 9.75^m (right) in Orion.

group of *B* stars (*O* stars, which also belong to the group are indicated by open circles), the second with the class *A* stars (*B*8—*A*3) between magnitudes of $8^3/_4$ and $9^3/_4$. The exact coincidence of the accumulation of these *A* stars with the group of *B* stars at once strikes the eye. Stars brighter than $8^1/_4$ show no trace of any concentration. The surplus of *A* stars within the area of the group over the average density begins at $8^1/_4{}^m$ and attains a maximum at 9.2; from the distance deduced by means of the *B* stars we should expect it at magnitude $13.0—4.1 = 8.9$. If, however, account is taken of the increasing incompleteness of the stars below 9^m, the maximum is displaced and the difference increases. In every case the result is that in the part of space occupied by the Orion group of *B* stars there is a corresponding condensation of *A* stars, only somewhat fainter than could be expected from the distance.

At the place of the densest group of *B* stars belonging to the "moving cluster" in Perseus, between α and δ Pers., there is a condensation of *A* stars between 6^m and 8^m. Its brightest members take part in the motion; for the fainter stars we have no proper motions, but it is probable that they are also connected with this group. At the place of the B star cluster ϑ Carinae there is also a condensation of A stars between 6^m and 8^m, somewhat larger in extension.

The distribution of the A stars between 5.25^m and 7.25^m (corresponding to $\varrho = 9.4 - 11.4$) shows (cf. fig. 4) on the S. hemisphere a large density on the S. border of the Galaxy, between 180° and 270° longitude reaching from 0° to 20° S. latitude; from longitude 270° to 330° it extends also on the N. side of the Galaxy to 20° latitude over the Lupus-Scorpio region of B stars. For the A stars 7.25—8.25 ($\varrho = 11.4$—12.4) the latter region has a low density (cf. fig. 5). Great densities are found for these and for still fainter stars over the S. border of the Galaxy, especially in some areas in Puppis and Vela. The latter coincide rather well with the condensations of the B stars, considering the different treatment, viz. the use of the single B stars and the use of counts over rather large square fields for the A stars. The magnitudes 8.25—10.25 show moreover a condensation in Monoceros, which may be connected with the Monoceros stream of B stars at $\varrho = 13.9$. The magnitudes 7 and 8 show a condensation at 17^h50^m—$35°$ about ε Sagittarii—λ Scorpii.

The chief feature in the distribution of the A stars of 8^m and 9^m on the S. hemisphere is a large condensation, extending along the Galaxy from longitude 240° to 280° and having its densest part in Carina, nearly coinciding with the strong Carina condensation of B stars. Its core consists of a dense cluster near x Car, visible to the naked eye as an elongated nebula, which consists only of A stars of 8—11^m, without B stars belonging to it. From the distribution of its stars over the magnitude classes, taking the incompleteness of the fainter ones into account, we may estimate its distance at $\varrho = 13.8$ (580 parsecs); this holds for the whole large condensation. Hence it has nothing to do with the Carina group of B stars at distance 1700 parsecs, and is only projected before it.

The chief feature on the Northern hemisphere is the large Cygnus condensation, for which great densities are found from 80 to 300 parsecs distance. Beyond this limit the density, according to the HENRY DRAPER Extension in Cygnus, rapidly decreases, at variance with our former results, which gave its distance 600 parsecs. On the charts of the B stars this region shows only a moderate density of stars situated at a distance of about 400 parsecs. It is doubtful whether we have to consider this as a real connection.

6. The relation found here between the distribution of the B stars and the A stars can be expressed in this way: the groups of B stars always contain condensations of A stars in the same part of space; but the reverse is not true: there are important condensations of A stars which contain few or no B stars. The first thesis can only be tested for the groups at small distance; because the A stars are 2 magnitudes

fainter than the B stars, they fall for the more remote groups below the limit of the Catalogue used, and an extension of the spectral catalogue will be necessary to study their distributon. These rules are in accordance with what is known from the starclusters proper; in the Pleiades we know that the brightest stars are B stars, and then follow the A stars in a series of decreasing brightness; the Hyades stream, on the other hand, contains chiefly A stars and no B stars. The question posed above, whether the system of the B stars could be considered as a skeleton for the distribution of the stars at large, must be answered — on the supposition that the rule holds also for the remote B groups, — partly in the affirmative: these groups are at the same time regions of strong concentration of the numerous class of A stars. The A stars do not form such isolated groups; they are dispersed everywhere through space — i.e. in the galactic layer —, and only show a higher density within some parts of space which are partly at the same time groups of B stars, for the other part concentrations of A stars (Cygnus, Carina, a smaller one in Sagittarius) without B stars.

This coincidence may be considered as a dynamical or as a cosmogonical phenomenon. In the first named point of view it is the combined attraction of the massive B stars which has condensed a larger number of the other dispersed stars into their realm. On the other supposition they have a common origin and are the larger and smaller members of a group — comparable with the smaller clusters — originally belonging together and with increasing age more dispersing and intermingling with other groups or stars.

On both suppositions we may expect that other types from the main series are also present in these groups. A positive evidence could, however, not be found; no concentration of F stars or G stars could be found in the realm of the Orion group, the δ Persei and the ϑ Carinae groups. By their smaller absolute brightness they fall too near to the limit or even below the limit of the catalogue; or they are too few in number. Even if the spectral catalogue for these regions is extended to fainter limits, it will be difficult to find positive evidence of a greater density of such dwarfs, because they are mixed with the giants of the same spectral class and apparent magnitude. Probably the isolated group of Orion may offer the best prospects for finding them.

7. Next to the A type stars class K is the most numerous among the spectral classes. Among the K stars of a certain apparent magnitude only a very small fraction are dwarfs; for the giants a mean absolute magnitude — 4.3 (after LUYTEN) was assumed. The study of their distribution in space was made parallel with that of the A stars, by means of computing space densities for cells filling up the sphere with a radius of 300 parsecs, as well as by comparing the surface distribution for consecutive magnitude classes, representing spherical shells at increasing

distance. The distribution of density over the sky for both spectral classes may be seen from figs. 4 and 5. For both classes the galactic band is

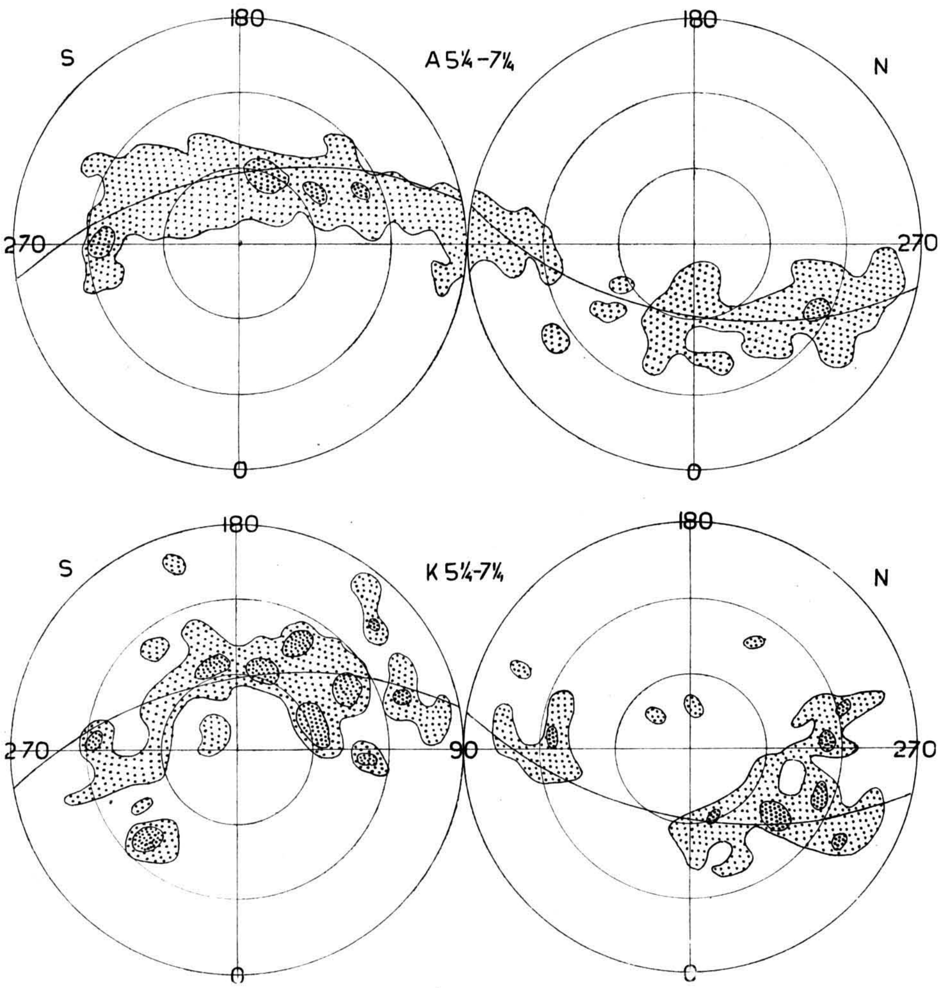

Fig. 4. Distribution of spectral classes A and K between 5.25^m and 7.25^m. (The lines denote for A 5 and 10 stars, for K 4 and 6 stars per 25 sq. d.).

interrupted by a large gap $l = 330^\circ—10^\circ$, where the dark nebulae of Ophiuchus diminish the stars, and by a depression from $l = 120^\circ—160$, by parts of the Taurus nebulosities; these absorbing nebulae produce of course identical distributions of great and small apparent densities. As regards the minor features there is not much resemblance. The large Cygnus condensation appears also in the bright K stars, but with somewhat less depth, at 100 to 200 parsecs distance. It extends broadly to both sides of the Galaxy and shows great densities at high latitudes; its densest part lies at $22^h + 42^\circ$, where the A stars show nothing particular. On the S. hemisphere in the same way its condensations generally do not coincide with those of the A and B stars. In Sagittarius about $17^h\ 50^m$ — $35°$ a condensation coincides nearly with that of the A stars; the region

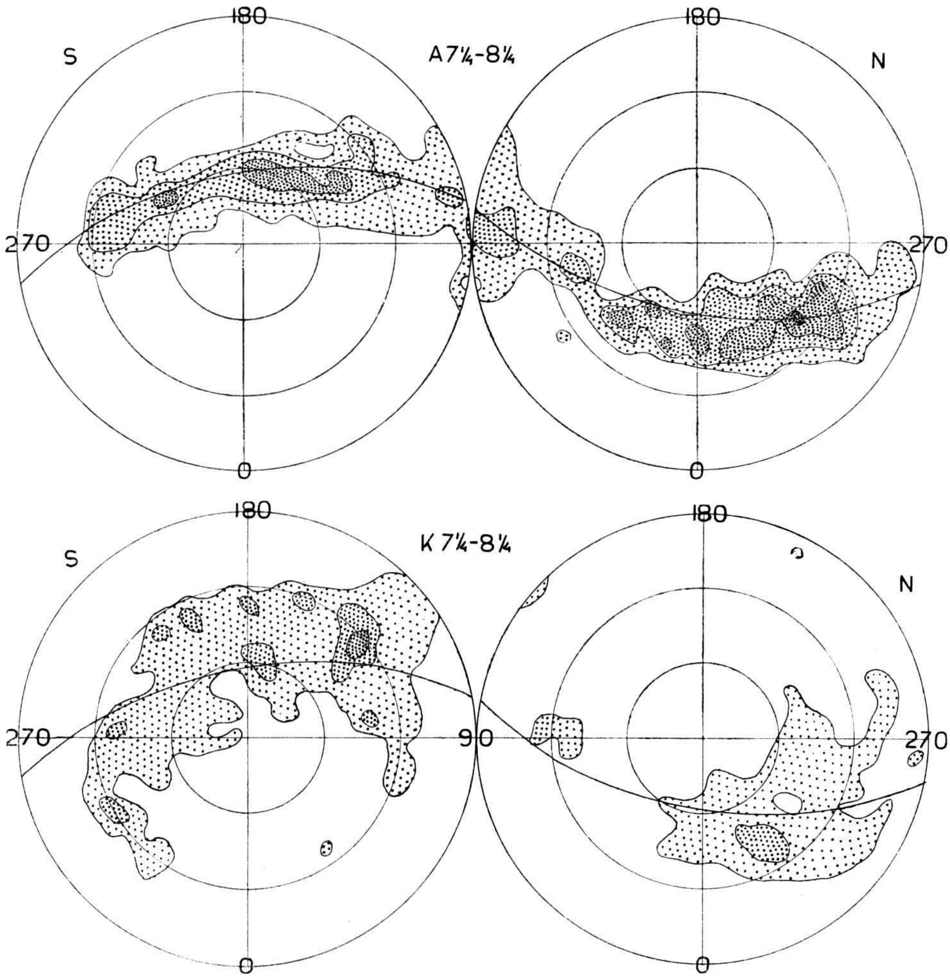

Fig. 5. Distribution of spectral classes A and K between 7.25^m and 8.25^m. (The lines denote 10, 15, 20, 25 stars per 25 sq. d.).

of great density in Carina coincides not exactly, since it is situated somewhat more to the N. The other ones have a tendency to occupy high latitudes, or in lower latitudes to shift away from the A condensations. The same behaviour is found in the case of some smaller groups. In the region of the Orion group of B stars not a trace of condensation of the K stars is seen; there seem even to be a smaller density of them at the place of the group stars, which may give the impression of a somewhat increased density in adjacent regions. At the place of the ϑ Carinae cluster a group of K stars is seen at the N. side of the A star group. The average density as a function of the perpendicular distance to the galactic plane, compared with the A and the B stars, is given by the following values of the number of stars per 1000 cubic parsecs :

at distance	0	50	100	150	parsecs
we have	0.35	0.24	0.14	0.07	*A* stars,
	0.018	0.010	0.004		*B* stars,
and	0.18	0.16	0.13	0.10	*K* stars.

In concordance with what was said above on the extension of the *K* stars to higher latitudes we find here a slower decrease of them and a preponderance over the *A* stars at large distances from the galactic plane.

Thus we find that the giant *K* stars have a distribution of their own, in general independent of the distribution of the *A* and the *B* stars. This could point to a cosmogonical independence of the two spectral groups, perhaps related to their different places in the Russell diagram, where the *B* and the *A* stars with the dwarfs form the main series, and the *K* giants, according to JEANS, form part of a parallel series with less ionized atoms. There are, however, also some instances where accumulations of *K* stars and *A* stars coincide, viz the nearer parts of the Cygnus condensation, the condensation λ Sco—ε Sgr, and the Carina condensation in its N. part. These are just the *A* condensations, where the *B* stars are lacking. They are so far analogous to the Hyades stream, where also some *K* giants are among the brightest members. If this is more than an accidental coincidence it means that there are two types of *A* condensations, one coincident with *B* star groups and free from *K* giants, and the other containing a greater density of *K* stars but no *B* stars. According to the prevailing views of stellar development there is a line of development, caused by loss of mass, along the main series, whereas coloured giants may attain at this series through contraction along lines in a cross direction. Then the idea offers itself, that these two types of stellar agglomerations may represent two different types of stellar development.

8. If we compare these results with our former investigation (Publications Amsterdam 1.), where the spectral classes were not separated, we find now a greater complexity of structure. Formerly a mixture of *A* stars and *K* giants, with dwarfs at small distance and some *B* stars was treated as a whole by means of a luminosity curve of large dispersion. In this way condensations situated behind another were confounded and combined into one. Now such condensations are separated and the complex origin of the distribution of the stars at large is revealed. Thus e.g. about 260° of longitude in Carina we have between 100 and 200 parsecs the extension of the Scorpio-Centaurus group, at 300 parsecs the extension of the Puppis-Vela group, at 600 parsecs a strong condensation of *A* stars, and at 1700 parsecs another dense condensation of which only *B* stars occur in our catalogues. In other cases, where in the same line of sight

only one condensation is found, the former research could give substantially correct results.

The stars surrounding our sun have often been spoken of as a local system which was considered as a part of the large galactic system, of the same importance as some of the chief galactic clouds. Our results show that a local system, in this sense of a separate large condensation, does not exist. We may use the word in a technical sense, comprising in it the whole of the near stars contained in and studied by means of our catalogues. But in reality it consists of a number of separate smaller or larger condensations and clusters which probably have no more connection with another than with the more remote groups. Each of them has its own orbit around the centre of the galactic system as a part of the general rotation discovered by OORT. Whereas the motions of the single stars around this centre can only be treated statistically, the motions of these most important groups have to be studied individually.