BULLETIN OF THE ASTRONOMICAL INSTITUTES
OF THE NETHERLANDS.

1938 July 25. Volume VIII. No. 308.

COMMUNICATION FROM THE OBSERVATORY AT LEIDEN.

Absorption and density distribution in the galactic system, by *J. H. Oort.*

Summary.

The article is principally concerned with the following problem: What information can be obtained about the structure of the galactic system if counts of faint stars in moderate and high galactic latitudes are combined with absorption data from HUBBLE's counts of extra-galactic nebulæ?

For this purpose the star density at various distances in each of KAPTEYN's Selected Areas was compared to that at the same elevations above the galactic plane in the region surrounding the sun (the region above 50° latitude). The individual differences between the logarithms of the numbers of stars so obtained are given in Table 8 for 5 different levels north as well as south of the galactic plane (see also Figures 5, 6 and 7); the results for the lowest level ($z_0 = 170$) are considerably less certain than those for the other layers. As has also been indicated independently by VASHAKIDSE, these density differences can be derived geometrically, without any knowledge of the luminosity curve or of the distribution in distance. The amount of absorption to be used for each Selected Area has been estimated with the aid of the nebular counts in neighboring fields (section 2).

If it is assumed tentatively that the absorption takes place in front of the stars studied the investigation leads to a picture of the galactic system which is rather different from the prevalent conception: the sun appears to be situated in a region of relatively low star density surrounded in all galactic longitudes by extensive regions where the density is at least twice as high (see Table 9 and Figures 5, 6 and 8); however, the part of the sky below − 30° declination could not be investigated. The structural features indicated are large-scale phenomena, extending on both sides of the galactic plane to distances of 500 or 700 parsecs from this plane. The analogy between this structure and the spiral structure of strongly flattened extra-galactic systems is discussed, but the data are still too inaccurate and incomplete to permit any conclusion about the course of the eventual "arms", except that the sun should be between two arms.

At larger distances from the galactic plane the unevenness in the density distribution disappears; at levels between 800 and 1800 parsecs the equidensity surfaces can be well represented by planes inclined at angles of about 10° to the galactic plane, the sign of the inclination being opposite for the two galactic hemispheres (Figure 8); the inclination corresponds to an increase of density in the direction of the galactic centre by a factor 1·38 per 1000 parsecs. The two galactic hemispheres give identically the same value for the inclination as well as for the total number of stars. From these high levels the longitude of the centre has been found at 324°±3° (p.e.).

Except as regards the high levels the inferences drawn depend entirely upon the absorption values adopted. If it were assumed that the absorption found from the nebular counts occurs at distances of more than 500 parsecs from the galactic plane the unevenness in the density distribution would practically disappear. For this reason an extensive investigation has been made of the distribution of the absorbing matter, from color-excesses of stars in Selected Areas (section 3) as well as from B-star colors (section 4). Since knowledge of the ratio of photographic to selective absorption is also required, the problem of determining this ratio has been discussed in section 5.

The selective absorption in the Selected Areas has been determined from PARKHURST's colors of faint stars in the areas at + 45° declination combined with spectra from the *Hamburger Spektral-Durchmusterung*, and also from direct data recently published by SEARES. Sections 3—5 contain also some general results concerning the distribution of the absorbing material. The evidence points to a strong galactic concentration of the absorbing clouds (contrasting with the much smaller concentration of the interstellar gas), and seems rather conclusive in showing that the greater part of the absorption derived from

HUBBLE's counts must have occurred relatively near-by. The evidence derived from the Selected Areas themselves is the most convincing.

Various direct arguments pointing to the reality of the structural features found have been collected on page 260.

1. *Introduction.*

The present paper contains a study of the density distribution of stars situated in galactic latitudes of about 10° and higher. It would perhaps have appeared more natural to commence a study of structural features of the galactic system by a discussion of the results found from stars in or near the galactic plane, but lack of knowledge concerning the absorption of light prevents this. The surface distribution of stars in the Milky Way shows many local irregularities as well as large-scale variations in density, but in general it is impossible to say which part of these variations is to be ascribed to the absorbing clouds (of which we know that they are distributed most irregularly) and which part is due to structural features of the stellar system. For, as yet, independent knowledge about the absorption is far too scanty to permit general separation of these two phenomena in Milky Way regions. However, in directions which are inclined to the galactic plane the situation is quite different. While the indications are that the surface distribution of stars in the Milky Way regions is mainly determined by that of the absorbing material, rather than by the structure of the system, the opposite holds for the regions above 30° latitude, where the absorption plays only a minor part. As shown on page 263 it is even possible to determine the longitude of the galactic centre from the counts of faint stars in these high latitudes, with a probable error of not more than ± 3°; a similar attempt for the lowest latitudes would give a value of the longitude at least 25° away from the true centre.

In the moderate latitudes with which we shall be mainly concerned in the present article the absorption cannot be neglected, but in these regions its influence can, to some extent, be determined and eliminated. It is very probable that at least a great part of the absorbing material is situated within 200 parsecs of the galactic plane, so that, for a study of the density distribution of stars at some distance from this plane, we need only know the total absorption which the light coming from the direction of the stars investigated has undergone when passing through this layer. There are two entirely independent types of information concerning this absorption: on one hand the counts of faint extra-galactic nebulæ, and on the other hand the color-excesses of faint stars. The counts of nebulæ give direct determinations of the total absorption, which in several longitudes are usable down to about 10° latitude. As will be shown in the following the color-excesses give valuable indications about the absorption for regions between roughly 10° and 25° latitude. It must be borne in mind that part of the absorption shown by the counts of nebulæ might be caused by material at very great distances from the galactic plane, so that it is possible that these data indicate only a maximum value for the absorption suffered by the light of the stars. Similarly, the color-excesses of the stars yield only a minimum value for this absorption, because the exact factor by which the color-excesses need to be multiplied in order to find the total photographic absorption is still unknown, and we must at present content ourselves with a minimum value for this factor (cf. section 5).

It appears that even this approximate knowledge of the absorption is sufficient to reveal large-scale features of galactic structure which were still unknown, and which contrast to some extent with current conceptions of this structure.

In an earlier paper [1]) it had been shown that the numbers of stars computed upon the assumption that the equi-density surfaces were, on the average, parallel to the galactic plane agreed very well with the observed numbers down to 15° latitude (averaged over all longitudes). Attention was called to the apparent contradiction between these results, which seemed to show that there was not much absorption above 15° latitude, and the decrease of the numbers of extra-galactic nebulæ at lower latitudes, which indicated very considerable absorption. The publication of detailed nebular counts by HUBBLE offered an opportunity for a better investigation of this point, which was taken in hand in 1933, in collaboration with Mr VELDT. These more detailed computations led to the same discrepancies, but publication was deferred because we were unable to obtain sufficient certainty about their correct interpretation. Evidently, two alternative inferences were possible: 1. the sun is situated in a kind of local void, bounded on nearly all sides by regions of considerably higher star density; 2. the major part of the absorption shown by the nebular counts is caused by matter farther from the galactic plane than the stars considered.

Studies of colors of stars in Selected Areas as well as studies of color-excesses of B-stars finally showed fairly conclusively that at least great part of the absorption takes place in the immediate vicinity of the

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[1]) *B.A.N.* VI, No. 238 (1932).

galactic plane. It was also shown that the abnormal results for the density distribution remained even if the extreme supposition were made that only half of the absorption derived from the counts of nebulæ took place in front of the stars, so that it became very probable that the first alternative must be adopted [1]).

The present article contains a more detailed discussion, in which each Selected Area has been treated separately, and all data bearing upon the distance of the absorbing matter have been brought together.

Throughout the present article the galactic co-ordinates for the Selected Areas are those given in the *Harvard Groningen Durchmusterung* [2]); these have been computed for the galactic pole at $\alpha = 12^h41^m{\cdot}3$, $\delta = +27^\circ{\cdot}4$. The co-ordinates for the B-stars in section 4, taken from STEBBINS and HUFFER's catalogue, are relative to NEWCOMB's pole at $\alpha = 12^h44^m{\cdot}4$, $\delta = +26^\circ{\cdot}8$, differing about 1° from the former. In his study on star counts [3]) VAN RHIJN has found the position $\alpha = 12^h56^m$, $\delta = +25^\circ{\cdot}5$ from stars fainter than 8^m, differing 4° from the pole used here; SEARES [4]) has likewise found a pole deviating considerably from that adopted. I have preferred the position used in the *Harvard Groningen Durchmusterung* because this is confirmed and very accurately defined by all classes of distant galactic objects such as O-stars, faint B-stars, δ Cephei variables, c-stars, etc. A further justification of this choice may be found in the symmetry observed in the density distribution at large distances from the galactic plane. As shown on page 262 the inclination of the equi-density surfaces to the galactic plane is found to be $8^\circ{\cdot}7$ for the region north of the galactic plane, and $8^\circ{\cdot}9$ for the southern region. If e.g. the pole were shifted to the position given by VAN RHIJN the former inclination would be reduced to about 5°, while the latter would become 13°. Such a difference seems quite improbable.

2. *Values of the total absorption derived from Hubble's counts of nebulæ.*

The total absorption suffered by the light of the stars between 10° and 40° latitude studied in the present article has been derived from counts of faint extra-galactic nebulæ. From the North Pole down to -30° declination by far the most extensive and homogeneous data are those given by HUBBLE [5]), and these have been used exclusively. The counts extend to limiting magnitudes about $19^m{\cdot}5$ and $20^m{\cdot}0$ for the 60″- and 100″-plates respectively. By an inspection of the counts in latitudes between 40° and the galactic poles HUBBLE gives convincing proof that, with this faint limiting magnitude, the linear dimensions of the space surveyed are so large that relatively little sign remains of the irregularities in the nebular distribution which show up so strongly in the surveys of brighter nebulæ. The diminishing numbers of nebulæ in intermediate latitudes may thus safely be used to determine the difference of absorption, intermediate latitude minus pole, within the galactic system. HUBBLE finds that the numbers of nebulæ are consistent with the hypothesis of a galactic absorbing layer of $0^m{\cdot}5$ total optical thickness (from pole to pole); in this estimate various longitudes have been combined, but the parts of the sky in which no nebulæ were found, as well as the fringes of local partial obscuration were excluded; the result was considered as referring to a more or less smooth pervading medium.

For the investigations in the present paper the absorption in the direction of each of KAPTEYN's Selected Areas was estimated from HUBBLE's counts of nebulæ. For the regions above 45° latitude, where the absorption is of little consequence and shows no sensible fluctuations, it was simply computed by means of the expression ${}^m{\cdot}31/\sin b$ (see below). In the computations of the star density in section 6 the region above 50° was used as standard, all calculations being made relative to the average star counts and the average absorption in this region; according to the above expression this average absorption is ${}^m{\cdot}36$, and the differences between the absorption in the area studied and that in the standard region thus amount to ${}^m{\cdot}31/\sin b - {}^m{\cdot}36$. These differences will be denoted by Δa.

For the areas between 30° and 45° latitude we have computed the average value of $\log N$ (N being the normalized number of nebulæ taken from the last column of HUBBLE's Tables I, IIa and b, IIIa and b, and IVa) for the field nearest to the Selected Area investigated and the 8 fields of the systematic survey situated on the rectangle extending 10° in longitude and 5° in latitude to either side of this field; eventual extra-survey fields lying within this

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[1]) *Annales d'Astrophysique* I, No. 1 (1938). Cf. Tableau 5 (p. 88) and also Tableaux 6 and 7. It should be noted that the fairly large positive values of *o—c* for the fainter stars at 40° latitude in Tableau 5 are probably partly spurious, and due to the uncertainty of the star density adopted for the galactic poles.

The influence of eventual systematic errors in the stellar magnitudes has been discussed, but quite incredible errors would be required to explain the observed differences (l.c. p. 91).

[2]) *Harvard Annals* **101–103**.

[3]) *Publ. Kapteyn Astr. Lab. Groningen*, No. 43 (1929).

[4]) *Ap. J.* **67**, 123 (1927); *Mt Wilson Contr.* No. 347.

[5]) *Ap. J.* **79**, 8 (1934); *Mt Wilson Contr.* No. 485.

rectangle were also included. The value of Δa was computed from the formula

$$\Delta a = \frac{\overline{\log N} - 1{\cdot}95}{{\cdot}55}.$$

In this expression 1·95 represents the total average value of log N for $b > 50°$; this has been found from HUBBLE's Table XI (north and south combined); the numerator would have been exactly 3/5 if there were no red-shift, the adopted value takes roughly account of the effect of the red-shift upon the limiting magnitudes as shown in Table XVIII of HUBBLE's paper. The probable errors of the absorption values thus derived will not exceed $\pm^{\mathrm{m}}{\cdot}1$. For latitudes lower than 30° it was not feasible to use a more or less general rule because of the rapid fluctuations in the absorption, and the absorption values were determined either by averaging or by interpolating between nebular counts in surrounding fields. On the average about 5 nebular fields were so used in connection with each Selected Area. In combining these fields some personal judgment had to be used; it is quite possible that in several cases the absorptions might be estimated rather differently by other investigators, as some arbitrariness could hardly be avoided [1]). The results are especially weak for the areas Nos 145 to 160 at − 30° declination, which are situated at the outer limit of the region studied by HUBBLE. The uncertainty is likewise considerable for nearly all areas at lower latitudes, because of the small and irregularly varying numbers of nebulæ and the fact that there is often a rather appreciable distance between the Selected Area and the nebular fields. The ideal would be to have counts, if possible down to still fainter limits, in regions coinciding with the Selected Areas. A tentative comparison was made with FATH's counts of nebulæ on Selected Area plates [2]), but it appeared that these do not extend far enough and are not sufficiently homogeneous to be of use. Areas situated within HUBBLE's "zone of avoidance" have generally been omitted; for a few of these (Nos 2, 7, 133 and 156) minimum values for the density were tentatively computed by assuming that the absence of nebulæ indicated that the average value of N certainly would not exceed 10, which is equivalent with assuming a minimum absorption of $1^{\mathrm{m}}{\cdot}73$. The values for Δa finally adopted are shown in the 5th column of Table 8.

In the course of these computations we also computed, from the tables enumerated, general averages of N for various galactic latitudes; in this computation all longitudes were combined, only excepting the region of abnormally strong absorption surrounding the centre of the system; the limits of the excluded region are:

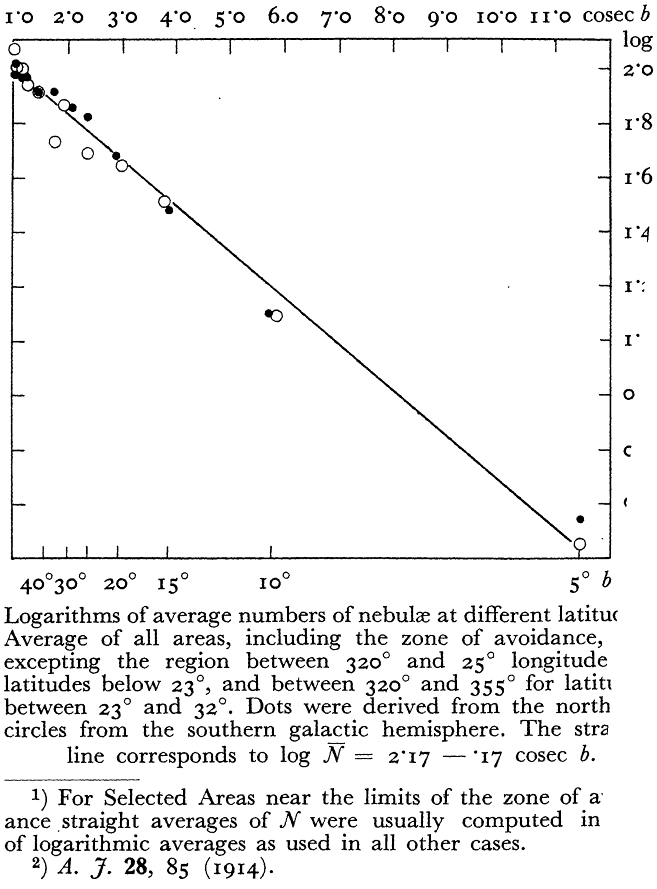
b − 22° to + 22° from $l = 320°$ to $l = 25°$
b − 32° to + 32° from $l = 320°$ to $l = 355°$.

As I wanted to obtain an estimate of the true average absorption for the part of the sky between about 0° and 200° longitude, the region of avoidance was included. The averages of all values of N (including zero values) in each zone of latitude are shown in Table 1 and in Figure 1. The second column refers to positive, the third to negative latitudes; the numbers of regions used are in parentheses. The points for latitudes above 40° were taken from HUBBLE's Table XI (columns "Total"), + ·03 being added in order to reduce to log $\overline{N}$.

TABLE 1.

b	north $\overline{N}$ (n)	south $\overline{N}$ (n)
35°	82·5 (53)	54·6 (21)
30	73·2 (31)	72·1 (27)
25	66·2 (33)	49·8 (34)
20	47·7 (25)	45·6 (29)
15	30·8 (23)	31·6 (32)
10	12·4 (23)	12·9 (30)
5	2·2 (36)	1·8 (32)

FIGURE 1.



Logarithms of average numbers of nebulæ at different latitu
Average of all areas, including the zone of avoidance,
excepting the region between 320° and 25° longitude
latitudes below 23°, and between 320° and 355° for latit
between 23° and 32°. Dots were derived from the north
circles from the southern galactic hemisphere. The stra
line corresponds to log $\overline{N}$ = 2·17 — ·17 cosec b.

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[1]) For Selected Areas near the limits of the zone of a ance straight averages of N were usually computed in of logarithmic averages as used in all other cases.

[2]) *A. J.* **28**, 85 (1914).

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It may be noted that for high as well as low latitudes, even down to $\pm 5^\circ$, the points can be well represented by a straight line. The line drawn corresponds to $\log \bar{N} = 2{\cdot}17 - {\cdot}17 \operatorname{cosec} b$, or to an absorption of $^{m}{\cdot}31 \operatorname{cosec} b$.

For the part of the sky south of declination — 30° no extensive data are as yet available. SHAPLEY's investigation [1]) of the nebular distribution in the south-polar cap might possibly be used for estimating the average absorption in the region between 240° and 300° longitude. For the zone — 10° to — 20° latitude the median number of nebulæ per square degree is about 3·5, against 9·3 for the zone between — 40° and — 57° latitude, giving an average difference of absorption of $^{m}{\cdot}71$ between these two zones. But the limiting magnitude of these counts is considerably brighter than that of HUBBLE's counts; they refer therefore to a much smaller extent of space, and the irregularity in the distribution of the nebulæ appears to be so great that the value found for the absorption is quite uncertain.

3. *The distance of the absorbing matter as inferred from the colors of faint stars in the Selected Areas.*

The essential point to be investigated is the location of the absorbing medium responsible for the diminution of the nebulæ in low latitudes. Does the absorption take place in front of, or beyond the stars that will be studied?

The only quantities, known at present, from which we can hope to obtain any answer to this question are the color-excesses. The information most directly applicable to our problem is that found from the stars in the Selected Areas themselves, and I will, therefore, begin by considering the color-excess data available for these areas.

In 1927 results were published of a photometric study of 1550 stars in the Selected Areas 20–43, carried out by J. A. PARKHURST [2]). The work comprised the determination of photographic as well as photovisual magnitudes of stars down to the 14th photographic magnitude. For part of the stars spectral classes have been determined by HUMASON [3]), and these permitted a derivation of the color-excesses [4]). Recently data of the *Hamburger Spektral-Durchmusterung* [5]) have become available; this catalogue contains spectra for practically all of PARKHURST's stars, and as it was very desirable to strengthen the results, especially for the areas in high latitude, a rediscussion has been made based on the Hamburg classifications.

First a standard curve connecting color and spectral type was derived by means of the areas in high galactic latitude. The computation is shown in Table 2, which gives the average colors for four spectral groups. The Selected Area number and the galactic latitude is indicated in the first column, while the next column gives the average absorption for the general region in which the area is situated, derived by means of HUBBLE's nebular counts (see section 6, Table 8). The numbers of stars used in computing the average colors are shown behind the corresponding averages. Though the areas 27 and 37 are at rather moderate latitude they were included among the standard areas because the counts of nebulæ indicated a very low absorption.

The original computations were made separately for stars between 9·0 and 11·0, between 11·0 and 12·5, and between 12·5 and 13·5 Harvard photographic magnitude, but as the results did not reveal any systematic difference between bright and faint stars, the three groups were combined in Table 2. It should be noted that the stars fainter than 13·0 photographic magnitude are very incomplete; in lower latitudes the incompleteness begins already at $12^{m}{\cdot}5$. It might be feared that this fact could give rise to effects of selection upon the colors. But I have convinced myself that such is not the case for the high latitudes; the exclusion of all stars fainter than 12·5 would result in an increase of the standard colors by only $^{m}{\cdot}02$. For the lower latitudes separate results will be given for the groups $11^{m}{\cdot}0$ to $12^{m}{\cdot}5$ and $12^{m}{\cdot}5$ to $13^{m}{\cdot}5$.

The average colors (and the corresponding average spectral types) to be adopted as standard colors for the comparison with low-galactic areas are shown in the last lines. It will be noted that the relation between color-index and spectrum is not linear; there appears to be a bend at about G2, after which the curve rises more steeply. This is not due to a special peculiarity of the Hamburg spectra, for the same characteristic had been found when using HUMASON's classifications.

In order to form an estimate of the systematic errors which might occur when comparing average color-indices in different areas I have entered in the last column of Table 2 the weighted average difference between the colors in the area and the standard colors. The average of these residuals for the 11 areas considered, i.e. the average systematic error of the colors of one area, amounts to $\pm\, ^{m}{\cdot}09$.

The weights used in combining the different areas for the derivation of the standard colors in the lowest

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[1]) *Harvard Annals* **105**, 137 (1937).

[2]) *Yerkes Publ.* IV, Pt 6 (1927) (prepared for publication after the author's death by ALICE H. FARNSWORTH).

[3]) *Ap. J.* **76**, 224 (1932); *Mt Wilson Contr.* No. 458.

[4]) *Annales d'Astrophysique* I, No. 1, pp. 77, 78.

[5]) 2. Band (1938).

TABLE 2.

Average colors for stars between $9^{\mathrm{m}}\cdot 0$ and $13^{\mathrm{m}}\cdot 5$ pg in Selected Areas at high latitudes.

No.	b	Δa	A0—A9	F0—F9	G0—G6	G7—K9	Area minus average
	°	m	m	m			
27	+ 29	+ ·04		+ ·01 5	+ ·22 16	+ ·76 3	— ·01
28	+ 39	— ·10	— ·50 1	— ·11 6	+ ·18 13	+ ·95 6	— ·02
29	+ 50	+ ·05	·00 3	+ ·15 2	+ ·25 9	+1·14 3	+ ·13
30	+ 60	·00		— ·15 2	+ ·12 5	+ ·65 1	— ·12
31	+ 68	— ·03		— ·05 6	+ ·19 6	+ ·23 1	— ·09
32	+ 72	— ·03		+ ·15 4	+ ·40 2	+ ·82 2	+ ·11
33	+ 67	— ·02	— ·22 1	+ ·05 1	+ ·31 9	+ ·62 2	+ ·04
34	+ 59	·00		+ ·12 2	+ ·26 10	+ ·82 2	+ ·05
35	+ 49	+ ·05		+ ·22 6	+ ·31 8	+1·09 7	+ ·19
36	+ 39	+ ·23	— ·53 : 1	— ·02 3	+ ·20 15	+ ·65 9	— ·07
37	+ 28	+ ·11	— ·16 1	+ ·01 7	+ ·06 26	+ ·59 11	— ·14
Average	27—32		— ·16 4	·00 25	+ ·21 51	+ ·83 16	
,,	33—37		— ·30 3	+ ·08 19	+ ·22 68	+ ·75 31	
Total average		+ ·03	— ·23 7	+ ·03 44	+ ·22 119	+ ·79 47	
Average spectrum			A4	F6	G2	K0	

lines were computed from the formula $w = 1/r^2$, where $r = \sqrt{\cdot 08^2 + \cdot 15^2/n}$; ·08 is the probable error of the zero-point, and ·15 that of an individual color; n is the number of stars. The probable error of the zero-point of the adopted standard colors is $\pm\,{}^{\mathrm{m}}\cdot 02$, which is quite satisfactory. In order to verify that the colors derived by PARKHURST do not vary systematically with right-ascension, the standard colors were computed separately for the group of areas 27 to 32 inclusive (situated between $7^{\mathrm{h}}38^{\mathrm{m}}$ and $12^{\mathrm{h}}51^{\mathrm{m}}$ right-ascension) and for the group of areas 33 to 37 inclusive (between $13^{\mathrm{h}}50^{\mathrm{m}}$ and $17^{\mathrm{h}}49^{\mathrm{m}}$). As may be seen from the numbers in the third and fourth lines from the bottom of Table 2 there is no evidence of systematic difference.

Color-excesses for the areas at lower galactic latitudes were now derived by subtracting the standard colors from the observed color-indices for each spectral group. As the absorption in high latitudes is small the standard colors derived may be considered as the intrinsic color-indices of the high-latitude stars concerned. The intrinsic colors of the G- and K-type stars in lower latitude will, however, be somewhat redder, because these stars are of brighter absolute magnitude. From the mean parallaxes in *B.A.N.* No. 290 (p. 102) I infer that the difference in

TABLE 3.

Average color-excesses for stars between $11^{\mathrm{m}}\cdot 0$ and $13^{\mathrm{m}}\cdot 5$ in Selected Areas below 20° latitude.

No.	l	b	Δa	A0—A9	F0—F9	G0—G6	G7—K9	Total average	Average $11^{\mathrm{m}}\cdot 0$–$12^{\mathrm{m}}\cdot 5$	Average $12^{\mathrm{m}}\cdot 5$–$13^{\mathrm{m}}\cdot 5$
	°	°	m	m	m	m	m	m	m	m
26	138	+ 18	·44	+ ·78 2	+ ·37 15	+ ·26 17	+ ·48 7	+ ·36 41	+ ·49 19	+ ·25 22
38	42	+ 18	·62		+ ·21 3	+ ·31 22	+ ·28 17	+ ·29 42	+ ·29 30	+ ·31 12
20	89	— 17	·38	— ·19 4	— ·05 11	— ·06 31	+ ·31 5	— ·03 51	+ ·01 27	— ·08 24
21	99	— 17	·33	+ ·68 3	+ ·20 12	+ ·36 27	+ ·28 7	+ ·33 49	+ ·36 30	+ ·27 19
43	80	— 17	·69	— ·06 1	+ ·01 9	+ ·03 25	+ ·06 10	+ ·03 45	+ ·07 20	·00 25
22	111	— 13	·71	+ ·42 13	+ ·35 7	+ ·49 46	+ ·13 2	+ ·45 68	+ ·38 25	+ ·49 43
42	70	— 13	·89	+ ·61 7	+ ·52 12	+ ·48 9	+ ·63 3	+ ·54 31	+ ·57 23	+ ·44 8
25	133	+ 9	1·76.	+ ·14 2	+ ·44 3	·00 11		+ ·10 16	+ ·15 11	— ·01 5
39	47	+ 9	·67	+ ·27 9	+ ·11 13	+ ·22 12	+ ·08 8	+ ·17 42	+ ·17 30	+ ·17 12
41	61	— 8	> 1·73	+ ·19 18	+ ·10 10	— ·13 3	+ ·05 5	+ ·12 36	+ ·11 33	+ ·19 3
23	120	— 7	1·75	— ·17 1	+ ·11 3	+ ·14 12	+ ·27 9	+ ·17 25	+ ·09 17	+ ·33 8
24	128	0	. . . .	+ ·53 10	+ ·74 2	+ ·87 2		+ ·61 14	+ ·65 9	+ ·54 5
40	53	0	. . . .	+ ·53 2	+ ·60 22	+ ·40 17	+ ·19 7	+ ·47 48	+ ·55 27	+ ·37 21

absolute magnitude between the G-stars in high latitude and those in latitudes below 20° is $1^m{\cdot}1$; for the group G7—K9 this difference amounts to about $1^m{\cdot}5$. Assuming an increase of color-index of $^m{\cdot}05$ per magnitude increase of absolute brightness [1]) we find corrections of $+ {}^m{\cdot}05$ and $+ {}^m{\cdot}07$. After applying these corrections to the above standard colors for the G- and K-stars, respectively, the corrected color-indices were subtracted from the average colors found for the areas below 20° latitude. The average color-excesses so obtained are shown in Table 3 which has been arranged in the same way as Table 2, except that the order of the areas is according to latitude, and that the galactic longitudes have been added in the second column. The average colors in this table rest exclusively upon stars between $11^m{\cdot}0$ and $13^m{\cdot}5$, the brightest having been omitted because they are not sufficiently distant for our purpose. Average colors were also computed for the two intervals $11^m{\cdot}0$ to $12^m{\cdot}5$ and $12^m{\cdot}5$ to $13^m{\cdot}5$ separately. These are shown in the last columns; the interval $12^m{\cdot}5$ to $13^m{\cdot}5$ is very incomplete, in most areas only less than half of the stars in this group have been observed, and selection may have played an important part. For this reason the further discussion has been limited to the data for the group between $11^m{\cdot}0$ and $12^m{\cdot}5$ shown in the next to the last column. The average photographic magnitude is then about $11^m{\cdot}8$, corresponding to a logarithmic average parallax of approximately $''{\cdot}0018$ for these latitudes [2]).

It will be observed that there is a rather strong tendency for positive color-excesses. For seven of the areas there can be hardly any doubt about the reality of the excess, while for the four remaining areas below 15° the excess exceeds the probable error of the zero-point ($\pm {}^m{\cdot}08$). The correlation of the individual color-excesses with the absorption derived from the counts of nebulæ (see the column Δa) is not very pronounced, but this is hardly surprising in view of the considerable accidental uncertainty in both of the quantities compared. Combining the 5 areas between 17° and 18° latitude we find $+ {}^m{\cdot}24$ for the average color-excess, as against $+ {}^m{\cdot}49$ for the average total absorption Δa. The color-excess should be multiplied by a factor of at least 3·0 to obtain the corresponding total absorption; the result indicates, therefore, that the major part of the absorption inferred from the counts of nebulæ is due to material situated in front of the 12th magnitude stars, or at distances within 170 parsecs from the galactic plane. For the group of 6 areas between 7° and 13° a similar result is indicated, though perhaps a little less convincingly; the average color-excess is here $+ {}^m{\cdot}24$, as against $\Delta a = 1^m{\cdot}25$. It does not seem improbable that the large discordances between total absorption and color-excess for the areas Nos 23, 25 and 41 are due to the fact that the stars considered are mostly in front of the dense absorbing clouds in these regions. The logarithmic average distance from the galactic plane is only about 80 parsecs for the stars in the areas between 7° and 9° latitude, so that it is not surprising to find that these are not yet outside the layer of absorbing clouds.

On the whole, the evidence appears to be rather in favor of the hypothesis that most of the absorption revealed by the nebular counts is due to matter relatively close to the galactic plane. The two galactic areas, 24 and 40, give some indication of the considerable absorption suffered by 12^m stars in this plane.

Parkhurst himself was well aware of the increase of the color-indices with decreasing galactic latitude; he showed [3]) that the stars of the 12th and 13th photovisual magnitude near the Milky Way were nearly half a magnitude redder on the average than the high-latitude stars. However, he had no data on spectral types for these faint stars, and he interpreted his results as indicating that the faint stars in the galaxy would on the average be of later type than those in high galactic latitudes. Though this interpretation is evidently incorrect Parkhurst should be given the credit of being the first to have observed in a general manner the phenomenon of the reddening in interstellar space.

Independent evidence on the reddening of stars between 10^m and $13^m{\cdot}5$ in the Selected Areas has been published two years ago by Seares [4]), who showed that a close correlation appears to exist between color-excess and nebular density in the neighborhood of the area considered. Seares distinguishes four sorts of regions, according to the various degrees of obscuration, viz. regions of normal nebular density (N), regions of normal density with a sporadic field of low nebular density in the immediate vicinity ($N\ddagger$), partially obscured areas (P) and areas within Hubble's zone of avoidance (O). Areas of the first kind contain no stars with color-excesses, while considerable reddening is found in all other areas.

Considering more particularly the 10 P- and O-areas above 6° latitude, for which the average absorption has been estimated in Table 8 of the present paper, we find that in 8 of these areas all stars are indicated as reddened, while in the remain-

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[1]) Compare Mrs Payne Gaposchkin, *Harvard Annals* **89**, No. 6 (1935).

[2]) *B.A.N.* No. 290, p. 90 (1936).

[3]) L.c. p. 56.

[4]) *Proc. Nat. Ac. Washington* **22**, 327, (1936).

ing 2 a group of stars of normal color as well as a group showing color-excess is found. In the first 8 areas SEARES distinguishes in general two groups of stars, one of strong, and one of moderate reddening. The average color-excess for the former stars is + ^{m}·46, while the average value of the total absorption for these 10 areas, as compared to the high latitude region, is found to be approximately 1^{m}·20. Considering that the color-excess should at least be multiplied by 3 SEARES' results appear to give strong evidence for a relatively small distance of the material responsible for the absorption indicated by the nebulæ, in good accordance with what has been found above from PARKHURST's colors. The groups of stars considered have been selected on the basis of large color-excesses; presumably they represent the excesses for, roughly, the most distant half of the stars between 10^{m} and 13^{m}·5. The logarithmic average distance of these groups may thus be estimated at roughly 1000, and the distance from the galactic plane at 300 parsecs. It should be borne in mind that this selection of large color-excesses will tend to make the average excesses found somewhat too large; likewise they should be slightly diminished on account of the effect of absolute magnitude (see above). In order to correct for both effects the color-excesses mentioned should be decreased, but it does not seem likely that the combined negative correction would exceed ^{m}·10, nor that this would affect our general conclusion. Yet, the somewhat surprising result that a number of stars with pronounced color-excesses are also found in the areas classed N‡ by SEARES, in latitudes where we would hardly have expected much absorption, warns us to some caution.

Additional and more detailed data both on colors and on nebular counts in the fields of the Selected Areas themselves are evidently most desirable in order further to strengthen the argument. The only other published data on faint stars known to me are the colors determined by BOK and SWANN for 6 northern Selected Areas [1]). In the 3 areas between 10° and 20° latitude the most distant stars (B6—A4) appear to show definite color-excesses, averaging + ^{m}·17, + ^{m}·25 and + ^{m}·47 respectively.

4. *The color-excesses of B-type stars and the general distribution of the absorbing matter.*

The color-excesses of faint B-type stars measured by STEBBINS and HUFFER [2]) form a valuable material for determining the distribution of the absorbing dust in the immediate vicinity of the galactic plane. STEBBINS and HUFFER's colors were measured with the photo-electric cell in combination with two filters; the effective wavelengths are 4260 and 4770 A. There are several reasons why these Washburn measures, which comprise all stars of spectrum B5 and earlier brighter than 7^{m}·5 and north of − 15° declination, lend themselves exceptionally well for an investigation of the absorption.

Firstly, the intrinsic colors of stars of these early types are sensibly equal, so that all coloring found may confidently be ascribed to the effect of interstellar matter [3]). The relative independence of the colors of the high-temperature stars from both temperature and absolute magnitude can be inferred at once by inspecting the "normal" colors derived by STEBBINS and HUFFER from stars brighter than 6^{m}·0 and above 15° latitude (l.c. Table IV). The difference between the normal colors of B0- and B5-stars is only ^{m}·05, notwithstanding a considerable difference in ionisation temperature and a difference of about 3 magnitudes in absolute brightness. E. G. WILLIAMS has recently published detailed measures of line intensities and line profiles, which appear to permit a very efficient sub-classification of the B-type stars according to absolute brightness [4]). WILLIAMS' list contains 10 stars above 30° latitude, for which, therefore, the absorption should be negligible; grouping these according to absolute magnitude I find the following values of the Washburn color-excess E [5]). The first two columns show the divisions according to WILLIAMS' M, and the mean absolute magnitude; n is the number of stars; the probable error of each value $\overline{E}$ is ± ^{m}·013.

M_{W}	$\overline{M}_{\mathrm{W}}$	$\overline{Sp}$	$\overline{E}$ m	n
< − 4·0	− 4·8	B1	+ ·01	2
− 3·0 to − 3·9	− 3·4	B2	+ ·02	2
− 2·0 to − 2·9	− 2·4	B4	+ ·01	3
− ·9 to − 1·9	− 1·3	B6	− ·03	3

There is no evidence of change of E with M. This important fact may be further confirmed by grouping the stars according to the designations "n" or "s" describing the character of the spectral lines, which designations are available for a larger number of stars. From a comparison with WILLIAMS' absolute magnitudes it is found that, while there may be little difference between n- and s-stars in the sub-types earlier than B3, the average absolute magnitude of

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[1]) *Harvard Annals* **105**, 371, (1937).

[2]) *Publ. Washburn Obs.* XV, Pt. 5 (1934).

[3]) This statement does not apply to the emission-line stars however, all emission-line stars were excluded in the following investigations.

[4]) *Ap.J.* **83**, 305 (1936); *Mt Wilson Contr.* No. 541.

[5]) The color-excesses are the differences between the color of the stars and the normal colors quoted above.

the s-stars of types B3—B8 is about 3 magnitudes brighter than that of the n-stars of the same types [1]. In the Washburn catalogue I find 10 s-stars of types B3—B9 above 20° latitude; the average color-excess is $+{}^{\rm m}\!\cdot\!015$, while the 16 n-stars above 20° give $+{}^{\rm m}\!\cdot\!022$. A similar result has just been published by GREENSTEIN [2].

The second reason why these color-excesses are so well suited for determining the effects of absorption is their great accuracy. STEBBINS and HUFFER estimated the average probable error of a value of E in their catalogue at about $\pm{}^{\rm m}\!\cdot\!015$. The probable error was derived from internal evidence, but the true probable error cannot be much larger, as is shown by the color-excesses of stars above 30° latitude. There are 55 such stars in the catalogue; the average deviation of E from its mean value for each spectral type, found from these 55 stars, is only $\pm{}^{\rm m}\!\cdot\!025$, corresponding to a probable error of $\pm{}^{\rm m}\!\cdot\!021$. A considerable part of this amount will be due to variations in the small amount of absorption still persisting at these latitudes, and the remaining part can therefore hardly be larger than the probable error of the measurements as given by the authors. Incidentally, we note that this remaining part should also contain the differences between the intrinsic colors of the stars, if they exist; the fact that the average deviation comes out so small and is just about what we should expect from the accidental errors gives additional evidence that the intrinsic colors of all stars of the same sub-type are identically the same.

A third advantage of the present material lies in the fact that for nearly all of these stars radial velocities have been determined, especially at Victoria [3], so that for the more distant groups average distances can be determined from the effects of differential rotation of the galaxy.

What we are mainly interested in, in connection with the problem of this article, is the general distribution of the absorbing matter, averaged over the entire region of space covered by these observations. For, on account of the small distances of the B-stars from the galactic plane we cannot use individual B-type stars for a direct determination of the total selective absorption in the direction of a particular Selected Area.

In order to study this general distribution average values of the color-excess and average distances were computed for various groups of spectral type, brightness and galactic latitude. All relevant data are shown in Tables 4 and 5, and in the notes following. The color-excesses for the bright stars ($m < 5{\cdot}50$) of types B3 and later have not been included; these stars are too near to show any variation of color-excess with galactic latitude.

TABLE 4.

Average color-absorption for the region within 800 parsecs from the sun, and between 0° and 200° longitude (Type O brighter than $7^{\rm m}{\cdot}5$ and types Bo to B2 between $5^{\rm m}{\cdot}5$ and $7^{\rm m}{\cdot}5$).

b	$\bar{b}$	$\bar{m}$	$\bar{E}$	p.e.	n	av.dev.	$\bar{E}_{\rm corr}$	$\bar{I}$	$\bar{r}A$	p.e.	$\bar{r}$	$\bar{z}$
° °	°		m	m		m	m					
0 — 2	1·2	6·68	+ ·201	± ·010	(51)	± ·092	+ ·250	5·40	+ 14·8	± 1·0	780	16
3 — 5	4·0	6·62	+ ·174	± ·014	(26)	± ·080	+ ·223	5·62	+ 15·1	± 1·6	790	55
6 — 11	8·6	6·30	+ ·126	± ·013	(20)	± ·068	+ ·175	5·36	+ 17·8	± 1·9	940	141
≥ 12	18·4	5·64	+ ·060	± ·007	(19)	± ·037	+ ·109	5·07	+ 16·3	± 2·6	860	272

Notes to Table 4.

The stars in the double cluster in Perseus have been combined and counted as one star; the stars in a concentrated group at 112° longitude, + 7° latitude, and the stars in the Orion nebula, $l = 176°$ and 177°, $b = -18°$ and $-19°$, were similarly combined into one average each and counted for one; another average, counted as one star, was formed for the remaining stars in the surroundings of the Orion nebula, between 171° and 178° longitude and between — 14° and — 22° latitude. Except in the last line, in which 8 other stars were included in the determination of $\bar{E}$, all stars with peculiar radial velocities larger than 25 km/sec and stars for which no interstellar velocities were available were excluded.

The adopted average distances in parsecs, $\bar{r}$, rest upon the effects of differential galactic rotation, the coefficients of which are shown under $\bar{r}A$. A was taken equal to ·019 km/sec.ps [4]. In the computation of these values the velocities from both stellar and

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[1] This is contrary to the differences generally adopted which are of the order of $0^{\rm m}{\cdot}5$ only; cf. STEBBINS and HUFFER l.c. p. 246, Table IX.

[2] *Ap.J.* **87**, 151 (1938).

[3] *Victoria Publ.* V, Nos 1 and 2 (1931).

[4] See *B.A.N.* VIII, No. 298, p. 152 (1937).

interstellar lines have been used, and combined with proper weights after multiplying the rotation effect from the interstellar lines by a factor of two. As the computations had originally been made for a study of the interstellar lines, a few stars for which no color-excesses were available were included in this determination. The probable errors of $\overline{rA}$ as well as of $\overline{E}$ were determined from the residuals.

A comparison of the mean distances found here with the average of STEBBINS and HUFFER's distances, viz. 814, 684, 606 and 546 parsecs for the four latitude groups respectively, indicates a good agreement for the two low-latitude groups, while in the groups above 5° the present distances are slightly over 50 % larger. The difference between the two comparisons is, at least partly, explained by the fact that the visual absorptions adopted in the Washburn catalogue are too small. With more plausible values for the absorption the average distances in low latitudes would also have come out about 2/3 of those found in Table 4. STEBBINS and HUFFER have calculated their distances by assuming certain values for the absolute magnitudes; the result indicates, therefore, that the assumed absolute magnitudes for the O—B2-stars were about one magnitude too faint.

The last column gives the distance from the galactic plane, averaged without regard to sign. The columns $\overline{E}_{\text{corr}}$ and $\overline{I}$ will be explained below.

Attention should be called to a somewhat remarkable discrepancy found in the course of these computations. When calculating the rotation effects separately for 6th and 7th magnitude stars it was found that, for each of the three sub-types considered, these effects were larger for the 6th magnitude than for the 7th magnitude, instead of smaller as might have been expected. Combining the sub-types we obtain the following values:

m	$\overline{rA}$ (stars)	$\overline{rA}$ (Ca⁺)	$\overline{I}$
5·5—6·5	+ 24·6 ± 1·3 (p.e.)	+ 12·0 ± ·9 (p.e.)	5·8
6·5—7·5	+ 13·4 ± 1·4 (p.e.)	+ 8·3 ± ·7 (p.e.)	5·3

The mean intensities of interstellar Ca⁺, in the last column, show a similar difference, though in a less degree. I have not been able to trace the cause of the discrepancy.

Notes to Table 5.

In the group of bright B0—B2-stars the Orion stars

TABLE 5.

Average color-absorption for the region within 350 parsecs from the sun, and between 0° and 200° longitude.

b	$\overline{b}$	$\overline{m}$	$\overline{E}$	p.e.	n	av.dev.	$\overline{E}_{\text{corr}}$	$\overline{r}$	$\overline{z}$
			B0 to B2 brighter than $5^{m}\!\cdot\!50$						
° °	°		m	m		m	m		
0—11	4·6	4·46	+ ·101	± ·016	(12)	± ·069	+ ·150	310	24
≧12	25·7	3·80	+ ·028	± ·009	(22)	± ·051	+ ·077	,,	130
			B3 (B4) $5^{m}\!\cdot\!50$ to $7^{m}\!\cdot\!50$						
0— 4	2·2	6·71	+ ·082	± ·007	(35)	± ·033	+ ·131	360	14
5— 9	7·0		+ ·047	± ·005	(31)	± ·041	+ ·096	,,	44
10—19	14·5	6·41	+ ·043	± ·005	(39)	± ·036	+ ·092	,,	90
≧20	37·0		+ ·045:	± ·011	(14)	± ·050	+ ·094:	,,	206
			B5 to B9, $5^{m}\!\cdot\!50$ to $7^{m}\!\cdot\!50$						
0— 4	2·2	6·71	+ ·081	± ·007	(44)	± ·068	+ ·130	330	13
5— 9	7·0		+ ·039	± ·006	(30)	± ·033	+ ·088	,,	40
10—19	14·5	6·52	+ ·035	± ·005	(42)	± ·033	+ ·084	,,	82
≧20	26·0		+ ·022	± ·006	(17)	± ·028	+ ·071	,,	145

were excluded; group averages for all these stars have been included in Table 4, as explained in the notes to that table. In each group a few stars with uncertain radial velocities or large peculiar velocities were also excluded.

The adopted average distances $\bar{r}$ are a compromise between the distances derived from proper motions and from radial velocities. The proper motions used are those of Boss' *Preliminary General Catalogue*, corrected for the effects of galactic rotation, the constants used being $A/4{\cdot}74 = +^{''/a}{\cdot}0040$ and $B/4{\cdot}74 = -^{''/a}{\cdot}0030$, while also systematic corrections were applied to μ_δ [1]) and to the precessions [2]).

For the two groups of bright B0—B2-stars secular parallaxes of $^{''/a}{\cdot}023$ and $^{''/a}{\cdot}012$ were found, respectively. As it is improbable that the high-latitude stars are more distant than those at low latitude the two values were combined into one average. With a solar velocity of 20 km/sec and an assumed value of 1·24 for the ratio $r:(1/p)$ (corresponding to a dispersion of $\pm$ 1·0 in the absolute magnitudes of stars of a given apparent magnitude) we obtain $\bar{r}$ = 310 parsecs; as the determination from radial velocities has a negligible weight this value was adopted.

In the case of the faint stars in the other two divisions of the table good proper motions were available for only a small fraction of the stars considered. It was judged that in these cases a better estimate of the mean distance could be obtained by using the proper motions of the brighter stars for determining the average absolute magnitude, and by assuming that the same value holds for the fainter group of the same spectrum, a slight correction being applied for the difference in absorption between the two groups. The material used consisted of stars in the Washburn catalogue, and brighter than $5^{m}{\cdot}5$.

The bright B3-stars yield average secular parallaxes of $^{''/a}{\cdot}029$ and $^{''/a}{\cdot}023$ for 39 stars below and 35 above 10° latitude, respectively (average magnitudes 4·90 and 4·80). From the weighted average we find an average distance of 210 parsecs. The corresponding distance for the faint stars is 440 parsecs. A direct determination from the rotation effects gives 190$\pm$50 ps. I adopt 360 ps, obtained by giving double weight to the former value. The average color-excess in the last line for this group is greatly influenced by one star with a color-excess $+^{m}{\cdot}30$ lying behind an extension of one of the densest Taurus clouds; if this star is excluded the average excess becomes $+^{m}{\cdot}026 \pm ^{m}{\cdot}006$ (p.e.), while the average deviation from the mean diminishes to $\pm ^{m}{\cdot}031$.

For the B5—B9-stars I find a secular parallax of $^{''/a}{\cdot}030$ from 35 stars below 20°, and an identical value from 30 stars above 20° latitude (average magnitude 4·72). The corresponding distance for the faint stars in all latitude groups is 380 ps. Giving again half weight to the value 240 $\pm$ 50 ps. derived from the rotation effect we get $\bar{r}$ = 330 ps. as adopted in the table.

As was explained above, the color-excesses have been determined with respect to the colors of stars above 15° latitude as standards. In view of the results found from the colors in the Selected Areas it is to be expected that these standards will themselves be somewhat affected by the absorption, so that the Washburn color-excesses would still need a slight positive zero-point correction. In order to estimate the probable amount of this correction I have selected the stars which are presumably nearest to us, namely the stars brighter than $4^{m}{\cdot}5$ and of types B3 and later. Excluding emission-line stars, the Pleiades, which are clearly involved in interstellar clouds, and 3 other stars situated in the direction of the near-by Taurus and Ophiuchus nebulosities, 14 stars remain, for which $\bar{E} = -^{m}{\cdot}019 \pm ^{m}{\cdot}005$ (p.e.), $\bar{m}$ = 3·7. The average distance of these stars is roughly 100 parsecs; assuming for lack of better information that the color absorption over these 100 parsecs is equal to the average, i.e. $^{m}{\cdot}030$, we find that the color-excesses E require a correction $+^{m}{\cdot}049$ in order to be reduced to excesses over the true intrinsic colors. It is to be noted that this correction is rather uncertain, because it is quite possible that the absorption within 100 parsecs deviates considerably from the average; but I see no way of obtaining a better estimate. The values obtained after applying the correction $+^{m}{\cdot}049$ are shown under $\bar{E}_{\text{corr.}}$ in Tables 4 and 5.

The strong galactic concentration of the coloring material, which has been so strikingly illustrated in the plots accompanying STEBBINS and HUFFER's paper, is clearly seen in the run of the average excesses with galactic latitude in both tables.

The distribution of the interstellar dust appears to contrast sharply with that of the interstellar gas, as may be seen by comparing the column $\bar{E}$ in Table 4 with the column $\bar{I}$ showing the average intensities of the interstellar K-line for practically the same stars (in the last line the determination of $\bar{E}$ rests on more stars than that of $\bar{I}$; however, the comparison would not have changed perceptibly if the determination had been restricted to the stars for which Ca^+ intensities were available). This comparison furnishes additional evidence of the lack of

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[1]) BOSS and JENKINS, *A.J.* **37**, 177 (1927).

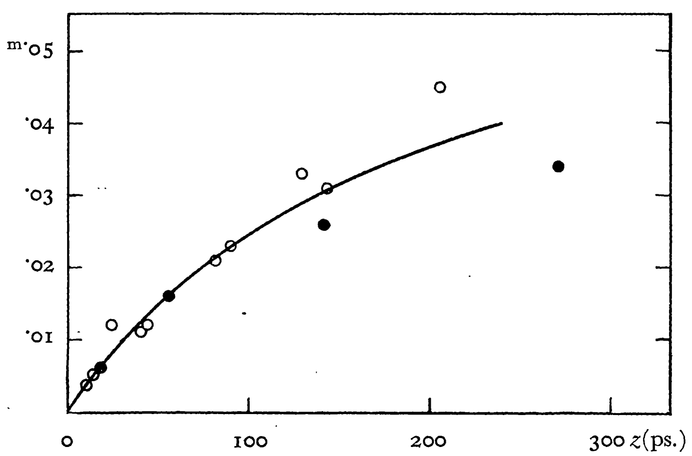
[2]) *B.A.N.* IV, No. 132 (1927).

association between the Ca clouds and the absorbing clouds, a fact upon which several investigators have already commented [1]).

From the corrected color-excesses and distances of the groups of stars for which $\bar{z}$ is less than 60 parsecs the average coefficient of absorption per 1000 parsecs is found to be $^{\mathrm{m}}{\cdot}30$ for the region up to 800 parsecs distance (Table 4), and $^{\mathrm{m}}{\cdot}35$ for the region within 350 parsecs (Table 5); the latter value depends to a considerable extent upon the zero-point correction, and is thus rather uncertain. The two values are about the same as the average galactic absorption coefficient found by STEBBINS and HUFFER by means of distances derived from assumed values of the absolute magnitudes. In this case no zero-point correction was applied.

The accompanying Figure 2 shows a plot of the values $\bar{E}_{\mathrm{corr.}} \sin \bar{b}$ against $\bar{z}$, as deduced from Table 4 (dots) and Table 5 (circles). The ordinates in this figure thus represent the average color absorption for rays passing perpendicularly to the galactic plane from a distance z down to this plane, the average being taken over all rays filling the semi-cylinder covered by the observations. The derivative of the curve represents the variation of the average density of the absorbing material with distance from the galactic plane. It is to be noted that in calculating the point at $\bar{z} = 206$ the one exceptionally red star to which I have referred in the notes to Table 5 has been rejected. This point, as well as that for $\bar{z} = 272$, rests on a rather small number of stars. For this reason the value of $\bar{z}$ for the latter group is especially uncertain; it is likely that it has been estimated somewhat too large.

FIGURE 2.



Selective absorption suffered by rays passing from z to the galactic plane in a direction perpendicular to this plane.

Dots represent averages for the region within about 800 parsecs from the sun and between roughly 0° and 200° longitude, while circles refer to the region within 350 parsecs and between the same longitudes.

It appears from the figure that for z above 150 parsecs the density of absorbing clouds is only a fraction of that near the galactic plane; the galactic concentration of the diffusing material would appear to be of the same order as that of the typically galactic objects, like O- and B-type stars, open clusters, δ Cephei variables, etc. The average optical thickness of the layer between $z = 0$ and $z = 200$ is roughly $^{\mathrm{m}}{\cdot}036$. With a minimum factor of $5{\cdot}5$ for reducing this amount to total photographic absorption (see the next section) the latter comes out $^{\mathrm{m}}{\cdot}20$, that is, about two thirds of the optical thickness $^{\mathrm{m}}{\cdot}31$ found from the nebular counts in the same longitudes.

It will be clear that, mainly on account of the uncertainty of the normal colors, the uncertainty of these results is considerable. But even if we suppose that the absorption for the stars from which these normal colors were derived is only half the average, and that, in consequence, the zero-point correction would be $+\,^{\mathrm{m}}{\cdot}034$ instead of $+\,^{\mathrm{m}}{\cdot}049$, the optical thickness calculated would not decrease by more than 1/6th of its amount.

The optical thickness may also be estimated in a slightly different manner. The color-excesses show that for the region studied the average absorption in the galactic plane is at least $5{\cdot}5$ times $^{\mathrm{m}}{\cdot}32$ or $1^{\mathrm{m}}{\cdot}76$ per 1000 parsecs, this value depending only to a slight extent upon the correction applied to the zero-point of the color-excesses. Estimating the half thickness of the layer of absorbing clouds at 100 parsecs as a minimum, which seems conservative, the photographic half thickness comes out as at least $^{\mathrm{m}}{\cdot}18$.

It should be stressed that the values found represent at best averages for a large region, and that the actual distribution, both of the absorbing material and of the B-stars, is extremely uneven, so that it is by no means certain that the values derived also apply to the average of the regions studied for the star counts. Remembering these limitations we may nevertheless conclude that the results from the B-star colors are in good harmony with those found from the colors of stars in the Selected Areas. They tend to confirm the inference that at least large part of the absorbing layer observed in the nebular counts lies within a few hundred parsecs of the galactic plane.

It should be noted that somewhat different results have recently been published by STEBBINS and

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[1]) For a further discussion concerning the problem of the apparent lack of galactic concentration of interstellar calcium see *Annales d'Astrophysique* I, No. 1, pp. 79–82 (1938).

WHITFORD[1]), who derive a semi-thickness of only $+{}^{\rm m}\!\cdot\!007$ from the colors of B-type stars in various latitudes; the color scale is the same as that used in the Washburn catalogue just considered. As the authors do not give the detailed data on which this determination rests it is difficult to trace the origin of the large difference with the results found above. Large part is probably due to the fact already pointed out by STEBBINS and WHITFORD, that the B-stars selected are not sufficiently distant to be outside the absorbing layer. As this will be especially true for the stars in moderate and low latitude a representation by a formula $E = \alpha + \beta \operatorname{cosec} b$ may yield a negligible value for β even in the case of a strong absorbing layer.

STEBBINS and WHITFORD give also values for the color absorption shown by extra-galactic nebulæ at various latitudes, and also by globular clusters. Reduced to the color scale used for the B-stars the values found from the former correspond to a semi-thickness of ${}^{\rm m}\!\cdot\!017 \pm {}^{\rm m}\!\cdot\!005$ (p.e.) of the layer, those for the latter to ${}^{\rm m}\!\cdot\!013 \pm {}^{\rm m}\!\cdot\!009$ (p.e.), both considerably smaller than the values found from the colors in Selected Areas and from the above considerations concerning the B-type stars. The low result for the clusters is entirely due to the limitation to clusters above 20° latitude, and by the exclusion of clusters in the zones of partial obscuration. Using the complete data on colors of globular clusters published by STEBBINS and WHITFORD[2]) I find a semi-thickness of ${}^{\rm m}\!\cdot\!054 \pm {}^{\rm m}\!\cdot\!004$ (p.e.) from 52 clusters below 30° latitude. The result from the nebulæ is of rather greater weight, and I see no good way of explaining the difference between this and the result obtained from the Selected Area colors[3]). A small selection factor may have entered, as the Selected Areas are distributed at random, while specific objects, such as nebulæ or B-stars, must show some preference for the most transparent regions; but this effect cannot be very large[4]).

One important conclusion can be drawn with considerable certainty from the colors of nebulæ and clusters, namely, that the total amount of reddening material above the distances z reached by the B-stars and by the stars in the Selected Areas must be negligible: all the reddening material in the galactic system is thus seen to be closely confined to the immediate vicinity of the galactic plane.

It is of some interest to compare the average coefficient of absorption in the galactic plane as deduced in the present section from the Washburn colors with another determination applying to a large region of space, namely, that made by ZUG by means of colors in 23 open clusters[5]). ZUG's final solution gives ${}^{\rm m}\!\cdot\!36 \pm {}^{\rm m}\!\cdot\!04$ for the absorption per 1000 parsecs, but this value requires two corrections before it can be compared with that derived from the B-type stars. In the first place the scale of TRUMPLER's original distances[6]) which were used by ZUG, is much too large. TRUMPLER used a general photographic absorption of ${}^{\rm m}\!\cdot\!65$ per 1000 parsecs to correct his distances; if we use the more plausible value of $1^{\rm m}\!\cdot\!5$ per 1000 parsecs the distances of ZUG's more distant clusters are reduced to about half their original values[7]). Reducing the distances with this larger value of the absorption, and representing the corrected data by ZUG's formula $E = a + br$, I find, roughly, $b = +{}^{\rm m}\!\cdot\!69 \pm {}^{\rm m}\!\cdot\!10$ (p.e.) (the 6 clusters for which no photometric distances were available being excluded); this result applies to a region extending to roughly 1200 parsecs from the sun. In order to compare this result with that obtained from the B-stars it must be reduced to the same color system. In ZUG's system the difference in color between A0- and K0-giants is $1^{\rm m}\!\cdot\!21$; in order to reduce to STEBBINS and HUFFER's system the color-excesses should be multiplied by about ·50, so that we finally obtain ${}^{\rm m}\!\cdot\!34 \pm {}^{\rm m}\!\cdot\!05$; this agrees well with the values of ${}^{\rm m}\!\cdot\!30$ and ${}^{\rm m}\!\cdot\!35$ found from the B-stars.

5. *The ratio of general absorption to color-excess.*

Let us denote by $A_{\rm pg}$ the total absorption in photographic light, by $E_{\rm c}$ the differential absorption between the effective wavelengths 4400 and 5500 A., or the color-excesses on the international scale; let

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[1] "Photoelectric magnitudes and colors of extragalactic nebulæ", *Ap.J.* **86**, 267, 268 (1937); *Mt Wilson Contr.* No. 577.

[2] *Ap.J.* **84**, 132 (1936); *Mt Wilson Contr.* No. 547.

[3] The following consideration may give a loop-hole; 18 out of the 45 nebulæ above 27° latitude are concentrated in a region of perhaps 3° radius constituting the central part of the Virgo cluster. The mean color-excess of these 18 nebulæ between 73° and 76° latitude is ${}^{\rm m}\!\cdot\!05$ larger than that for the 12 nebulæ in the division 54° to 69° latitude. It may be, therefore, that the intrinsic colors of the Virgo nebulæ are larger than those of the nebulæ in general. If they are omitted the coefficient of cosec b comes out quite appreciably larger.

[4] In *Publ. of the Kapteyn Laboratory at Groningen* No. 47, p. 33, VAN RHIJN has computed the amount of this effect for Cepheid variables in the galaxy and finds a systematic difference of 20 %. This gives some idea of the order of the differences to be expected.

[5] *Lick Bull.* XVI, No. 454 (1933).

[6] *Lick Bull.* XIV, No. 420 (1930), Table 3, 8th column.

[7] That a reduction of this order is required is also indicated by Miss HAYFORD's work on the differential rotation from radial velocities of open clusters (*Lick Bull.* XVI, No. 448). Her solution (5), which does not include the doubtful higher harmonics, gives $A = +\,\cdot0083$ km/sec. parsec. This is 2·3 times smaller than the value adopted in the present paper and thus indicates that TRUMPLER's distances, which were used in computing A, were as much too large.

further E_{St} represent the color-excess in the system used by STEBBINS and HUFFER (effective wavelengths 4260 and 4770 A.). Knowledge of the ratio A_{pg}/E is evidently of the greatest importance in connection with the investigations of the present article. We may distinguish four different ways in which this ratio may be estimated; namely, *a*) from spectro-photometric measures, *b*) from a general comparison of total and selective absorption, *c*) from a similar comparison for dark nebulæ, *d*) by comparing the color of the light diffused by reflection nebulæ with that of the illuminating stars.

a) Spectro-photometric measures.

Because the absorption can never become negative spectro-photometric comparisons of stars reddened by interstellar absorption with normal stars enable us to estimate a lower limit to the general absorption which the photographic light of the reddened star must have suffered. It is evident that we can never obtain more than a lower limit for this absorption, as the eventual presence of non-selective absorption by large particles or free electrons will remain unnoticed. But it will appear that even the information obtainable from these lower limits is of sufficient interest.

The first convincing spectro-photometric measures made in this connection are by TRUMPLER [1]); he measured 4 Bo-stars in two distant open clusters, and found that the relation between absorption and wavelength is practically linear from 3400 to 6300 A. A similar result has been found by practically all later investigators, though measures up to longer wavelengths showed that the absorption could be somewhat better represented by $a + b/\lambda$. In the following we shall therefore adopt the latter relation. The only case, found so far, in which the observations could not be represented by this law is that of a few stars in the Orion nebulæ investigated by BAADE and MINKOWSKI [2]).

Beside for TRUMPLER's two clusters and the Orion stars detailed spectro-photometric measures have been made for the following reddened stars:

	l	b	distance	wavelengths	E_{St}
	°	°			m
ζ Persei [3]) . .	130	− 17	480 ps	3500 to 10000 A.	+ ·17
55 Cygni [4]) .	53	+ 1	1300	4000 „ 6300	+ ·25
h and χ Persei [5])	102	− 4	2000	4000 „ 8000	+ ·28
HD 17088 [6]) .	105	− 2	2000 (?)	3700 „ 10000	—

It is clear that if the curve connecting the absorption with $1/\lambda$ were known for all wavelengths the ratio A_{pg}/E_{St} could be read off at once. But the observations do not reach beyond 10000 A., and we have to extrapolate the rest. In order to make sure that the ratio was not over-estimated I made the rather extreme hypothesis that beyond the longest wavelength observed the absorption begins to decrease in inverse proportion to the 4th power of λ (thus conforming to RAYLEIGH's law). In this case we have

$$A_{pg}/E_{St} = 9{\cdot}04 - 2{\cdot}99/\lambda_1,$$

if λ_1 is the longest wavelength, in microns, up to which the linear relation has been observed. The ratio calculated in this way can hardly be over-estimated, the amount of absorption beyond 10000 A. being only 15% of the total photographic absorption.

For $\lambda_1 = 10000$, as in ζ Persei and HD 17088, we thus find a minimum ratio of 6·0; for $\lambda_1 = 8000$, as in h and χ Persei, we get 5·3. These figures refer to only three special cases, and though the Perseus clusters are very distant the values might not be representative for the majority of the stars. This holds especially for ζ Persei, which is situated at a relatively high galactic latitude and appears to owe its reddening almost exclusively to the influence of the dark nebula in Taurus. However, HALL has measured photo-electric color-indices in the extreme red which permit a very general confirmation of the results obtained [7]). HALL's data refer to the effective wavelengths 6110 and 8000 A.; he has measured the difference in intensity between these two wavelengths as well as the red magnitudes at 8000 A. The material comprises 19 stars of STEBBINS and HUFFER's catalogue, 9 of fairly normal color and 10 showing strong reddening. Comparing the red magnitudes with the Harvard visual magnitudes HALL obtains another measure for the colors of his stars. For the 10 stars in question we have thus three measured differences of intensity. The average results are as follows:

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[1]) *P.A.S.P.* **42**, 267 (1930).

[2]) *Ap.J.* **86**, 123 (1937); *Mt Wilson Contr.* No. 572.

[3]) KIENLE, *M.N.* **88**, 700 (1928); STRUVE, KEENAN and HYNEK, *Ap.J.* **79**, 1 (1934); JESSIE RUDNICK, *Ap.J.* **83**, 394 (1936); HALL, *Ap.J.* **85**, 145 (1937). The latter combines his own measures with a general discussion of all previous observations and shows that from 3700 to 10500 A. the absorption can be well represented by a formula of the form $a + b/\lambda$.

[4]) JESSIE RUDNICK, l.c.

[5]) BAADE and MINKOWSKI, l.c. and HALL, l.c. (see Figure 3 of the present article).

[6]) WHITFORD, *Publ. Am. Astr. Soc.* **9**, 138 (1938).

[7]) *Ap.J.* **85**, 145 (1937).

Data		λ_2	λ_1	$1/\lambda_2$	$1/\lambda_1$	$\overline{E}$
						m
Stebbins and Huffer	(E_{St})	4260	4770	2·347	2·096	+ ·260
Hall	(E_H)	6110	8000	1·64	1·25	+ ·365
Hv—Hall red magnitude	(E_m)	5020 [1]	8000	1·99	1·25	+ ·921

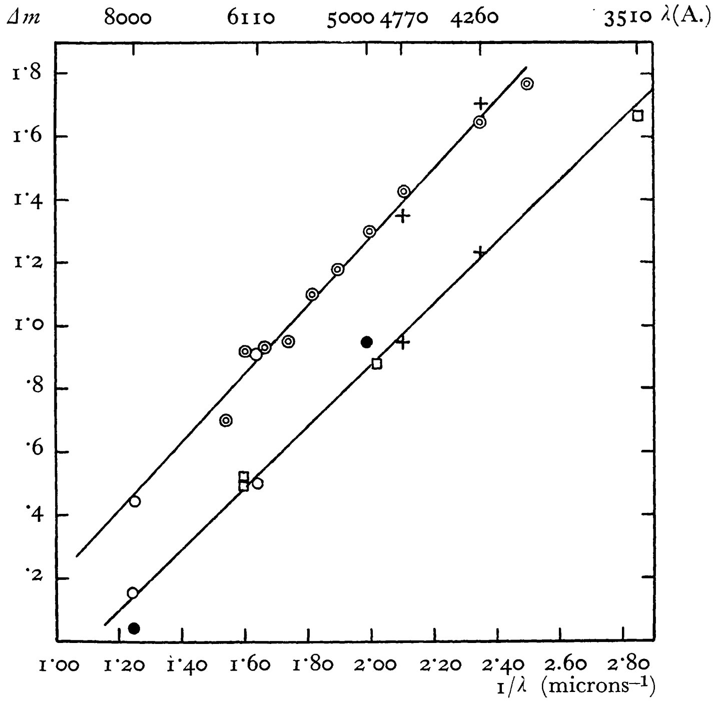
In Figure 3 a linear relation between Δm and $1/\lambda$ has been fitted to the two first gradients (shown by crosses and circles respectively); they are seen to agree very well. The third colorequivalent, shown by dots, which is much more uncertain than the former two, is also much less accordant. It is interesting to note the inter-agreement of the ratio E_H/E_{St} for the various stars; the average deviation from the mean ratio 1·40 is only ± ·12, indicating that the law connecting absorption and wavelength differs very little from star to star. In a private letter Prof. van Rhijn has remarked that, though it has been shown that E_{St} does not vary with the absolute magnitude, it is still possible that such a variation might exist for the color-equivalents extending over larger intervals of wavelength and that this effect might invalidate our present conclusions. However, a closer investigation shows that this is not very probable; for, in the first place, I do not believe that there is considerable difference in absolute brightness between the 9 standard stars and the 10 colored stars, and, in the second place, neither the standard stars nor the colored stars show an appreciable variation of either E_H or E_m with spectral type.

Quite recently additional data have been published by Greenstein [2]), who has made spectro-photometric measurements between 3500 and 6250 A. for a considerable number of stars, including 38 B-stars of the Washburn catalogue which showed considerable reddening. The magnitude differences corresponding to Greenstein's gradients $\Delta\varphi_{1-4}$ and $\Delta\varphi_{1-9}$ for the 3 stars also observed by Hall have been entered in the lower part of Figure 3 (squares), after being reduced, with the aid of the Washburn color-excesses, to the mean of the 10 stars observed by Hall.

It will be seen from the figure that the 10 stars in question, which may be considered as more or less representative of the average conditions for distant stars in the galaxy, give a good confirmation of the linear variation of Δm with $1/\lambda$ up to the limit of observations at 8000 A. The minimum value of A_{pg}/E_{St} which may be derived from these data is again 5·3.

If we combine all results the minimum factor 5·5 adopted in the preceding section for transforming the Washburn color-excesses into photographic absorption appears to be on the safe side. The corresponding factor for color-excesses on the international scale is 3·1.

Figure 3.



Spectro-photometric data extending into the infra-red. Lower line: average for the 10 colored B-stars observed by Hall. Upper line: stars in h and χ Persei. Circles represent E_H, crosses E_{St}, dots E_m, double circles the observations of Perseus stars by Baade and Minkowski. The squares represent mean magnitude differences corresponding to Greenstein's $\Delta\varphi_{1-4}$ and $\Delta\varphi_{1-9}$; these were available for only 3 out of the 10 stars observed by Hall, but they were reduced to the mean of the 10 by multiplication by the ratio of $\overline{E}_{St}$ for the 10 stars to $\overline{E}_{St}$ for the 3 stars.

Should it prove possible to extend similar spectro-photometric investigations still farther into the infra-red this would be extremely valuable for a better determination of these ratios, which are undoubtedly among the most important quantities for the study of galactic structure.

Greenstein observes that $\Delta m = k/\lambda^{0\cdot 8}$ appears to fit his observations a little better than the linear relation with $1/\lambda$; but this is of very little consequence for the present considerations. He also gives a provi-

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[1]) Hall used 5500 for the effective wavelength of the Harvard visual magnitudes. This seems much too large. The present value has been taken from a paper by Wesselink, *B.A.N.* VII, No. 265, Table 2, who finds 5070 for the average effective wavelength of the Harvard visual system. For the present material consisting of B-type stars the effective wavelength will be about 50 A. smaller than the average.

[2]) *Ap.J.* **87**, 151 (1938).

sional estimate of the ratio E_c/A_{pg} (which he denotes by ε) by assuming that the linear relation holds for all wavelengths. The result is 0·17, corresponding to $A_{pg}/E_{St} = 11$, but this rests, admittedly, on a large and quite hypothetical extrapolation.

b) Comparison of total and selective general absorption.

GREENSTEIN adds another, less hypothetical determination of the ratio E_c/A_{pg}; for this he starts from the conception, which is to some extent supported by his results, that the coloring of his stars is mainly due to one or more concentrated dark clouds, and that it is possible, therefore, to determine the photographic absorption by comparing star counts in the region of the reddened star to counts in near-by regions which are not affected by the irregular clouds. Adding a "general" absorption of $0^{m}{\cdot}5$ per 1000 parsecs (which is, of course, very uncertain) he finds from 34 reddened stars $\varepsilon = E_c/A_{pg} = {\cdot}26 \pm {\cdot}02$ (p.e.). As $E_c/E_{St} = 1{\cdot}81$, the corresponding ratio $A_{pg}/E_{St} = 7{\cdot}0$. There are many uncertain factors in this determination; nevertheless, it is interesting to remark the close approach between this result and the minimum value 6·0 found above by means of the stars investigated up to $\lambda = 10000$ A.

Another, and more direct estimate of the ratio of total to selective absorption may be obtained by comparing the O—B2-stars in low galactic latitude with those in high latitude, or else, with bright stars of the same spectral types. Assuming that for each sub-type the average absolute magnitudes are equal for stars at low and high galactic latitude I found from all O—B2-stars between $4^{m}{\cdot}5$ and $7^{m}{\cdot}5$ $A_{pg}/E_{St} = 10{\cdot}7 \pm 2{\cdot}8$ (p.e.); stars for which no interstellar velocities had been published were excluded in this determination. The uncertainty is mainly due to the distances, which were calculated from radial velocities. Using distances derived from the Victoria estimates of the intensity of the interstellar K-line (omitting all stars for which less than 2 Victoria plates were available) I found the following ratios: O-stars, $10{\cdot}2 \pm 1{\cdot}9$ (p.c.); B0, $9{\cdot}6 \pm 1{\cdot}0$ (p.e.); B1—2, $7{\cdot}2 \pm 1{\cdot}1$ (p.e.). The last value is somewhat uncertain; if we give weights one half to this and to the first value the weighted average is $9{\cdot}2 \pm {\cdot}7$ (p.e.). Should the true mean absolute magnitude of the high-latitude stars be fainter than that of the low-latitude stars the ratio would become still higher.

Comparing the stars fainter than $4^{m}{\cdot}5$ and below 5° latitude with stars brighter than $4^{m}{\cdot}5$ and of all latitudes, and assuming again that the average absolute magnitude for each sub-type is equal for the two groups, I found an average value of 6·9 for the same ratio. The mean distances for the faint stars were derived from radial velocities, those for the bright stars from proper motions, but they are uncertain, so that the determination has a low weight.

By far the most trustworthy determination of the average photographic absorption in the galaxy appears to be that determined by JOY with the aid of faint Cepheids [1]). JOY has determined radial velocities of a considerable number of faint δ Cephei variables [2]), and has used these to determine average distances from the effects of differential galactic rotation. The intrinsic absolute magnitudes being known by the period-luminosity relation he could derive the average photographic absorption in the galactic plane, for which he found a value of $0^{m}{\cdot}85$ per 1000 parsecs.

It is interesting to compare this with the average value, ${}^{m}{\cdot}32$, found for the coefficient of color-absorption on the Washburn scale (p. 244). As shown above, there is rather strong evidence that the factor by which this should be multiplied in order to reduce to photographic absorption must be *at least* 5·5, so the photographic absorption would be at least $1^{m}{\cdot}8$ per 1000 parsecs, instead of ${}^{m}{\cdot}85$ as found by JOY. It is true that JOY's value may not be quite representative for the Milky Way in general, as faint Cepheids may preferently have been found in bright parts, but according to VAN RHIJN [3]) allowance for this effect would not give an increase of more than 10%. If we assume that the neglection of absorption in the computation of the zero-point of the period-luminosity relation used has made this zero-point $0^{m}{\cdot}5$ too faint, JOY's value would be further increased to about $1^{m}{\cdot}2$ per 1000 parsecs. This remains considerably below the minimum value derived from the B-type stars. Inversely, if the comparison of JOY's results with those from the B-stars is accepted as correct, it appears to lead to a very small value (about 3·8) for the ratio A_{pg}/E_{St}, which seems irreconcilable with the spectro-photometric results and the other values quoted above. As JOY's absorption coefficient is largely determined by his two farthest groups, at mean distances of 1800 and 2400 parsecs, the most direct explanation would be that at distances beyond 800 parsecs the average absorption becomes much smaller than within that distance; but other explanations are, of course, possible. In this connection the results of the color determinations which are being carried out by OOSTERHOFF will probably yield very valuable information, as these will furnish the necessary data for a direct and reliable determination of

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[1]) *P.A.S.P.* **45**, 202 (1933).

[2]) *Ap.J.* **86**, 363 (1937); *Mt Wilson Contr.* No. 578.

[3]) *Publ. of the Kapteyn Laboratory at Groningen*, No. 47, pp. 5–11 (1936).

the ratio of photographic to differential absorption for these stars.

c) Dark nebulæ.

Much more certain information concerning the ratio of photographic to color absorption may be obtained from special investigations of regions with well-defined dark nebulæ. SCHALÉN has been the first to publish an apparently successful determination of the change of color produced by such nebulæ [1]). For a dark cloud in Auriga he finds the total photographic absorption as $1^m\cdot9$, while the color-excess caused by the same cloud is determined at $^m\cdot21 \pm {}^m\cdot02$ (p.e.). The effective wavelengths used are 3950 and 4400 A., so that the interval in $1/\lambda$ is ·259 (λ measured in microns), which is practically the same as for the effective wavelengths used by STEBBINS and HUFFER; we may thus denote SCHALÉN's color-excesses by E_{St}, and we find $A_{pg}/E_{St} = 1\cdot9/\cdot21 = 9\cdot0$. A similar, but much less certain, determination in Cepheus (SCHALÉN's two nebulæ being combined) yields $A_{pg}/E_{St} = \cdot9/\cdot07 = 13$. This same general region has likewise been investigated by STICKER [2]) and by BERG [3]). The former finds a total photographic absorption of $0^m\cdot5$ for the dark nebula and a color absorption of $0^m\cdot2$. The effective wavelengths used are 4460 and 6360; reducing again to the same interval in $1/\lambda$ as in the Washburn measures we get $A_{pg}/E_{St} = 6\cdot7$. BERG assumes again two clouds; the combined absorption of the two clouds is found to be $2^m\cdot0$, the selective absorption (photographic minus photovisual) $^m\cdot51$. Reducing the color-excesses to the Washburn scale we find 7·2 for the ratio A_{pg}/E_{St}. The differences between the results of the three investigations, especially with respect to the total amount of absorption, illustrate the difficulties of these investigations.

As will be shown in another paper STEBBINS and HUFFER's color-excesses permit a very good determination of the amount of color absorption caused by the Taurus nebulæ in the region from 125° to 155° longitude and from $-10°$ to $-20°$ latitude. On account of the relatively high latitude and the consequent small effect of *general* space absorption the results in this region seem to be entitled to much confidence. The color absorption found from the 14 stars behind the nebula is $+ {}^m\cdot090 \pm \cdot005$ (p.e.). This is to be compared with the total photographic absorption as found from counts of extra-galactic nebulæ in this region ($1^m\cdot0$), or from star counts ($1^m\cdot3$). The resulting average ratio A_{pg}/E_{St} is thus 13 for this region.

HELMUT MÜLLER and HUFNAGEL [4]) have estimated that in the region of the North America nebula the selective absorption is from 15 to 20% of the total absorption, corresponding to a ratio A_{pg}/E_{St} of about 10. BRÜCK's measures [5]) indicate a minimum ratio of about 6 in the region of the Coal Sack. From the extensive data by CLIFFORD E. SMITH on spectra and colors in the regions inside and surrounding the great rift in Aquila [6]) I have estimated that for stars of the 13th magnitude inside the rift compared with stars at the same average distance outside the rift the total and selective absorption ($\lambda_{eff.}$ 4150 and 5950) are $2^m\cdot7$ and $^m\cdot85 \pm {}^m\cdot08$ respectively, corresponding to a ratio $A_{pg}/E_{St} = 9\cdot3$.

Except for the near-by Auriga and Taurus nebulæ these results are all more or less tentative; yet, they appear to agree in showing that for dark nebulæ the selective absorption, reduced to the Washburn scale, is only a small fraction of the total absorption: the average ratio A_{pg}/E_{St} may perhaps be estimated as 9. The question arises, however, whether the results obtained in this way for concentrated dark nebulæ would be applicable also to interstellar space in general. In the case of ζ Persei, which star probably owes its red color mainly to the Taurus nebulæ, the relation between absorption and wavelength was found to be the same as that found for the stars in general; so that, at least for the spectral region investigated, no difference between the concentrated dark nebula and general space appeared to be indicated. But, on the other hand, the adoption of a ratio as high as 9 for general space would lead, in combination with the coefficient of selective absorption found from B-stars, to a value of the coefficient of absorption amounting to nearly 3 magnitudes per 1000 parsecs, which seems impossible to admit in view of other data (especially those derived from the Cepheids). A difference in the constitution of dense nebulæ and general interstellar clouds would therefore seem to be indicated. If this conclusion be accepted it would necessarily follow that the discrete dense clouds can account for only part of the galactic absorption observed in faint B-stars.

d) The colors of reflection nebulæ.

If the process by which light is weakened when passing through a dark nebula were a pure scattering phenomenon it would be possible to derive the ratio between photographic and selective scattering from the differences in color between reflection nebulæ and their illuminating stars. These color differences have been observed by STRUVE, ELVEY and KEENAN

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[1]) *Upsala Medd.* No. 58 (1934).

[2]) *Veröff. Bonn,* Heft 30 (1937).

[3]) *Bull. Poulkovo* XV, Fasc. 2 (1936).

[4]) *Zs. f. Ap.* **9**, 331 (1935).

[5]) *Zs. f. Ap.* **8**, 75 (1934).

[6]) *Lick Bull.* XVIII, No. 484 (1937).

for the Pleiades[1]), and by COLLINS[2]) for 7 other nebulæ, and have always been found much smaller than the values to be expected in case of Rayleigh scattering. From the mean observed difference in color I find $A_{\mathrm{pg}}/E_{\mathrm{St}} = 13{\cdot}8$, thus again a very large value; but, as it is doubtful whether the scattering theory of the process is adequate, not too much weight should be attached to this estimate.

6. *The distribution of density in the galactic system.*

It is apparent from sections 3 and 4 that in all probability a considerable fraction, if not all, of the absorption derived from the counts of nebulæ must take place within a relatively small distance from the galactic plane. In the present section we propose to investigate the density distribution resulting if we assume that the entire absorption found from the nebulæ takes place in front of the stars considered.

This density distribution has been investigated by studying the differences between the star counts in the Selected Areas and the numbers of stars to be expected if the surfaces of equal density were parallel to the galactic plane. As indicated in a previous paper[3]) the computations can be made with the aid of geometrical considerations involving no knowledge of luminosity function or distance distribution.

Let us assume that the equidensity surfaces are parallel to the galactic plane, and let us consider stars of magnitude m at galactic latitude b. It is clear that, except for a difference in the scale, these stars must show the same distribution in distance as stars of magnitude m_{90} near the poles of the Milky Way, where m_{90} is defined as follows

$$m_{90} = m + 5 \log \sin b - \Delta a, \tag{1}$$

Δa representing the difference between the absorption suffered by the light of stars at latitude b and that for stars at the galactic pole. The scale of distances for the stars at latitude b is, however, $1/\sin b$ times larger than that for the corresponding stars at the galactic poles; consequently, the number of stars per square degree, $A(m,b)$, will be $1/\sin^3 b$ times larger. So we have the relation

$$A_{\mathrm{b}}(m) = \frac{1}{\sin^3 b} A_{90}(m_{90}). \tag{2}$$

By means of formulæ (1) and (2) the "expected" numbers of stars at any latitude can at once be computed from the star counts near the poles of the Milky Way as soon as the quantity Δa is known. For each Selected Area the latter has been derived from HUBBLE's spiral-nebula counts in surrounding fields (see section 2).

The density distribution was investigated separately for five layers on each side of the galactic plane and parallel to it, each layer being made up of stars corresponding to a given value of m_{90}. The values of m_{90} used and the logarithmic average distances, z_0, from the galactic plane are shown in Table 6; the values z_0 were taken from *B.A.N.* No. 290, p. 90, those for $16^{\mathrm{m}}{\cdot}0$ and $17^{\mathrm{m}}{\cdot}0$ being extrapolated.

TABLE 6.
Logarithmic mean distances of the layers studied from the galactic plane.

m_{90}	z_0 (parsecs)
10·0	173
12·0	316
14·0	574
16·0	1040
17·0	1410

For part of the stars in the first layer the absorption will be only a fraction of the total absorption in the direction considered, and the absorption values applied will thus be slightly too large. The true distribution of the absorbing material not being known with any accuracy I have not tried to correct for this.

The star densities for various points in these layers were now computed in the following manner.

With the aid of VAN RHIJN's tables[4]) values of log $A(m)$, $A(m)$ representing the number of stars per square degree between $m - \frac{1}{2}$ and $m + \frac{1}{2}$, were calculated, and for each Selected Area smooth curves were drawn through the points obtained. For the areas below 50° latitude the curves finally used are determined almost entirely by the *Mount Wilson Catalogue of Selected Areas* and the *Harvard–Groningen Durchmusterung* reduced to SEARES' system of magnitudes, which in most cases yield significant points from $12^{\mathrm{m}}{\cdot}5$ down to $17^{\mathrm{m}}{\cdot}5$. The counts for the brighter stars were, in general, plotted only in those cases where it was necessary to read off the curves at magnitudes brighter than 12. A small systematic correction was applied to the magnitudes of the bright stars, in connection with the fact that VAN RHIJN had derived the numbers of stars brighter than

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[1]) *Ap.J.* **77**, 274 (1933).

[2]) *Ap.J.* **86**, 529 (1937). See also KEENAN, *Ap.J.* **84**, 600 (1936) and STRUVE, ELVEY and ROACH, *Ap.J.* **84**, 219 (1936).

[3]) *Annales d'Astrophysique* I, No. 1, 71 (1938). The same method has independently been used by M. A. VASHAKIDSE in *Bulletins of the Abastumani Observatory* No. 1, 87 (1937) and No. 2, 109 (1938) in a discussion of the apparent distribution of stars of known spectral types.

[4]) *Publ. Kapteyn Astr. Laboratory at Groningen* No. 43, Table I (1929).

10·5 from star counts according to visual magnitude. More recent determinations [1]) of the color-indices corresponding to the various spectral classes come out somewhat smaller than those adopted by VAN RHIJN [2]). The determination of these standard colors is an intricate matter, complicated by the selective interstellar absorption; provisionally, a correction of $-^{\mathrm{m}}\cdot20$, as derived from an unpublished discussion by Mr VELDT, has been applied to VAN RHIJN's photographic magnitudes between 6^{m} and 11^{m} for the high latitude areas. It should be noted that the uncertainty in the reductions from visual to photographic magnitude must be reflected in the results for the layer corresponding to $m_{90} = 10$.

In order to derive, for a given layer, the deviations from a simple plane-parallel distribution of density the $A(m)$-curves were now read off at $m = m_{90} - 5 \log \sin b + \Delta a$, inserting for m_{90} the fixed value corresponding to the layer investigated. Differences were then formed between the "observed" results $\log A_{b}(m)$ so obtained and the "expected" values $\log A_{90}(m_{90}) - 3 \log \sin b$ corresponding to the case of equi-density surfaces parallel to the galactic plane, $\log A_{90}(m_{90})$ being read off the curve in Figure 4. These differences, observed minus computed, may be found in the columns $\Delta \log A(m)$ of Table 8.

The standard curve for $\log A(m)$ at the Milky Way poles, $\log A_{90}(m)$, shown in Table 7 and Figure 4, has been derived from the mean of the areas above 50° latitude. The observed values read off the smooth $\log A(m)$-curves for each area were compared with values computed by formulæ (1) and (2) with the aid of preliminary estimates for $A_{90}(m)$, neglecting the differences of absorption. The final curve for $\log A_{90}(m)$ was so adjusted that the average of the computed values of $\log A(m)$ was equal to the average of the observed values for the areas above 50° latitude. Areas south of the $-15°$ zone of declination were omitted in this discussion, because SEARES and VAN RHIJN have pointed out the existence of rather serious systematic magnitude errors for these areas. The adjusted values of $\log A_{90}(m)$ are shown in the lower half of Table 7, for the northern and southern polar cap separately, the numbers of areas on which each value rests being added between parentheses;

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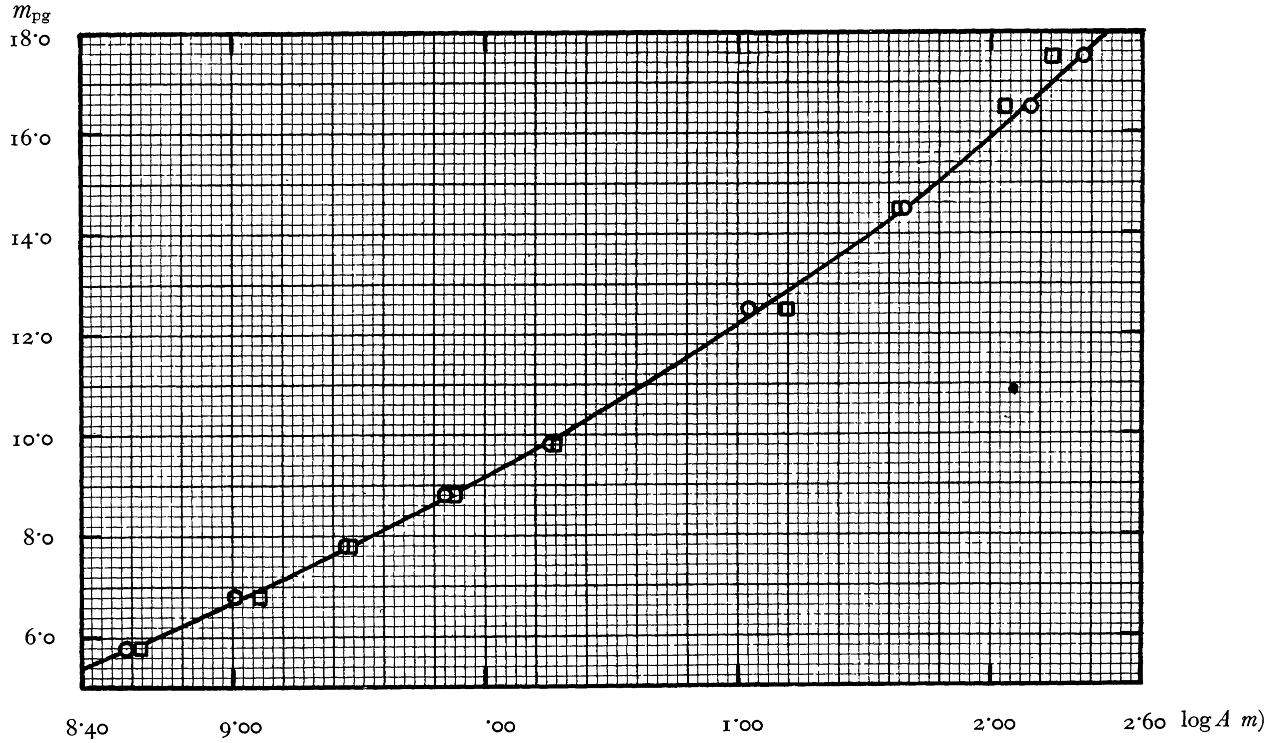
1) Cf. SEARES, *Trans. Int. Astr. Union*, IV, 137 (1932).
2) L.c. p. 3, Table B.

FIGURE 4.



Standard curve for the logarithm of the number of stars per square degree and between $m-\frac{1}{2}$ and $m+\frac{1}{2}$ at the galactic poles. Circles have been derived from the region surrounding the north galactic pole, squares from that surrounding the south pole; the curve represents the weighted mean.

the columns headed "average residual" indicate the arithmetical average of the residuals observed minus computed 1). It should be noted that in order to ensure an approximately symmetrical distribution with respect to the galactic centre the areas in the southern polar cap with longitudes between 105° and 195° were excluded. The final values in the last column, which have been used for the curve in Figure 4, were obtained by combining the results for the northern and southern cap with weights equal to the numbers of areas used; the probable errors in this column have been derived from the residuals of the individual areas, and take account, therefore, of all sources of error except eventual systematic errors in the Polar Sequence, which would be common to all. It will be observed that only in two cases the probable errors exceed ± ·01.

The results for the magnitudes brighter than 10, in the upper half of the table, have been obtained in a similar way, except that values of log A (m) directly calculated from the numbers given in Table I, *Groningen Publication* No. 43, were used instead of smooth curves, and that the areas south of −15° declination were included, so that the results for −90° rest on *all* areas between −50° and the south galactic pole.

A comparison of the values for the northern and southern polar cap in Table 7 and in Figure 4 (in which the points derived for each polar cap have been indicated separately) shows that the agreement between these two regions is quite satisfactory, the differences appearing to be largely of accidental nature. In the case of the faint stars the small number of southern areas renders the comparison somewhat uncertain; the number of southern areas may be nearly doubled by including in a similar way the 4 Mount Wilson areas between −40° and −50° latitude (again excluding the quadrant from 105° to 195° longitude). The average values for log $A_{90}(m)$ as derived from these 9 areas differ very little from those for the 5 areas in the table. For $12^{\rm m}$·5 the difference between the results for the 9 areas and for the 5 areas is −·07, for $14^{\rm m}$·5 it is ·00, for $16^{\rm m}$·5 and $17^{\rm m}$·5 + ·03.

TABLE 7.

Logarithms of numbers of stars at the galactic poles, per square degree and between $m-\frac{1}{2}$ and $m+\frac{1}{2}$, derived from areas between ± 50° and ± 90° latitude.

$m_{\rm pg}$	$b = +90°$		$b = -90°$		Adopted	
	log $A(m)$	average residual	log $A(m)$	average residual	log $A_{90}(m)$	p.e.
5·8	8·58 (25)	± ·160	8·63 (24)	± ·147	8·60	± ·019
6·8	9·01 ,,	± ·094	9·11 ,,	± ·084	9·06	± ·011
7·8	9·45 ,,	± ·050	9·47 ,,	± ·058	9·46	± ·007
8·8	9·84 ,,	± ·037	9·89 ,,	± ·046	9·86	± ·005
9·8	0·26 ,,	± ·047	0·28 ,,	± ·045	0·27	± ·006
12·5	1·04 ,,	± ·075	1·19 (5)	± ·061	1·07	± ·012
14·5	1·66 ,,	± ·049	1·64 ,,	± ·032	1·66	± ·007
16·5	2·16 ,,	± ·087	2·06 ,,	± ·068	2·14	± ·013
17·5	2·37 ,,	± ·121	2·25 ,,	± ·083	2·35	± ·018

The results in Table 8 have been arranged according to the galactic latitudes of the Selected Areas. The table contains all areas outside HUBBLE's zone of avoidance in the zones from −15° declination to the north pole; a few areas within the zone of avoidance but above 10° latitude have been added. Of the areas in the zone −30° only those between ± 10° and ± 35° latitude were included; the results for this zone are especially uncertain, because it is situated

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1) The smallness of these residuals illustrates the great accuracy of the Mount Wilson magnitude scales and zero-points.

TABLE 8.

S.A. No.	l	b	x_0/z_0	y_0/z_0	Δa	Δ log $A(m)$ and $d(\Delta \log A)/d(\Delta a)$					$m - m_{90}$
						$m_{90} = 10$ $z_0 = 173$	$m_{90} = 12$ $z_0 = 316$	$m_{90} = 14$ $z_0 = 574$	$m_{90} = 16$ $z_0 = 1040$	$m_{90} = 17$ $z_0 = 1410$	
						Areas at northern galactic latitudes					
	°	°			m						m
57	30	84	+ ·05	+ ·10	− ·05		+ ·02: ·32	+ ·07 ·26	− ·04 ·16	− ·14 ·08	− ·04
56	163	80	− ·17	− ·06	− ·04		+ ·06 ·26	− ·03 ·26	− ·02 ·26	+ ·02 ·26	·00
80	240	76	+ ·02	− ·25	− ·04		− ·02: ·28	− ·06 ·26	− ·04 ·26	− ·01 ·23	·02
81	301	75	+ ·25	− ·11	− ·04		+ ·03 ·30	+ ·02 ·27	+ ·03 ·21	+ ·01 ·18	·04
55	166	74	− ·27	− ·10	− ·04			− ·10 ·33	− ·14 ·15	− ·24 ·10	·04
58	12	72	+ ·22	+ ·23	− ·03		+ ·08 ·27	+ ·05 ·27	+ ·04 ·22	+ ·03 ·19	·08
32	84	72	− ·16	+ ·28	− ·03		− ·21: ·36:	− ·09 ·36	− ·02 ·22	− ·06 ·15	·08
31	123	68	− ·37	+ ·15	− ·03		− ·08 ·30:	− ·09 ·28	− ·04 ·27	·00 ·26	·13
33	57	67	− ·01	+ ·42	− ·02		− ·05 ·33:	+ ·02 ·32	+ ·15 ·31	+ ·24 ·29	·16
79	208	67	− ·19	− ·37	− ·02		+ ·09 ·25	+ ·01 ·25	− ·02 ·24	·00 ·23	·16
82	336	65	+ ·46	+ ·09	− ·02		− ·10: ·32	− ·04 ·32	+ ·10 ·32	+ ·20 ·32	·20
104	268	63	+ ·28	− ·43	− ·01		− ·01 ·34	+ ·06 ·30	·00 ·26	+ ·15 ·19	·24
30	135	60	− ·57	+ ·10	·00		− ·03 ·29	− ·03 ·26	− ·10 ·18	− ·16 ·12	·31
54	166	60	− ·54	− ·21	·00		− ·03 ·26	− ·13 ·23	− ·21 ·19	− ·25 ·17	·31
103	244	60	+ ·09	− ·57	·00		+ ·01 ·30	+ ·03 ·29	+ ·05 ·22	+ ·03 ·17	·31
105	295	60	+ ·50	− ·29	·00		− ·03 ·32	+ ·03 ·32	+ ·12 ·28	+ ·17 ·25	·31
59	13	59	+ ·40	+ ·45	·00		− ·09 ·34	+ ·01 ·34	+ ·14 ·30	+ ·20 ·23	·34
34	43	59	+ ·12	+ ·59	·00		+ ·05 ·28	+ ·04 ·28	+ ·07 ·26	+ ·10 ·23	·34
14	81	57	− ·28	+ ·58	·01		− ·15 ·38:	·00 ·34	+ ·07 ·28	+ ·12 ·23	·39
78	192	54	− ·50	− ·53	·02		− ·08 ·30	− ·08 ·28	− ·08 ·23	− ·10 ·17	·48
13	111	53	− ·62	+ ·42	·03		− ·02 ·28	− ·04 ·27	− ·04 ·24	− ·04 ·19	·52
83	347	53	+ ·70	+ ·28	·03		− ·05 ·34	+ ·03 ·32	+ ·14 ·29	+ ·19 ·24	·52
102	221	52	− ·19	− ·76	·03		− ·07 ·37	+ ·07 ·34	+ ·12 ·22	+ ·10 ·14	·55
106	320	51	+ ·81	− ·07	·04		− ·30 ·54	+ ·16 ·38	+ ·16 ·17	+ ·08 ·10	·59
29	141	50	− ·84	+ ·06	·05	− ·01 ·32	− ·03 ·32	·00 ·29	− ·10 ·11	− ·25 ·05:	·63
35	39	49	+ ·24	+ ·84	·05	− ·03 ·33	− ·02 ·33	+ ·07 ·33	+ ·22 ·32	+ ·31 ·28:	·66
15	62	48	− ·11	+ ·89	·06	− ·03 ·35	+ ·01 ·32	+ ·05 ·30	+ ·13 ·27	+ ·14 ·22:	·70
60	15	47	+ ·60	+ ·71	·06	− ·02 ·34	+ ·01 ·34	+ ·10 ·34	+ ·08 ·16	·00 ·08:	·74
53	164	47	− ·88	− ·30	·06	− ·07 ·36	− ·01 ·32	− ·01 ·26	− ·04 ·21	− ·08 ·13	·74
128	260	47	+ ·39	− ·84	·06	+ ·03 ·32	+ ·05 ·31	+ ·08 ·30	+ ·11 ·23	+ ·10 ·16:	·74
129	282	47	+ ·68	− ·63	·06	+ ·05 ·33	+ ·06 ·32	+ ·09 ·27	+ ·05 ·21	+ ·03 ·15:	·74
5	91	42	− ·65	+ ·90	·15	− ·04 ·32	− ·04 ·32	− ·02 ·29	+ ·04 ·26		1·02
127	241	42	+ ·12	− 1·10	·16	− ·01 ·40	+ ·05 ·35	+ ·13 ·29	+ ·10 ·17		1·03
130	299	42	+ 1·00	− ·49	·09	− ·01 ·35	+ ·04 ·34	+ ·13 ·32	+ ·17 ·24	+ ·16 ·14:	·96
12	123	41	− 1·07	+ ·43	·00	− ·10 ·34	− ·09 ·34	− ·02 ·26	− ·24 ·08	− ·42:·04:	·92
101	206	41	− ·56	− 1·01	− ·04	− ·07 ·34	− ·03 ·33	− ·03 ·25	− ·12 ·16	− ·21 ·09:	·88
107	334	40	+ 1·18	+ ·19	·41	+ ·02 ·35	+ ·08 ·35	+ ·17 ·30	+ ·26 ·25		1·37
84	357	40	+ 1·01	+ ·63	·16	+ ·08 ·36	+ ·17 ·36	+ ·28 ·33	+ ·33 ·19	+ ·27:·09:	1·12
36	38	39	+ ·36	+ 1·18	·23	+ ·04 ·35	+ ·08 ·33	+ ·11 ·25	·00 ·13		1·23
28	143	39	− 1·23	+ ·04	− ·10	− ·09 ·34	− ·07 ·31	− ·06 ·26	− ·15 ·16	− ·23 ·09:	·90
77	183	39	− ·97	− ·76	·18	+ ·04 ·36	+ ·06 ·30	+ ·01 ·24	− ·07 ·19	− ·11 ·11:	1·18
6	75	36	− ·47	+ 1·30	·37	+ ·09 ·32	+ ·07 ·31	+ ·10 ·27	+ ·03 ·15		1·53
52	161	35	− 1·37	− ·39	− ·16	− ·12 ·33	− ·10 ·33	− ·07 ·26	− ·20 ·10	− ·34 ·05:	1·04
126	226	35	− ·22	− 1·41	·23	+ ·02 ·32	+ ·03 ·31	+ ·05 ·28	+ ·01 ·16		1·43
61	19	34	+ ·87	+ 1·20	·32	+ ·10 ·36	+ ·17 ·34	+ ·22 ·27	+ ·11 ·11		1·58
131	315	34	+ 1·46	− ·26	·57	+ ·18 ·35	+ ·23 ·33	+ ·28 ·30	+ ·36 ·25:		1·83
16	56	33	− ·03	+ 1·54	·55	+ ·15 ·35	+ ·19 ·34	+ ·20 ·25	+ ·10 ·13		1·87
4	107	32	− 1·26	+ ·99	·23	+ ·04 ·34	+ ·06 ·31	+ ·05 ·25	− ·04 ·13:		1·61
152	266	32	+ ·82	− 1·37	·35	+ ·07 ·37	+ ·17 ·37	+ ·35 ·37:			1·73
153	280	32	+ 1·13	− 1·13	·00	+ ·08 ·43	+ ·22 ·31	+ ·07 ·15:			1·38
27	141	29	− 1·80	+ ·13	·04	− ·04 ·36	+ ·01 ·33	·00 ·22	− ·20 ·10:	− ·31:·07:	1·61
37	39	28	+ ·52	+ 1·81	·11	+ ·08 ·36	+ ·11 ·33	+ ·14 ·29	+ ·12 ·17		1·75

TABLE 8 (*continued*).

S.A. No.	l	b	x_0/z_0	y_0/z_0	Δa	$\Delta \log A(m)$ and $d(\Delta \log A)/d(\Delta a)$					$m - m_{90}$
						$m_{90} = 10$ $z_0 = 173$	$m_{90} = 12$ $z_0 = 316$	$m_{90} = 14$ $z_0 = 574$	$m_{90} = 16$ $z_0 = 1040$	$m_{90} = 17$ $z_0 = 1410$	
Areas at northern galactic latitudes (continued).											
	°	°			m						m
1	91	28	− 1·11	+ 1·52	·73	− ·01 ·30	− ·05 ·30	− ·02 ·30			2·37
100	196	28	− 1·18	− 1·46	·11	+ ·08 ·35	+ ·10 ·32	+ ·09 ·27	+ ·10 ·24:		1·75
154	295	28	+ 1·63	− ·94	·07	+ ·12 ·43	+ ·29 ·36	+ ·30 ·23:			1·71
108	343	28	+ 1·79	+ ·58	·82	+ ·19 ·40	+ ·34 ·40	+ ·49 ·29			2·46
85	4	27	+ 1·52	+ 1·23	·47	+ ·08 ·38	+ ·19 ·38	+ ·35 ·34	+ ·44:·24:		2·19
11	123	27	− 1·82	+ ·74	·29	+ ·08 ·35	+ ·09 ·30	+ ·01 ·19	− ·24 ·07:		2·01
76	177	27	− 1·66	− 1·04	·04	+ ·01 ·35	+ ·01 ·28	− ·09 ·22	− ·17 ·16		1·76
151	245	27	+ ·34	− 1·93	·33	+ ·10 ·39	+ ·23 ·39	+ ·43:·39:			2·05
125	214	24	− ·81	− 2·10	·16	+ ·11 ·38	+ ·14 ·28	+ ·07 ·23	− ·03:·13:		2·12
132	326	24	+ 2·25	+ ·04	1·64	+ ·39 ·32	+ ·40 ·32	+ ·46 ·32:			3·60
62	24	23	+ 1·22	+ 2·02	·60	+ ·22 ·36	+ ·30 ·36	+ ·39 ·31			2·64
51	156	22	− 2·44	− ·47	− ·02	− ·09 ·37	+ ·01 ·35	·00 ·22	− ·22 ·10:		2·11
150	233	21	− ·09	− 2·61	·25	− ·07 ·38	+ ·04 ·37				2·48
155	307	21	+ 2·48	− ·81	1·36	+ ·48 ·41	+ ·70 ·41				3·59
7	76	20	− ·98	+ 2·57	>1·29	>+ ·13 ·43	>+ ·29 ·39	>+ ·27 ·20:			>3·62
17	59	19	− ·20	+ 2·89	·71	+ ·13 ·31	+ ·10 ·30	+ ·12 ·29			3·15
38	42	18	+ ·69	+ 3·00	·62	+ ·30 ·32	+ ·28 ·30	+ ·24 ·24			3·17
3	102	18	− 2·25	+ 2·10	1·31	+ ·23 ·38	+ ·31 ·34	+ ·30:·20:			3·86
26	138	18	− 3·06	+ ·38	·44	+ ·03 ·33	+ ·03 ·30	+ ·01 ·25	− ·05 ·16:		2·99
99	188	15	− 2·73	− 2·54	·09	− ·02 ·46	+ ·17 ·33	+ ·12 ·22			3·03
75	170	14	− 3·63	− 1·70	·89	+ ·25 ·37	+ ·23 ·23	− ·02:·08:			3·97
109	353	14	+ 3·54	+ 1·88	>1·58	>+ ·30 ·46	>+ ·49 ·37	>+ ·42:·18:			>4·66
86	10	13	+ 3·06	+ 3·06	1·49	+ ·42 ·33	+ ·43 ·31	+ ·38:·16:			4·73
2	88	13	− 2·36	+ 3·63	>1·73	>+ ·28 ·36	>+ ·34 ·30				>4·97
10	118	13	− 3·86	+ 1·97	1·98	+ ·22 ·36	+ ·30 ·36				5·22
124	205	13	− 2·16	− 3·75	·55	+ ·26 ·28	+ ·18 ·28	+ ·16 ·28:			3·79
149	224	13	− ·83	− 4·25	1·58	+ ·52 ·39					4·82
156	317	12	+ 4·65	− ·65	>1·73	>+ ·68 ·50					>5·14
133	336	12	+ 4·62	+ ·90	>1·73	>+ ·34 ·48	>+ ·55 ·34				>5·14
63	29	10	+ 2·48	+ 5·10	1·18	+ ·45 ·35	+ ·33 ·17				4·98
50	151	10	− 5·64	− ·59	1·89	+ ·47 ·28	+ ·27 ·15				5·69
39	47	9	+ ·88	+ 6·25	·67	+ ·14 ·43	+ ·31 ·37				4·70
25	133	9	− 6·17	+ 1·31	1·76	+ ·16 ·28	− ·02 ·22:				5·79
Areas at southern galactic latitudes.											
116	63	76	− ·03	+ ·25	− ·04		+ ·23 ·17	− ·01 ·17	− ·19 ·17	− ·26 ·17	·02
117	118	75	− ·24	+ ·12	− ·04		·00 ·26	− ·05 ·26	− ·03 ·26	− ·01 ·22	·04
139	29	66	+ ·20	+ ·40	− ·02		+ ·17 ·25	+ ·05 ·22	− ·04 ·18	− ·08 ·16	·18
118	154	65	− ·46	− ·07	− ·02		+ ·08 ·25	− ·01 ·25	− ·03 ·24	− ·02 ·21	·20
92	95	62	− ·34	+ ·41	− ·01		+ ·07 ·26	+ ·01 ·26	− ·01 ·23	− ·01 ·19	·26
115	60	58	− ·05	+ ·62	·01		+ ·12 ·24	− ·01 ·22	− ·08 ·21	− ·09 ·19	·37
93	123	58	− ·57	+ ·23	·01		− ·03 ·34	+ ·03 ·27	− ·05 ·20	− ·09 ·14	·37
138	12	53	+ ·51	+ ·55	·03		+ ·15 ·29	+ ·13 ·26	+ ·07 ·18	+ ·02 ·17	·52
119	168	53	− ·69	− ·29	·03		− ·05 ·33	− ·05 ·26	− ·11 ·18	− ·18 ·11	·52
114	38	49	+ ·25	+ ·83	·05	+ ·02 ·33	+ ·03 ·33	+ ·09 ·32	+ ·21 ·31	+ ·28 ·30	·66
94	143	48	− ·90	+ ·03	·06	+ ·02 ·33	− ·01 ·26	− ·12 ·24	− ·16 ·22	− ·15 ·16:	·70
68	79	47	− ·38	+ ·85	·06	− ·05 ·36	+ ·02 ·36	+ ·07 ·27	+ ·01 ·17	− ·06 ·06:	·74
69	102	47	− ·68	+ ·63	·06	− ·03 ·32	− ·03 ·31	− ·05 ·24	− ·12 ·19	− ·16 ·15:	·74
91	61	43	− ·11	+ 1·06	− ·01	− ·10 ·34	− ·07 ·33	+ ·02 ·32	+ ·01 ·16		·82
70	121	42	− 1·01	+ ·45	·30	− ·08 ·31	− ·12 ·30	− ·12 ·27	− ·15 ·17	− ·23:·10:	1·17
137	3	40	+ ·94	+ ·73	·27	+ ·15 ·36	+ ·18 ·34	+ ·22 ·29	+ ·25 ·25		1·23
120	177	40	− 1·01	− ·63	·24	− ·02 ·31	− ·05 ·31	− ·02 ·31	+ ·08 ·31		1·20
113	24	38	+ ·66	+ 1·10	·31	+ ·16 ·39	+ ·24 ·32	+ ·20 ·22	+ ·01 ·10		1·37
95	157	37	− 1·30	− ·28	·44	− ·01 ·28	− ·10 ·27	− ·18 ·22	− ·33 ·09		1·54

TABLE 8 (*continued*).

S.A. No.	l	b	x_0/z_0	y_0/z_0	Δa	$\Delta \log A(m)$ and $d(\Delta \log A)/d(\Delta a)$					$m - m_{90}$
						$m_{90} = 10$ $z_0 = 173$	$m_{90} = 12$ $z_0 = 316$	$m_{90} = 14$ $z_0 = 574$	$m_{90} = 16$ $z_0 = 1040$	$m_{90} = 17$ $z_0 = 1410$	
Areas at southern galactic latitudes (continued).											
	°	°			m						m
90	45	34	+ ·26	+ 1·46	·50	+ ·19 ·37	+ ·21 ·29	+ ·16 ·23	+ ·04 ·13		1·76
71	135	34	− 1·46	+ ·26	−·07	− ·21 ·34	− ·20 ·32	− ·20 ·27	− ·19 ·21	− ·23 ·10:	1·19
145	199	34	− ·87	− 1·20	·04	− ·06 ·36	+ ·03 ·36	+ ·18 ·36			1·30
160	341	34	+ 1·42	+ ·41	·58	+ ·35 ·42	+ ·52 ·36	+ ·53 ·18:			1·84
44	85	32	− ·80	+ 1·39	·13	+ ·05 ·36	+ ·09 ·31	+ ·08 ·24	− ·03 ·16		1·51
45	101	32	− 1·15	+ 1·11	·13	+ ·03 ·34	+ ·01 ·29	+ ·01 ·26	− ·12 ·14		1·51
67	65	28	− ·33	+ 1·85	·53	+ ·14 ·36	+ ·18 ·31	+ ·12 ·22	− ·04 ·08:		2·17
46	117	27	− 1·73	+ ·92	·24	− ·14 ·34	− ·12 ·32	− ·11 ·25	− ·27 ·09:		1·96
121	184	26	− 1·59	− 1·29	·15	− ·03 ·32	− ·05 ·30	− ·08 ·24	− ·17 ·12:		1·94
136	356	26	+ 1·76	+ 1·06	1·24	+ ·50 ·37	+ ·59 ·36	+ ·70 ·32			3·03
112	15	25	+ 1·38	+ 1·64	·80	+ ·28 ·37	+ ·34 ·35	+ ·44 ·32			2·67
96	166	25	− 2·00	− ·77	·36	+ ·07 ·32	+ ·04 ·27	− ·04 ·21	− ·22 ·08:		2·23
72	146	24	− 2·25	− ·04	>1·38	>− ·12 ·36	>− ·06 ·34	>+ ·04 ·31			>3·34
89	33	23	+ ·89	+ 2·19	·76	+ ·21 ·37	+ ·29 ·35	+ ·35 ·28	+ ·24:·14:		2·80
146	204	22	− 1·28	− 2·13	·00	− ·02 ·41	+ ·11 ·35	+ ·12:·20:			2·13
159	336	22	+ 2·44	+ ·47	1·29	+ ·84 ·38	+ ·97 ·38:				3·42
66	53	21	+ ·09	+ 2·61	·96	+ ·38 ·33	+ ·38 ·31	+ ·36 ·25			3·19
47	127	21	− 2·48	+ ·81	>1·44	>− ·62:·39	>− ·47 ·39	>− ·27 ·39			>3·67
43	80	17	− 1·38	+ 2·96	·69	+ ·20 ·32	+ ·18 ·31	+ ·19 ·27			3·36
20	89	17	− 1·83	+ 2·71	·38	+ ·09 ·31	+ ·04 ·28	− ·03 ·23			3·05
21	99	17	− 2·27	+ 2·35	·33	+ ·08 ·31	+ ·06 ·30	+ ·07 ·28			3·00
135	350	14	+ 3·63	+ 1·70	1·40	+ ·64 ·44	+ ·88 ·44				4·48
42	70	13	− 1·12	+ 4·18	·89	+ ·11 ·42	+ ·27 ·35				4·13
22	111	13	− 3·59	+ 2·42	·71	+ ·06 ·36	+ ·09 ·28	− ·05 ·15			3·95
122	190	13	− 3·06	− 3·06	·78	+ ·05 ·36	+ ·11 ·33	+ ·13:·27:			4·02
88	24	12	+ 2·42	+ 4·03	1·55	+ ·60 ·36	+ ·65 ·32				4·96
65	43	12	+ ·98	+ 4·60	1·82	+ ·57 ·35	+ ·65 ·35				5·23
48	136	12	− 4·64	+ ·73	2·40	+ ·38 ·38	+ ·47 ·34				5·81
111	6	11	+ 3·88	+ 3·37	1·73	+ ·45 ·43	+ ·55 ·29				5·33
73	156	11	− 5·05	− ·98	1·60	+ ·13 ·45	+ ·18 ·24				5·20
97	174	11	− 4·50	− 2·49	2·24	+ ·16 ·34	+ ·07 ·25				5·84
147	209	9	− 2·76	− 5·67	1·27	+ ·55 ·41					5·30
41	61	8	− ·74	+ 7·08	>1·73	>+ ·49 ·38					>6·01
23	120	7	− 7·37	+ 3·44	1·75	+ ·02 ·34	+ ·01 ·26:				6·32

at the edge of the region studied by HUBBLE, so that the absorption values are at best rough estimates; moreover, the magnitudes in these areas have not been observed at Mount Wilson.

The galactic co-ordinates l and b following the number of the area have been taken from *Harvard Annals* **101**, **102** and **103**, and refer to a galactic pole at $\alpha = 12^h 41^m{\cdot}3$, $\delta = +27°21'$. The quantities $x_0/z_0 = |\mathrm{ctg}\ b|.\cos(l - 325)$ and $y_0/z_0 = |\mathrm{ctg}\ b|.\sin(l - 325)$ in the next column represent the logarithmic average co-ordinates of the stars expressed in z_0 as a unit; the axes of x and y are parallel to the galactic plane, that of x being directed to the longitude of the centre at 325°, that of y to 55° longitude. The column Δa gives the general absorption as derived from counts of nebulæ (section 2). The significance of the columns $\Delta \log A(m)$ has been explained above; the various layers are indicated by the corresponding values of m_{90} and z_0. The values of $\Delta \log A$ for $m_{90} = 10$ have not been given for areas above 50° latitude, since the data for bright stars in these areas had been treated in a slightly different manner.

The values used for the absorption are tentative, and, as explained above, they are in many cases by far the most uncertain factor in the computations. In order to enable later investigators to obtain the differences in density for other values of the absorption without having to reconstruct the $\log A(m)$-curves for each area we have added behind each value of $\Delta \log A(m)$ a number without sign giving the change which $\Delta \log A(m)$ would undergo if the absorption Δa were changed by a full magnitude.

FIGURES 5 and 6.

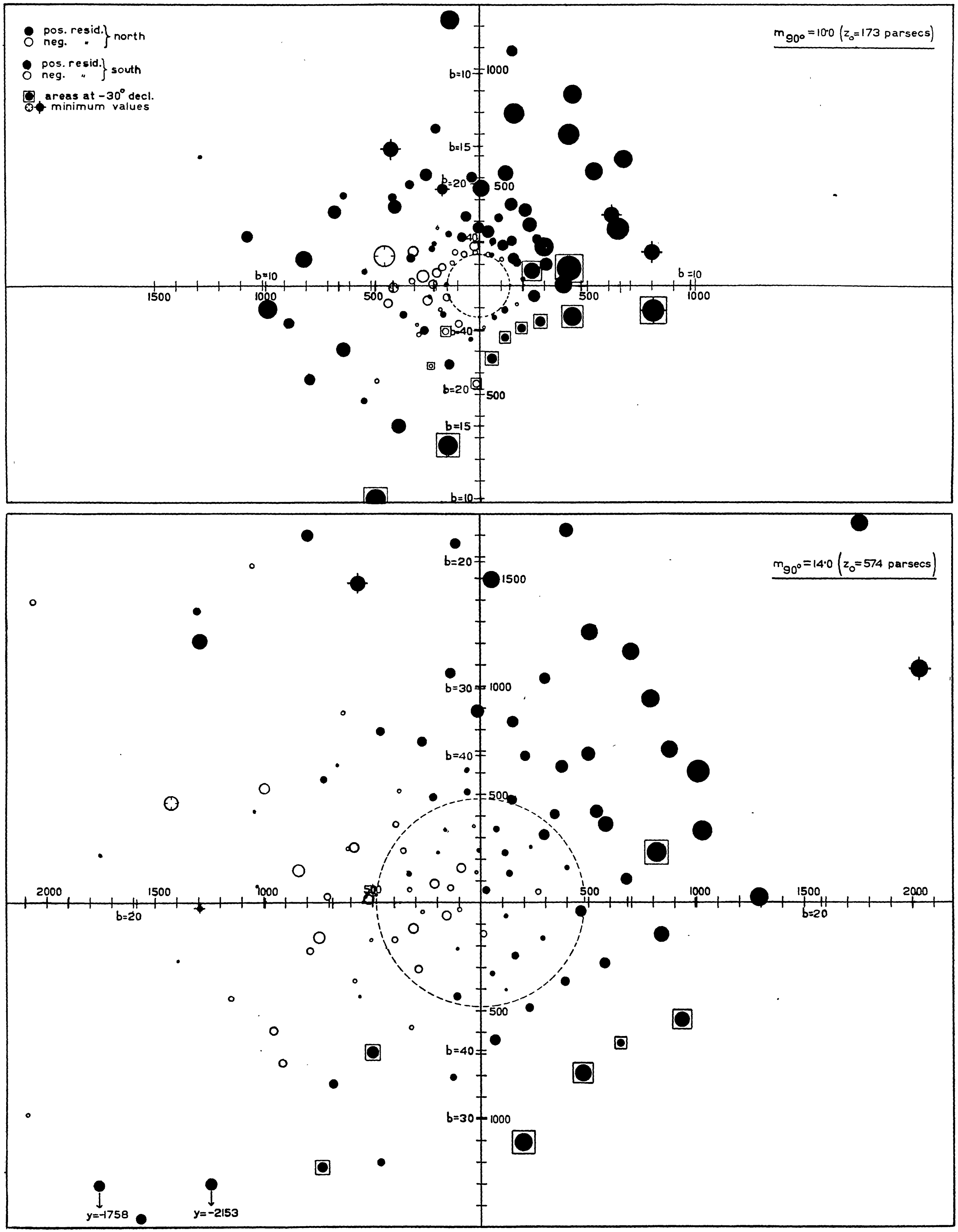
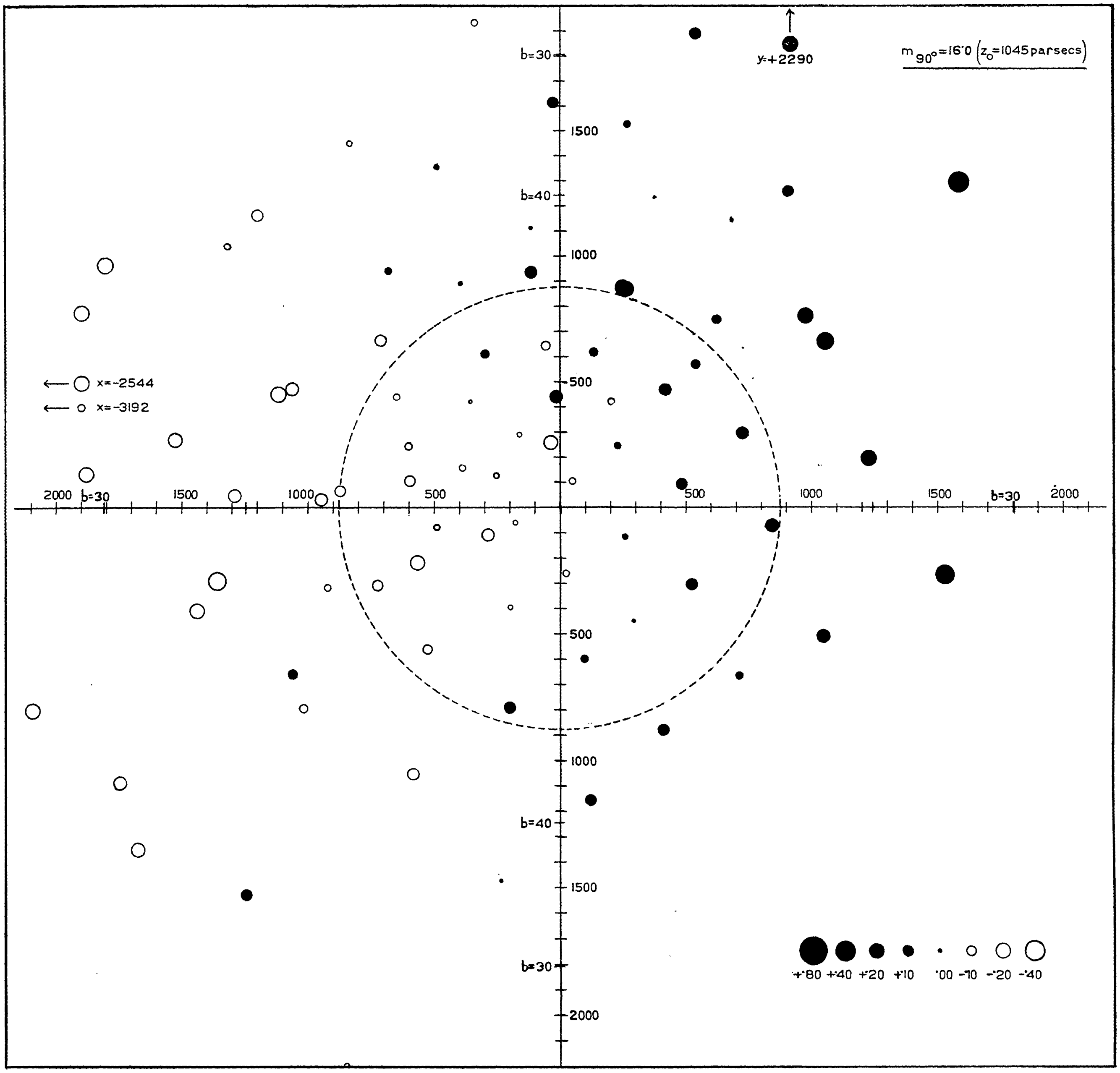


FIGURE 7.



Deviations of the logarithms of the actual numbers of stars from the values corresponding to the case of equidensity surfaces parallel to the galactic plane.

Each figure shows the deviations for levels at a distance z_0 from the galactic plane; Fig. 5 corresponds to $z_0 = \pm 173$ ps, Fig. 6 to $z_0 = \pm 574$, Fig. 7 to $z_0 = \pm 1040$, areas in levels north of the galactic plane being indicated in black, those south of this plane in red.

For each level the residual for a certain Selected Area is plotted as either a circle or a dot, the centre of which corresponds to the logarithmic mean position of the stars considered, as projected on the galactic plane. The abscissæ, x_0, are projected distances measured in the direction of the galactic centre, while the y_0-axis is in the direction of 55° longitude; these co-ordinates can be computed directly from the data given in Table 8. The scale of distances has been indicated in parsecs. The red numbers and divisions give the galactic latitudes corresponding to various distances from the centre of each diagram; the dotted red circles correspond to $b = 50°$, and delimit, therefore, the standard region.

A filled circle indicates that the number of counted stars is greater than would correspond to a plane-parallel density distribution, while open circles indicate the opposite. The area of the circles is proportional to the size of the logarithmic residual, the scale being shown in the lower right-hand corner of Figure 7. Cases where only minimum values could be computed have been designated by special signs. Dots or circles surrounded by squares represent areas in the zone a — 30° declination, and are especially uncertain.

For most areas situated within HUBBLE's zone of avoidance only a minimum value for the absorption, in general $1^{m}\cdot 73$, has been given[1]) (cf. p. 236); in these cases the $\Delta \log A$ are also minimum values. This is indicated by a $>$ sign in the columns Δa, $\Delta \log A$ and m–m_{90}; in several of these areas the true deviations $\Delta \log A$ may be considerably larger algebraically than those shown. In a few cases the $\log A(m)$-curves were a little extrapolated beyond the faintest magnitudes down to which the Durchmusterung was complete. The corresponding residuals and derivatives have been indicated by colons; these values were omitted in forming the averages of Table 9. The last column of Table 8 shows the quantities $m - m_{90} = \Delta a - 5 \log \sin b$; by adding these to the values of m_{90} in the preceding columns one obtains for each area the magnitudes corresponding to the different levels.

Plots have been made of the deviations $\Delta \log A$. Those for the levels corresponding to $m_{90} = 10\cdot 0$, $14\cdot 0$ and $16\cdot 0$ have been reproduced in Figures 5, 6 and 7. An examination of these plots shows conclusively that for the layers below 700 parsecs the deviations outside the standard region around the sun (for which the average residual is zero by definition) are preponderatingly positive, indicating that the sun is situated in a region of low density, surrounded on practically all sides by regions where the density is at least twice as large.

When considering these diagrams and the conclusions drawn from them it is well to keep in mind that the results for the lowest level ($m_{90} = 10\cdot 0$) are uncertain by two causes which do not, or at least very much less, impair the results for the higher levels; viz. 1. the uncertainty whether these stars are sufficiently outside the layer of absorbing clouds, and 2. the uncertainty involved in the comparison of counts of bright stars according to visual magnitude with those of faint stars according to photographic magnitude.

A closer inspection of the plots showed that the variations of density in the layers north of the galactic plane closely resemble the variations shown in the layers at the same distance south of the plane, except in the quadrant between 280° and 10° longitude, where the positive residuals in the southern latitudes appear to be about twice as high as those in the northern latitudes; the latter effect may indicate a real asymmetry in the distribution of the stars in the general direction of the centre. A considerable correction to the adopted position of the galactic pole seems out of the question (cf. p. 235); a change in the pole would, moreover, introduce a great asymmetry in the opposite quadrant.

In Table 9 the deviations $\Delta \log A(m)$ have been combined, averages having been formed in each of the four quadrants, for different projected distances from the sun. The centre of quadrant I coincides with the longitude of the galactic centre. In the second column of the table the distance from the sun projected on the galactic plane, $r_0 = \sqrt{x_0^2 + y_0^2}$, has been entered; it is expressed in parsecs. In the next three columns the uppermost values for each quadrant refer to areas between 33° and 50° latitude, the following to the regions from 20° to 33°, from 12° to 20°, and below 12°, respectively. The different levels are indicated at the top of the columns. In forming the average deviations $\Delta \log A(m)$ areas in northern and southern latitudes were combined. The probable errors of the averages have been added, as well as the numbers of areas used (between parentheses); the former have been derived from the inter-agreement of the individual values[2]); they should be a true measure of the reliability, as the individual values on which the averages rest are entirely independent, with regard to $A(m)$ as well as to the absorption. Areas within the zone of avoidance, for which only minimum values of $\Delta \log A$ were available, and also the values marked by a colon in Table 8 have been excluded. The average value of r_0 for the last ring is about 1600 parsecs in quadrant I, and 1900 parsecs in the other quadrants.

In quadrant I the lowest level shows a very rapid increase in density as we go away from the sun; it increases with a factor of two over a distance of about 350 parsecs. In the higher layers the increase becomes gradually less rapid, though it remains quite pronounced.

In the quadrant III, opposite the centre of the galactic system, the run of the density in the lower layers is more complicated; it starts with a small, but well defined decrease but rises again for $r_0 > 500$, the density for the ring between 870 and 1500 parsecs becoming about 60 % greater than that near the sun. For the levels at $z_0 = 1040$ and 1410 parsecs the density decreases quite regularly down to the limit of the observations at 2000 parsecs.

The quadrants II and IV, centered around longitudes differing 90° from that of the galactic

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[1] In a few cases where a number of HUBBLE's fields were situated in the close vicinity, and larger values for the absorption appeared to be fairly well established, values of Δa exceeding $1\cdot 73$ were adopted.

[2] More precisely: it was found that the mean residual depended strongly on the mean value of $\Delta \log A$. For various values of $\Delta \log A$ the probable errors corresponding to unit weight (i.e. to one area) were determined from the residuals in all corresponding groups, and these probable errors were used to compute the individual probable errors shown in the table.

TABLE 9. Average values of $\Delta \log A(m)$ for rings and quadrants 1).

Quadrant	Ring	$z_0 = 173$	$z_0 = 316$	$z_0 = 574$	$z_0 = 1040$	$z_0 = 1410$
I *l* 280° to 10°	145– 265	+ ·12 ± ·02 (7)				
	265– 480	+ ·34 ± ·07 (8)	+ ·18 ± ·03 (7)			
	480– 870	+ ·54 ± ·13 (2)	+ ·46 ± ·07 (8)	+ ·24 ± ·05 (7)	+ ·13 ± ·03 (4)	
	870–1500		+ ·66 ± ·14 (2)	+ ·40 ± ·08 (6)	+ ·21 ± ·05 (5)	+ ·10 ± ·04(3)
	> 1500		+ ·55 ± ·19 (1)		+ ·36 ± ·19 (1)	+ ·16 ± ·08(1)
II *l* 10° to 100°	145– 265	+ ·03 ± ·01(12)				
	265– 480	+ ·17 ± ·03 (9)	+ ·06 ± ·01(12)			
	480– 870	+ ·28 ± ·05 (9)	+ ·20 ± ·04 (9)	+ ·10 ± ·02(12)	+ ·04 ± ·02 (6)	
	870–1500	+ ·36 ± ·11 (3)	+ ·28 ± ·05 (8)	+ ·21 ± ·04 (8)	+ ·08 ± ·02 (8)	+ ·12 ± ·02(7)
	> 1500		+ ·32 ± ·13 (2)	+ ·16 ± ·03 (6)	+ ·04 ± ·02 (6)	
III *l* 100° to 190°	145– 265	— ·06 ± ·01(12)				
	265– 480	— ·01 ± ·02 (9)	— ·06 ± ·01(12)			
	480– 870	+ ·15 ± ·03 (8)	+ ·01 ± ·02 (9)	— ·07 ± ·01(12)	— ·09 ± ·02 (6)	
	870–1500	+ ·19 ± ·04 (5)	+ ·21 ± ·04 (8)	— ·03 ± ·02 (9)	— ·14 ± ·02(11)	— ·14 ± ·02(7)
	> 1500		+ ·10 ± ·03 (5)	+ ·03 ± ·03 (3)	— ·19 ± ·02(10)	— ·23 ± ·03(4)
IV *l* 190° to ± 230°	145– 265	— ·02 ± ·02 (5)				
	265– 480	+ ·04 ± ·02 (6)	+ ·03 ± ·02 (5)			
	480– 870	+ ·39 ± ·14 (2)	+ ·13 ± ·02 (6)	+ ·08 ± ·02 (5)	+ ·02 ± ·03 (4)	
	870–1500	+ ·55 ± ·19 (1)	+ ·18 ± ·08 (1)	+ ·17 ± ·05 (3)	+ ·02 ± ·03 (4)	+ ·03 ± ·03(3)
	> 1500			+ ·16 ± ·08 (1)	+ ·09 ± ·05 (1)	— ·21 ± ·05(1)

centre, appear to show much the same character; it should be kept in mind, however, that IV has only been observed to about 230° longitude. In a smooth galactic system with the sun at a great distance from the centre, it might have been expected that in these directions the surfaces of equal density would indeed be approximately parallel to the galactic plane and that, therefore, the average residuals $\Delta \log A$ would be zero or slightly negative. But the actual conditions seem to be quite different. In both quadrants the density appears to increase markedly with increasing distance from the sun. The phenomenon is strongest for the lowest levels; it almost disappears for the levels at 1040 and 1410 parsecs. The increase in the residuals starts at roughly $r_0 = 250$ parsecs and assumes its maximum value beyond 500 parsecs.

The phenomenon is clearly reflected in the average residuals over all longitudes, which for the rings between 480 and 1500 parsecs are shown in Table 10.

The probable errors have again been derived from the deviations of the individual areas from the averages given; the numbers of areas are added. Here again the systematic character of the residuals appears to be strongest for the lowest levels, the average residual decreasing rapidly above about $z_0 = 400$ parsecs, and becoming negligible in the levels at 1000 and 1400 parsecs 2).

TABLE 10.
Average values of $\Delta \log A(m)$ for all longitudes.

z_0	$\Delta \log A(m)$	p.e.	n
173	+ ·272	± ·023	30
316	+ ·231	± ·017	51
574	+ ·109	± ·015	62
1040	+ ·014	± ·013	50
1410	+ ·012	± ·030	20

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1) The differences are relative to the region between ± 50° latitude and the galactic poles, which region served as standard from which, in each level, the deviations $\Delta \log A$ have been counted.

2) I have tried to investigate whether an analogous phenomenon could be traced by a comparison of mean parallaxes of stars in different latitudes, but the material of mean parallaxes available does not appear to be sufficient to permit a definite conclusion. Computing roughly, from the tables in *B.A.N.* Nos 289 and 290, the mean parallaxes corresponding to $m_{90} = 11{\cdot}0$ in the case of a plane-parallel density distribution like that considered above, and assuming that the average absorption is $^{m}{\cdot}31/\sin b$ I obtained the following comparison of log $\bar{p}$ (computed) with the observed value of log $\bar{p}$ for the

These results are so different from what we might have been led to expect from other considerations concerning the galactic system that it seems well, once more, to scrutinize critically the basis of the calculations upon which they rest. The only point about which serious doubt can arise appears to be the absorption, or rather, the question whether the entire absorption found from the nebular counts, or large part of it, takes place in front of the stars. I have, therefore, tried to verify the main character of the results in the following ways.

In the first place I have selected from Table 8 the areas in quadrants II and IV and below 40° latitude for which the absorption, Δa, was smaller than $0^{\rm m}{\cdot}25$. There are 9 such areas; these give
$\overline{\Delta\log A(12)} = +\,{\cdot}117 \pm {\cdot}012$ (p.e.) and
$\overline{\Delta\log A(14)} = +\,{\cdot}094 \pm {\cdot}007$ (p.e.), the probable errors being computed by the residuals from the average. In all 9 areas the $\Delta\log A$ for $m_{90} = 12{\cdot}0$ and $14{\cdot}0$ are positive, so that the phenomenon of the increase in density appears to be fairly well established in this case where the influence of the absorption is negligible. The average value of Δa for these areas is only $0^{\rm m}{\cdot}12$, and the values found would only have been changed very little if this had been entirely neglected. For comparison, the average value of $\Delta \log A(12)$ in the same quadrants and between 24° and 40° latitude was also computed for the 10 areas with larger absorption; this yielded $+\,{\cdot}175 \pm {\cdot}020$ (p.e.), the average value of Δa being $0^{\rm m}{\cdot}48$ in this case. The difference with the above value is not more than what should have been expected on account of the selection effect upon the values of Δa. A similar confirmation, but of less weight, may be obtained from the areas in quadrant III, as well as from the areas between 40° and 49° latitude. Of the latter, 10 are situated in quadrants II and IV, yielding $\overline{\Delta \log A(14)} = +\,{\cdot}056 \pm {\cdot}011$ (p.e.), while $\overline{\Delta a}$ is only $0^{\rm m}{\cdot}05$.

In the second place I have recomputed the values of $\Delta\log A(m)$ for areas in which colors have been determined by PARKHURST or by SEARES, using the absorption calculated directly from the observed color-excesses (viz. $\Delta a = 3E_{\rm c}$, where $E_{\rm c}$ is the color-excess) instead of the absorption found from the extra-galactic nebulæ. Considering again the quadrants II and IV, there are 7 areas observed by PARKHURST, for which the resulting average value $\overline{\Delta\log A(12)}$ 1) is $+\,{\cdot}20$, as against $+\,{\cdot}23$ found previously with the aid of absorptions from nebular counts 2). Eight areas have been observed by SEARES, and only one of these had also been observed by PARKHURST, so that this set is practically independent of the first. Calculating the absorption from the color-excess for the most reddened group of stars in each of these areas, I find $\overline{\Delta\log A(12)} = +\,{\cdot}29$, as against $+\,{\cdot}30$ from the values adopted in Table 8 2).

For the regions in lower latitude attention may be drawn to the fact that the absorption values would have to be decreased very radically if we wanted to get rid of the density increase found. It has been indicated elsewhere 3) that the phenomenon persists clearly enough even if the absorptions are reduced to half the values obtained from the counts of nebulæ; it would only disappear approximately if the absorption were reduced to zero.

The direct tests indicated appear to confirm the conclusion already reached in previous sections, namely, that we are justified in assuming that the absorption found from nebular counts takes place between us and the stars. But further investigations are urgently required to establish the fact with certainty.

In the following I shall briefly discuss the principal consequences to which we are led if we assume, tentatively, that the deviations do reflect the true structure of the system. In order to obtain the real distribution of density we must in the first place know the distribution in z of the stars in the standard region surrounding the sun. For stars of a given magnitude this distribution may at once be derived from the luminosity curve and the density distribution as given, for example, in *B.A.N.* No. 290, p. 97. I have used slightly different values, but this is of not much consequence for the following estimates, which are necessarily rough on account of the uncertainty in the absorption data.

It was found that for the quadrants II and IV (so far as observed) the density deviations shown in Table 9 could be well represented by assuming that, between 600 and 1500 parsecs distance measured in

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latitude zones indicated. The intervals 10°—100° and 100°—190° longitude gave practically the same values and have, therefore, been combined. The last columns give the same comparison for $m_{90} = 12{\cdot}0$. The unit of p is $''{\cdot}001$.

b	$m_{90} = 11{\cdot}0$		$m_{90} = 12{\cdot}0$	
	obs.	comp.	obs.	comp.
10°—19°	·08	·15	—	—
20°—34°	·32	·41	·24	·28

As might have been expected from the results of the star counts the mean parallaxes seem indeed to be smaller than those computed upon the hypothesis that the equi-density layers are parallel to the galaxy, but the differences are small and uncertain.

1) For the area 41, for which $\Delta\log A(12)$ has not been given in Table 8, the value of $\Delta\log A(10)$ was used instead.

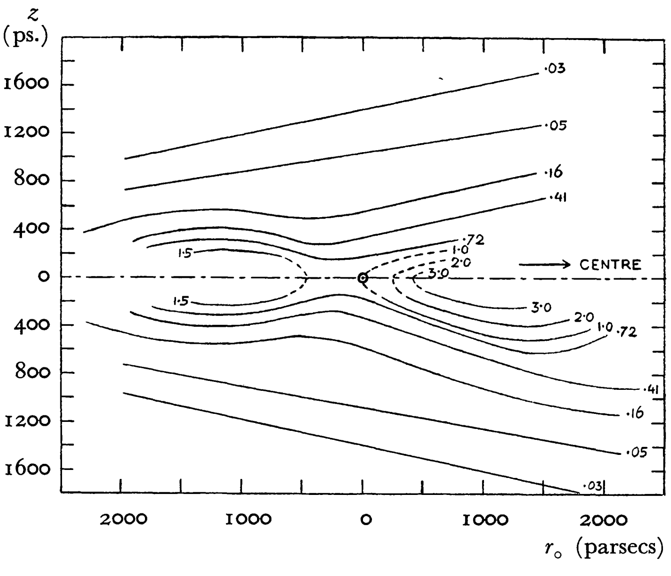
2) In computing this average the minimum values for $\Delta\log A(12)$ were used for areas within the zone of avoidance.

3) *Annales d'Astrophysique* I, No. 1, p. 88, Tableau 5.

the galactic plane, the actual density for the layers between $z = 150$ and $z = 320$ is 3 times that in the same layers near the sun, for the layers between $z = 320$ and $z = 500$ $2{\cdot}5$ times, and for the layers between $z = 500$ and $z = 790$ twice as large as in the corresponding layers in the neighborhood of the sun, while for the layers above 800 parsecs the equidensity surfaces are parallel to the galactic plane. It will be clear that the representation is to some extent arbitrary, as the extension in r of the region with increased density might e.g. have been chosen smaller, in which case the local density increase would have had to be larger, or vice versa.

Somewhat more detailed computations have been made for the quadrants I and III, the results of which are shown in Figure 8. This gives a tentative section of the galactic system by a plane perpendicular to the galactic plane, and passing through the sun and the centre. The vertical co-ordinate is the z co-ordinate perpendicular to the galactic plane, which latter is indicated by a dash-dot line; the horizontal co-ordinate is the mean distance from the sun for the areas in these quadrants; the true average co-ordinates x_0, in the direction of the centre, would be about 10 % smaller. The sun is indicated by its usual symbol, the centre may be imagined at about 8000 parsecs distance to the right of the sun. The full-drawn lines are equidensity curves; the dotted parts have not been observed. The corresponding densities expressed in the density near the sun as unit have been indicated; the points where these surfaces cut the vertical line through the sun have been taken from Figure 5, *B.A.N.* No. 290 ($M > + 4{\cdot}5$). As the observations in quadrant III do not show any difference between northern and southern latitudes I have assumed that to the left of the sun the curves are symmetrical with respect to the galactic plane; to the right of the sun the observations indicated a pronounced asymmetry, so that north and south have been treated separately.

FIGURE 8.



Section of the galactic system with a plane perpendicular to that of the galaxy, and passing through the sun and the centre of the system.

The lines shown are lines of equal density, the dotted parts being extrapolated. The corresponding densities indicated are expressed in that near the sun as unit. The sun is shown by a dot surrounded by a circle.

The most pronounced feature in the right-hand part of the diagram is the strong and very rapid increase in density towards the centre, indicated by the high inclination of the equidensity surfaces. To the left of the sun the density first decreases, a decrease which seems well established (compare the upper numbers in the various columns for quadrant III in Table 9) and then rises again to a density which, for the lower levels, surpasses about $2\frac{1}{2}$ times that at the corresponding levels directly above and below the sun. The higher levels (densities ·05 and ·03) show no signs of a hump to the left of the sun; they are flat, and inclined at angles of about 10° to the galactic plane. (See below for a separate discussion of these levels.)

The structural features inferred are evidently of large scope. In all three quadrants II, III and IV similar deviations of density have been found for the various layers between about 600 parsecs on either side of the galactic plane. Almost the same features are evidently found over considerable intervals of longitude. It seems reasonable to regard this structure as analogous with the spiral structure of extra-galactic nebulæ. The knowledge that such a large-scale structure has been traced in practically all well-observable extra-galactic systems for which we have reason to believe that they are as much flattened as the galactic system tends to eliminate great part of the surprise we might originally have felt with respect to the density distribution just discussed. The apparent local void surrounding the sun would then have to be interpreted as meaning that the sun is situated between two arms, the positions of which might roughly be guessed from Figure 8. But it should be stressed again that part of the arguments upon which these inferences are based are tentative. Also, the data used are still uncertain and not nearly sufficiently extensive to indicate, even roughly, the course of these hypothetical arms or to give an answer to the most important question: whether they are wound in the direction of the rotation, or oppositely.

The unevenness of the density distribution does not extend to distances of more than about 600 parsecs on either side of the galactic plane. In the higher levels the density appears to increase in a monotone manner in the direction of the galactic centre. This fact is well illustrated by Figure 7, and, more specifically, by Figure 9, in which average residuals have been plotted against x_0, the projection of the logarithmic mean distance on the line joining the sun and the centre. For this purpose the points in Table 8, referring to the high levels, have been arranged according to x_0 and combined into groups of generally about 5 areas each (Table 11). Extrapolated values, like those indicated by colons in Table 8, were given half weight; the weights used are shown under w. The areas in the zone at $-30°$ declination do not extend to sufficiently faint magnitudes, so that the material is limited to areas observed at Mount Wilson.

These averages, $\overline{\Delta \log A}$, which are mutually independent, have been plotted in Figure 9, circles referring to northern, squares to southern latitudes. It will be observed that the increase in the logarithm of the density in each level is linear. The exact agreement between the northern and southern points, not only in zero-point but also with regard to the density gradient, is remarkable. The straight lines were obtained from least-squares solutions (northern and southern points combined); they correspond to an increase of ·133 per 1000 parsecs in the logarithm of the density at the 1040-parsec level, and of ·150 per 1000 parsecs for the 1410-level 1).

These same data may be treated more adequately, and much more simply, by starting from equidensity surfaces inclined to the galactic plane instead of parallel to it. For this purpose "pseudo-galactic co-ordinates" l' and b' have been computed with respect to a pseudo-galactic plane inclined at an angle $+i$ to the ordinary galactic plane for the northern areas, and at an angle $-i$ for the southern ones, as illustrated in Figure 8. New residuals $\Delta' \log A(m)$ were then computed by means of formulæ (1) and (2), inserting b' instead of b. The mean residuals with respect to equidensity layers inclined $\pm 10°$ to the galactic plane are shown under $\Delta' \log A$ in Table 11. The true inclination is that for which the systematic variation of the residuals with x_0 would disappear. It should be noted that this way of computing i has the advantage of being entirely geometrical, no knowledge of the density distribution in the direction of z being required.

We obtain

for $m_{90} = 16{\cdot}0 \quad i = 9^\circ{\cdot}0 \pm 0^\circ{\cdot}5$ (p.e.)

for $m_{90} = 17{\cdot}0 \quad i = 12^\circ{\cdot}1 \pm 0^\circ{\cdot}7$ (p.e.)

These values are for north and south combined. For $m_{90} = 16{\cdot}0$ the northern areas separately give $i = 8^\circ{\cdot}7$, the southern ones $8^\circ{\cdot}9$.

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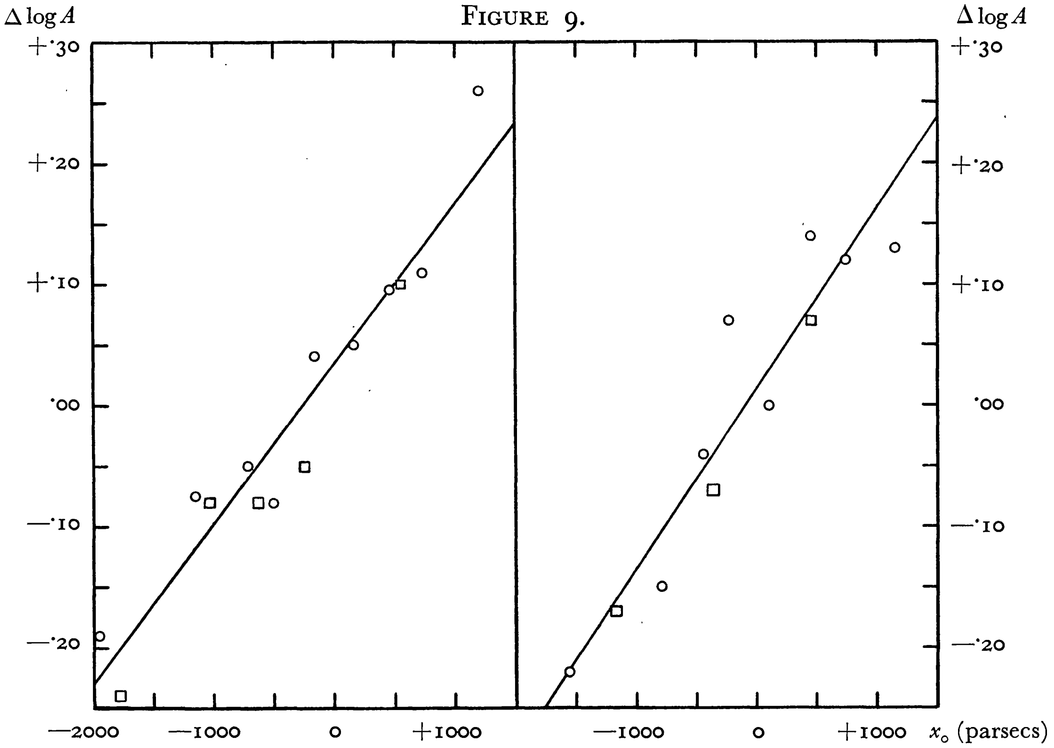
1) It may be noted that $\Delta \log A$ for $x_0 = 0$ is not zero, but about $+ {\cdot}036$ for the 1040-level and $+ {\cdot}014$ for the 1410-level. This is due to the fact that part of the stars grouped together in the level $m_{90} = 16$, for instance, are actually situated in lower levels, where the density increase in quadrants II and IV, which was discussed above, makes itself felt.

TABLE 11.

The density gradient for the layers between 800 and 1800 parsecs distance from the galactic plane. ($\Delta \log A$ refers to layers parallel to the galactic plane, $\Delta' \log A$ to layers inclined $\pm 10°$ to this plane; $\bar{x}_0$ is expressed in parsecs)

$m_{90} = 16{\cdot}0$, north				$m_{90} = 16{\cdot}0$, south				$m_{90} = 17{\cdot}0$, north				$m_{90} = 17{\cdot}0$, south			
$\bar{x}_0$	$\overline{\Delta \log A}$	$\overline{\Delta' \log A}$	w	$\bar{x}_0$	$\overline{\Delta \log A}$	$\overline{\Delta' \log A}$	w	$\bar{x}_0$	$\overline{\Delta \log A}$	$\overline{\Delta' \log A}$	w	$\bar{x}_0$	$\overline{\Delta \log A}$	$\overline{\Delta' \log A}$	w
+1200	+·26	+·06	5^5	+ 520	+·10	·00	6^5	+1160	+·13	−·04	4^5	+ 450	+·07	+·01	3
+ 730	+·11	−·02	4	− 220	−·05	−·04	7	+ 740	+·12	+·02	3	− 360	−·07	−·04	6
+ 460	+·10	+·02	6	− 630	−·08	·00	4	+ 420	+·14	+·08	6	−1240	−·17	−·04	5^5
+ 160	+·05	+·02	9	−1020	−·08	+·05	5	+ 100	·00	−·03	4				
− 170	+·04	+·05	10	−1690	−·24	+·01	5	− 230	+·07	+·08	6				
− 510	−·08	−·02	4^5					− 440	−·04	−·01	3				
− 720	−·05	+·02	4					− 790	−·15	−·07	5				
−1150	−·08	+·08	6					−1580	−·22	−·04	5^5				
−1940	−·19	+·10	5^5												

FIGURE 9.



Density gradient in the direction of the centre of the galactic system.

Left: level corresponding to $m_{90} = 16$, $z_0 = 1040$; right: level corresponding to $m_{90} = 17$, $z_0 = 1410$. Each point represents an average value of $\Delta \log A$ for, in general, about 5 areas. Circles indicate areas in northern, squares in southern galactic latitudes. Abscissæ are logarithmic mean co-ordinates, measured along the axis pointing to 325° longitude, and counted from the sun.

The density in the high levels varies so regularly that it is possible to determine the longitude l_0 of the centre of the galactic system from these star counts in high latitudes. For this purpose the $\Delta \log A$ for areas within the ring $480 < r_0 < 1180$ were plotted against l, and equations of conditions were formed as follows:

$$\overline{\Delta \log A} = c \cos (l - l_0),$$

in which c is an unknown constant and $\overline{\Delta \log A}$ represents the average of three neighboring areas within the ring considered. The same procedure was applied to the areas for which r_0 exceeded 1180 parsecs. Combining the results for the two rings we find

$l_0 = 327° \pm 4°$ (p.e.) for the areas in the north-galactic cap,

and $l_0 = 318° \pm 8°$ (p.e.) for the areas in the south-galactic cap,

while a combined solution gives

$l_0 = 324° \pm 3°$ (p.e.).

These results are in excellent agreement with the longitude derived from effects of differential rotation or from the distribution of globular clusters and planetary nebulæ.

But for one exception in each level the areas for which data concerning these high levels are available are situated above 21° latitude for the layer corresponding to $m_{90} = 16{\cdot}0$, and above 33° for that corresponding to $m_{90} = 17{\cdot}0$. The adopted absorption has, therefore, but a relatively small influence upon the above results for the inclination of the equidensity surfaces, and for the direction of the centre.

The fact that the density of faint stars in moderate and high galactic latitudes varies rather regularly with the longitude and shows a maximum near the longitude of the galactic centre has been noticed in several earlier investigations. SEARES [1]) showed that for the various latitude zones at 20° and higher, the longitude of the centre derived from smoothed star counts varies between the limits 318° and 341° for m 16 and 18, and similar results may be inferred from the Fourier coefficients by which VAN RHIJN has represented the star counts [2]). The same data

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[1]) "Structural features of the galactic system", *Ap.J.* **67**, 123 (1927); *Mt Wilson Contr.* No. 347, Table II.

[2]) *Publ. Kapteyn Laboratory at Groningen*, No. 43, Table 8 (1929).

were discussed by the author [1]), who also derived values for the density gradient (l.c. Table 28) and for the average inclination of the equi-density surfaces to the galactic plane, which agree reasonably well with the results found above. In all these articles the absorption was entirely neglected; on this account the course of the equidensity surfaces derived in *B.A.N.* No. 238 deviates considerably from that derived here for latitudes below 30°.

It will doubtlessly be of interest to compare the results of the foregoing investigations with those obtained from studies of galactic regions. But this, as well as the discussion of dynamical consequences of the structure indicated by the present study, was considered as being outside the scope of this article. As to the comparison with data at low latitudes, it might prove advisable to await more extensive data about color-excesses and, especially, about the ratio of photographic to selective absorption.

In conclusion it is a special pleasure to acknowledge my indebtedness to Mr VELDT, whose collaboration in the first stages of this work I have very deeply appreciated. My thanks are also due to Messrs PELS and KRIEST for their very efficient assistance in the greater part of the computations.

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[1]) *B.A.N.* VI, No. 238 (1932).