JOINT MEETING OF COMMISSIONS 8, 23, 24, 25, 27, 28, 29, 30, 32 AND 33 FOR A DISCUSSION ON GALACTIC STRUCTURE

On Saturday evening, August 6, a joint meeting was held of Commissions 8, 23, 24, 25, 27, 28, 29, 30, 32 and 33 for a discussion of the significance of the various branches of stellar astronomy for the problem of galactic structure. Prof. Lindblad presided over the meeting; introductory talks were given by Messrs Bok, Lindblad and Shapley, accounts of which may be found below.

STAR COUNTS

By B. J. Bok

Early advances in our knowledge of galactic structure were intimately connected with the gradual increase in the information concerning the numbers of stars to various limits of magnitude. Herschel's views on the structure of the Milky Way were based on his famous star gauges. Star counts on more or less accurate photometric systems played prominent parts in the classical theoretical studies of Kapteyn and Seeliger.

During the past forty years we have, however, come to realize the importance for statistical research of other types of observational data. Studies based on the distribution of spectra and colours have greater statistical resolving power than those from mere star counts. The discovery of various regularities in the motions of the stars has yielded entirely new modes of attack on the problems of galactic structure. It will hardly be necessary to remind you of the important role that studies on variable stars and the distribution of galaxies have come to play in galactic research.

The three most important recent advances in the study of our galaxy have been: (1) Shapley's determination of the distances of the globular clusters and his suggestion that the sun is located at a large distance from the centre of our galaxy; (2) the Oort-Lindblad theory of galactic rotation; and (3) the realization—through the work of Trumpler, Schalén and many others—that the light of distant galactic objects is dimmed to a considerable extent by interstellar absorption. These investigations were based on studies of variable stars, stellar radial velocities, and stellar spectra and colours. Shapley made some use of Nort's star counts, but we cannot claim that star counts have played a prominent part in galactic research during the past two decades.

It is therefore hardly surprising that astronomers have more and more turned away from star-counting projects. It is now ten years ago that Seares and van Rhijn completed their work on star counts from the Mount Wilson Catalogue of Selected Areas. Since that time some counts have been made for regions with dark nebulae of special interest, but the report of the chairman of Commission 33 of the I.A.U. indicates that, with the exception of a small group of astronomers associated with the Harvard Observatory, astronomers have no plans for the making of further star counts. I feel that many of us have come to underestimate the effectiveness of star counts as a tool for galactic research and I am therefore delighted to have to-day an opportunity to make, before the world's most competent audience, a plea for more star counts.

I have already referred briefly to the extensive distribution tables published by Seares in *Mount Wilson Contribution* 346 and by van Rhijn in *Groningen Publications* 43. Van Rhijn based his data for the brighter stars on counts in visual durchmusterung catalogues, while Seares depended largely on the extensive published material for the Carte du Ciel. This choice of sources was by itself the most effective plea for some straightforward counts referring to photographic magnitudes. The large systematic differences that were found to exist between the final distribution tables of Seares and van Rhijn demonstrated the insufficiency of the available material for the brighter stars. For the fainter stars both authors depended on the Harvard and Mount Wilson Durchmusterung of the Selected Areas. The magnitudes of the Mount Wilson Catalogue are excellent, but the catalogue does not include the areas south of declination $-15°$ and the total area covered is of the order of only one twenty-fifth of one per cent of the entire sky.

After the completion of the work of Seares and van Rhijn three important jobs remained to be done. The data for the stars brighter than the thirteenth magnitude were so unreliable that it was first of all necessary to provide accurate star counts between the ninth and thirteenth magnitudes for the entire sky. A second and very important job was the making of a fundamental catalogue, similar to the Mount Wilson Catalogue, for the Selected Areas south of $\delta = -15°$. Finally there remained the need for counts of stars beyond the thirteenth magnitude for areas of the sky much larger than those covered by the Mount Wilson Catalogue.

At the present moment our information on the distribution of the stars brighter than the thirteenth magnitude is nearly complete. The star counts of Lindsay have yielded distribution tables for the brighter stars in the southern hemisphere. The material published in the Harvard Tercentenary papers is shortly to be supplemented by star counts for the entire southern galactic belt. For the northern sky similar data are gradually becoming available as a by-product of the counts to fainter limits by Miller, McCuskey, Evans, Mrs Bok, Miss Risley and Baker. I may add that Schwassmann and van Rhijn's *Bergedorfer Spektral-Durchmusterung* contains much basic material for further work on star counts; the revised magnitudes of the Gaposchkins for the stars, the spectra of which have been determined at Potsdam, are similarly useful in the south.

The work for the southern counterpart of the Mount Wilson Catalogue has unfortunately not yet progressed very far. Shapley and the Gaposchkins have now undertaken the project with the aid of the 24-inch telescope at Bloemfontein, South Africa. The establishment of accurate photographic magnitude sequences for faint stars in the southern hemisphere will be important for many branches of astronomy.

The counts for the brighter stars, and the setting-up of magnitude sequences for faint stars in the southern hemisphere, are both jobs that are so evidently worth while doing that one need not defend their usefulness. Considerable difference of opinion may, however, exist on the subject of the desirability of extending the counts for faint stars over large areas of the sky. This problem is so complex that we can hardly dismiss it in a few words. Everyone will probably agree that it would be a waste of effort to attempt the making of star counts over the whole sky complete to the eighteenth or nineteenth magnitude. Personally I consider it, however, very important that star counts for the entire galactic belt should be at least complete to the fifteenth magnitude, but I realize that many of my listeners

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may disagree with me on that point. I shall therefore attempt to examine in detail the need for completeness in star-counting surveys. Before the discussion of counts in high, medium and low galactic latitudes, I shall consider briefly the techniques of star counting so as to give some suggestion about the amounts of time needed for the carrying through of various projects. I shall of course also discuss at some length the relation between star-counting projects and investigations dealing with spectra, colours and other data of importance for statistical studies.

For the case that a sequence of stars of known apparent magnitude is available on a given photographic plate, the actual counting of the plate is a simple undertaking that should not be time consuming. It is advisable to use a binocular microscope and to arrange the apparatus so that the scale of comparison images be continually in view during the counting. Great pains should be taken that the images on the comparison scale resemble in every respect the images on the plate that is to be counted. In spite of the simplicity of the arrangement, no one who has ever done any amount of star counting will deny that it remains a rather strenuous form of exercise and that constant attention from the side of the observer is required. In several respects we should feel ashamed that, in our modern days of radio tubes and counting gadgets, we should still have to depend on the human eye, a microscope, and pencil and paper for the making of star counts. I have during the past six years seen numerous suggested schemes for mechanical star counters, but I know as yet of no scheme which eliminates the repeated recording of the large images of bright stars. It is simple enough to suggest a machine, but the difficulties begin with its actual construction. During the past year McCuskey and Scott at Case School in Cleveland have been working on a semi-automatic star counter in which each image will still have to be placed inside a sensitive spot, but in which the actual counting to the various limits of image diameter is left to a photocell, amplifier, and a series of thyratron counter tubes working into ordinary telephone counters. McCuskey and Scott have finished all preliminary experiments and during this summer they are working on the construction of the machine. It is to be hoped that the first semi-automatic star counter may lead before long to the development of an entirely automatic model.

A few years ago the number of reliable magnitude sequences was still so small that the only satisfactory method for the setting up of a sequence was from series of polar-comparison plates taken on nights suitable for photometry. At present we have already available excellent photographic magnitudes for the stars in the northern Selected Areas, and before many years we may hope to have such sequences for the entire sky. The centres of the Selected Areas are only fifteen degrees apart and it is a simple matter to transfer a Selected-Area sequence to any neighbouring centre if we make use of the small cameras with large photometric fields that are now a part of the equipment of many observatories. Such a transferred sequence should be correct to one-tenth of a magnitude and reach stars of the fourteenth or fifteenth magnitude. It is not difficult to extend the sequence thus obtained to fainter magnitudes. If a large telescope is available long exposure grating plates will render it possible to extend the sequence to the eighteenth or nineteenth magnitude. In the absence of an objective grating the extension can be made through the use of a rotating sector or neutral filter, which should cover only part of the field. Miller and Hynek have found the sector and filter methods quite dependable in work on faint star counts with the 69-inch reflector at the Perkins Observatory.

Even with our present rather awkward techniques of star counting, and an insufficient number of reliable standard sequences, I consider it entirely within the realm of possibility to make star counts for the whole sky to the fifteenth magnitude and for a considerable portion of the sky to the eighteenth magnitude. It seems to me that we have every right to embark on ambitious star-counting projects, if only we have beforehand some guarantee that such counts will be of use in galactic research.

Let us now turn to the problems of analysis, where we shall consider separately the zones of high, medium and low galactic latitudes.

There is no special need for further extensive star counts in the galactic polar caps. The data for the Selected Areas in the north cap are mostly complete. The remaining gaps in our information for the south cap will be filled in as the various photometric programmes that are now under way are completed. Mrs Bok has recently made a further study of Lindsay's counts to the thirteenth magnitude for the southern hemisphere. Preliminary results of an analysis for irregularities in the polar caps give no indication for the existence of fluctuations that are statistically significant. The absence of a clustering tendency among the stars in high galactic latitudes is in marked contrast to the patchy distribution of the faint galaxies. It would be interesting to extend the star counts for some areas in the galactic polar caps to very faint limiting magnitudes, but I can see no need for programmes of star counts for large areas of the sky.

In the zone between galactic latitudes $\pm 15^\circ$ and $\pm 40^\circ$ the work on star counts should go hand in hand with studies on the distribution of faint external galaxies. If we omit a few regions that are obviously affected by local obscuration, we shall find considerable regularity in the stellar distribution for the intermediate zone. Oort in particular has shown how much information can be obtained from the analysis of star counts in this zone. The revolutionary results of Oort's recent study in *B.A.N.* 308 make it imperative that observers pay particular attention to the intermediate zone. We need galaxy surveys to faint limiting magnitudes, star counts to the sixteenth and preferably the eighteenth magnitude for regions of at least fifty square degrees of the sky around each Selected-Area centre, and detailed investigations on the distribution of spectra and colours for the faintest stars that can be reached with modern equipment.

Of considerable importance for galactic research should be special detailed investigations of the regions affected by local obscuration, such as the regions in Taurus, Ophiuchus and Cepheus.

In recent, as yet unpublished, investigations Lindsay and McCuskey show that it is impossible to obtain a good picture of the distribution of the absorbing material over an obscured region in intermediate latitudes unless we have a star-counting survey for the entire region which is complete to at least the thirteenth and preferably the fifteenth magnitude.

Lindsay finds from counts for the Ophiuchus region that the numbers of stars per unit area may, even at galactic latitude 20°, differ by factors five or six if we compare counts for the same limiting magnitude in two fields at the same galactic latitude, and whose centres are only two or three degrees apart.

McCuskey has studied the stellar distribution for a region of six hundred square degrees in Taurus; his counts are complete to the fifteenth magnitude. From an inspection of counts and photographs he has selected a number of reference regions that are apparently least affected by local obscuration. The variation of the counted numbers with the apparent magnitude is very similar for reference regions at the same galactic latitude, but with rather different longitudes. McCuskey concludes therefore that the irregularities in the apparent distribution of the stars are for this particular region largely caused by irregularities in the distribution of the absorbing material. He finds excellent agreement between van Rhijn's counts for single Selected Areas and his own counts for the same regions. It appears, however, that the average Selected Area in Taurus is affected to such an extent by absorption that van Rhijn's smoothed counts for the Taurus region refer to fields with an average absorption of seven-tenths of a magnitude. The star counts for the Selected Areas were found to be correct but not representative; it is simply impossible to obtain information on the stellar distribution in a region of variable obscuration from star counts for a few small areas chosen without reference to long-exposure photographs.

McCuskey finds that his values for the total absorption of some of the dark nebulae in Taurus check within two or three tenths of a magnitude with values derived from counts by others that reach to fainter limiting magnitudes. The obscuration in Taurus occurs, however, largely at comparatively small distances from the sun and it is therefore more significant to quote in the same connection a recent result of Miller, who has, with the aid of the 69-inch reflector of the Perkins Observatory, extended to very faint limiting magnitudes the star counts for some fields in Cygnus that were published in the Harvard Tercentenary Papers. The great majority of the dark nebulae in Cygnus lies beyond five hundred parsecs from the sun, but in spite of the large distances of these nebulae Miller finds it unnecessary to modify his original estimates of their distances and absorptions. It may be of interest to mention in passing that Miller finds a value of five magnitudes for the total absorption in certain parts of the northern "Coalsack" in Cygnus.

I have purposely postponed to the end of my brief talk a discussion of the use of star counts in studies for fields in low galactic latitudes. The reference to Miller's work has already brought up the study of dark nebulae in low latitudes; I shall first make a few remarks on this topic.

The work of our Swedish hosts, in particular that of Schalén, has demonstrated that our knowledge of dark nebulae may be greatly advanced through studies of stellar spectra and colours. Such studies, which have usually not reached beyond the twelfth or thirteenth magnitude, are, however, necessarily limited to comparatively small areas of the sky. Very few astronomers have attempted to supplement the laborious surveys for spectra, magnitudes and colours with some straightforward star counts to the fifteenth or sixteenth magnitude. It is true that the statistical "resolving power" of star counts is rather low and that the distances of dark nebulae, as found from star counts alone, may not be so accurate as those obtained from spectral surveys. We find, however, in all our investigations that the numerous stars between the twelfth and fifteenth or sixteenth magnitudes give very stable and reliable values for the total absorptions of the nebulae. Since star counts enable us in addition to survey large areas of the sky without too great an effort, I would not consider studies on dark nebulae complete without the data from star counts.

One cannot obtain from star counts alone definite information on the run of the star densities in low galactic latitudes. Unfortunately it is not possible to separate the effects of varying star density and interstellar absorption, even if we disregard for the moment the uncertainties arising from possible changes in the luminosity function. Miller has shown in the analysis of his star counts for the Milky Way in Cygnus that we may get somewhere in our analysis, if our counts are sufficiently extensive to make possible the elimination of regions affected by separate dark nebulae. But even under the most favourable circumstances our ignorance of a possible general absorption, which may affect the entire counted region, will leave us with a set of minimum values for the space densities as the final result of our analysis. Low-latitude star counts become, however, extremely useful when it can be shown from data on the distribution of galaxies that the total absorption of starlight for a particular direction must be small. It is obviously important to have star counts for a galactic window and the surrounding regions, but I shall leave the discussion of this topic to Dr Shapley.

Star counts can also frequently be used to great advantage in conjunction with data on spectra, colours or motions of distant stars near the galactic plane. The analysis of such data leads frequently to certain predictions for the run of the star densities and the average value of the coefficient of interstellar absorption for a section of the Milky Way. It is then possible to check the predicted numbers of stars per unit area for various limits of apparent magnitude against the totals that have actually been counted. All too frequently astronomers have neglected to make the obvious checks afforded by direct star counts. It would lead too far to go into details, but I believe that a result of an unpublished investigation of Edmondson, which I am at liberty to quote to-day, will serve to illustrate this particular point.

Edmondson has analysed star counts for the fields that have been the subject of extensive proper-motion studies at the McCormick Observatory. Van de Kamp and Vyssotsky had determined, from their material on secular parallaxes, what were the most likely values for the star densities and the coefficient of interstellar absorption. Edmondson shows that the predicted values for the counted numbers of stars, found on the assumption that the densities and coefficient of absorption of van de Kamp and Vyssotsky are correct, are very much smaller than the observed ones. Edmondson suggests that higher-order galactic rotation terms may have been the cause of the large apparent secular parallaxes found by van de Kamp and Vyssotsky.

I wish to emphasize that the example which I have just given is by no means the only occasion upon which star counts have not received the attention which they deserve. All too frequently investigators fail to include star counts in studies dealing with spectra, colours and stellar motions. Star counts should be of great value for any investigation in which conclusions are reached concerning star densities and interstellar absorption.

It seems to me that there is a need for more star-counting projects than we have to-day. No one has, for instance, investigated to what extent star counts on fast red-sensitive plates might replace the traditional counts for the photographic region. Baade's photographs of Milky Way regions suggest that real progress in galactic research can be made through accurate red counts. At present extensive work on star counts is practically confined to the Harvard Observatory and collaborating institutions. It is, however, distinctly inadvisable to leave the great majority of star-counting projects to the telescopes of a single institution. The possibility of photometric errors renders it desirable that independent checks be made at other observatories, and I can assure you that the Harvard astronomers would be delighted if their colleagues at other institutions should undertake to make star counts.

When I was first asked to speak on star counts at tonight's colloquium I felt strongly that I had to go out and defend a cause. I shall be very happy indeed if I have succeeded in making some of my colleagues a bit more "star count conscious".

I thank you.

In connection with Dr Bok's plea for more star counts Dr Oort remarked that fairly extensive star counts in the general region of the Ophiuchus nebulae were now being made by Prof. van Hoof at Leuven, using plates taken by Dr van Gent at Johannesburg.

Dr Baade was asked whether he would give some information concerning the advantages of the new red-sensitive plates for the problem of investigating the structure of the galaxy from star counts.

Dr BAADE: Everyone interested in stellar photography knows too well the difficulties which are encountered when one tries to photograph faint objects in the visual or red regions of the spectrum. Although a large number of orthochromatic and red-sensitive plates are available their sensitivities in the yellow and red are so low compared with the blue sensitivity of ordinary plates that prohibitive exposure times are necessary to reach really faint objects.

In the fall of 1936 Dr Mees of the Eastman Company sent us for trial a new red-sensitive emulsion, labelled Hα-special, which proved to be so fast in the red that one may say without exaggeration that it opens new fields in direct astronomical photography.*

The red-sensitivity of the new plate extends from about 5700 to 6700 A. Its grain is of about the same order as that of fast blue plates, e.g. the Imperial Eclipse or the Cramer high-speed plates. Best of all: ammoniating increases the red sensitivity of this fast plate by one magnitude without any perceptible increase of the chemical fog.

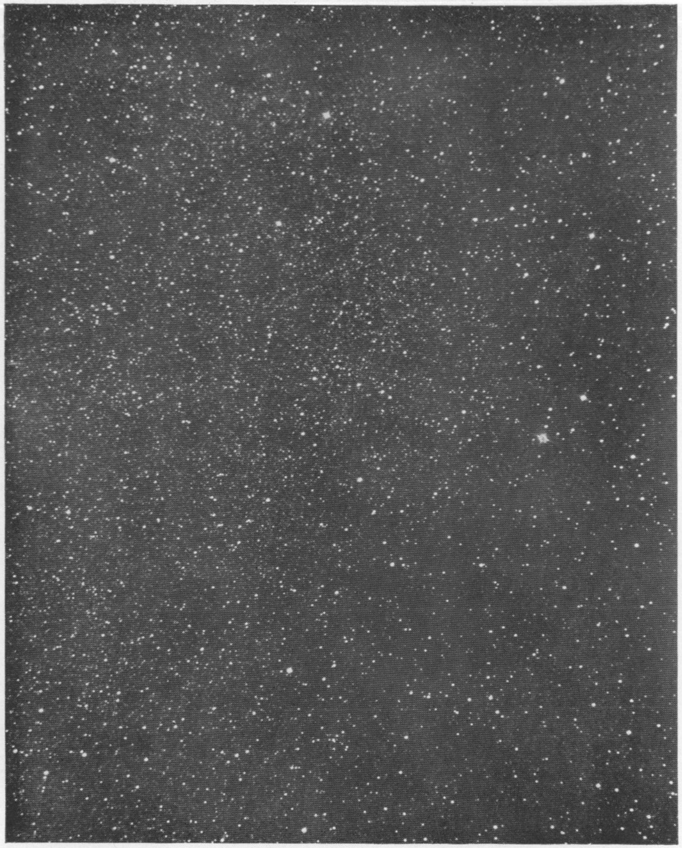
The new plates have been extensively used at the Mount Wilson Observatory. They are particularly effective in studying heavily obscured regions of the sky. This may be illustrated with the aid of photographs of two globular clusters, NGC 6553 and 6440, taken at the 100-inch telescope, alternatively on fast Imperial Eclipse plates with 50 min. exposure and on the new Hα-plate (ammoniated) with 75 min. exposure through a yellow filter which cuts out all wavelengths shorter than 5000 A. Checks by means of stars with known colour-indices (Polar sequence) show that for the relative exposure times here used stars of C.I. $= +0^{m}\cdot 40$, i.e. F7, will have at the limit of the plate the same densities on the blue and red plates. The photographs show the clusters much more strongly on the red plates; NGC 6440, which is the most difficult object among the globular clusters on ordinary blue-sensitive plates because the photographic magnitude of its brightest stars is close to 20^{m}, is a striking and easy object on the red plates. These plates illustrate the well-known fact that heavily obscured clusters are strongly reddened. But they show more: namely that the reddening not only affects the clusters but the whole stellar field in which they are imbedded. The observed reddening of the foreground stars in the present two cases is quite according to expectation if we accept that the obscuring material is strongly concentrated within a comparatively narrow layer around the main plane of the galaxy.

Strong reddening seems to be a general feature in all heavily obscured regions around the centre of our galaxy.

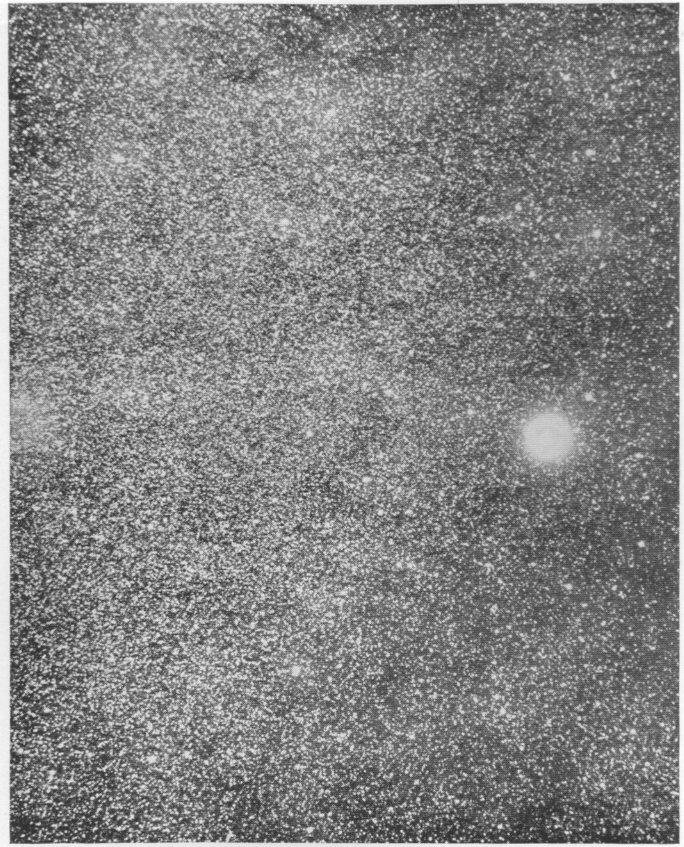
Plate II shows what happens when we photograph a region near the galactic centre which is apparently little affected by obscuration: one of the brightest

* Meanwhile the Agfa has put on the market red-sensitive emulsions of similar speed, of which the Superpan Press film should be mentioned especially because it combines extreme speed in the red and blue with a remarkably fine grain.

PLATE II



a



b

SAGITTARIUS CLOUD

a. Region at 329° galactic longitude and −4° latitude, in the large Sagittarius cloud, photographed on Imperial Eclipse plate. 100-inch Telescope. Exposure time 60 min.

b. Same region as on *a*, photographed on hypersensitized Hα-special plate through a yellow filter cutting out wave-lengths below 5000 A. 100-inch Telescope. Exposure time 90 min.

The relative exposure times of *a* and *b* are such that at the limit of the plates an F_7 star without colour-excess would have the same density on the two photographs.

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areas in the large Sagittarius cloud at longitude 329°, latitude −4°. The region was selected for the very obvious reason that the greater penetrating power of the Hα-plate might enable us to pass through the outer extensions of the hidden galactic nucleus.

Plate II*a* shows the region on a 60^m exposure taken at the 100-inch on an Eclipse plate, Plate II*b* the same region with 90^m exposure on an Hα-plate in the red.

Although the last reproduction gives a good impression of the very high stellar density in this area, the dense background of very faint stars shown on the original plate has been lost in the printing process. Actually the stellar density on the original plate is so high that the faintest star images just begin to merge into one another thus producing a background which reminds one of that of a globular cluster of moderate concentration. To obtain rough quantitative data, I have made counts on the original plate. A very conservative estimate for the stellar density in this area leads to the following figure: 800,000 stars per square degree. This is not yet the limit which can be reached with our present optical means since experiments have shown that the exposure times in the red region of the Hα-plates can be extended to 5 hours with the Mount Wilson reflectors on an average night before we reach a sky fog that corresponds to a 90^m exposure on a fast blue plate. Therefore under favourable seeing conditions it should be possible to increase the limit reached on the last plate by nearly another magnitude. It is very probable that for such an exposure even the resolving power of the 100-inch will be inadequate.

ABSORPTION PHENOMENA AS INFERRED FROM THE DISTRIBUTION OF EXTRAGALACTIC NEBULAE

By H. Shapley

(*Abstract*)

The absorption phenomenon that can be investigated through studies of the distribution of external galaxies is the relative amount, from one region to another, of the *total* photographic space absorption. The results of investigations in six different regions were reported.

1. In the South Galactic Polar Cap (β from −55° to −90°) the distribution of 90,000 faint galaxies indicates irregularities so large that the existence of a cosecant β law of space absorption (latitude effect) cannot be safely inferred. A conspicuous metagalactic density gradient appears in this region, and the *quantitative* use of nebular counts as indicators of space transparency is unfortunately thrown open to question. The distribution of faint stars in this polar cap supports earlier views that space in this direction is essentially clear of absorption (or clear, at least, of irregularities in absorption).

2. The magnitudes and positions have been determined for more than 30,000 galaxies of the eighteenth magnitude and brighter in the South Equatorial Polar Cap (δ from −60° to −90°), and evidence is found that absorbing material spreads to the Pole and beyond, 30° from the Milky Way plane. Also there is evidence of a rich metagalactic cloud extending from the region of the Clouds of Magellan towards the south galactic pole.

3. In the North Equatorial Polar Cap (δ from +70° to +90°) the distribution of 16,000 galaxies shows the patchy distribution of absorbing clouds in the vicinity of the North Pole. The nebular counts are supplemented by confirming studies of stellar distribution within ten degrees of the Pole.

4. In the Perseus-Cassiopeia region, where special investigations of the distribution of stars are being made by Dr Evans, an area of 1400 square degrees extending across the Milky Way has been searched for faint nebulae in order to assist in the location and measuring of absorbing clouds. This area includes the northern galactic window, where many galaxies are found within a few degrees of the galactic plane.

5. The region of the south-eastern galactic window ($\lambda = 300°$, $\beta = -15°$) has been further studied with respect to galaxies, variable stars (especially those of the cluster type), and space absorption. Several hundred new variables are found in fields that have a nearly average nebular population; some of the new cluster variables, with median magnitudes fainter than 16·0, must lie well beyond the galactic centre.

6. In the two "border" belts of galactic latitude, $+20°$ to $+30°$ and $-20°$ to $-30°$, a systematic programme of finding and measuring all galaxies brighter than magnitude eighteen is about one-third completed. The results, it is hoped, will closely indicate the amount of the absorption on the borders of the Milky Way, and also outline both the distinct clouds of absorbing material and the regions of high transparency, thus permitting the concurrent studies of faint variable stars in these border belts to furnish reliable measures of galactic form and dimensions.

The foregoing studies of nebular distribution are based on plates of three-hours exposure made with the Metcalf telescope at Oak Ridge and the Bruce telescope at Bloemfontein, supplemented at both stations with the large reflectors and with various small cameras.

In discussing the galactic absorption Father Rodés asked whether there was any certainty that the observed variations in the numbers of nebulae with galactic latitude were due to absorption. Dr Shapley mentioned the evidence from colour excesses. Dr Oort pointed out that the relative regularity of the distribution of faint nebulae over the entire region above $\pm 30°$ latitude made it extremely probable that the large deviations in lower latitudes were actually due to absorption. Dr Shapley agreed that the nebular distribution in low latitudes indicates absorption, but he wished to emphasize that the evidence obtained from the nebula-surveys at Harvard, which comprise very large numbers, proved that there were large-scale variations in the actual density of nebulae. Dr Oort remarked that for this particular problem a survey covering a number of small areas, but extending to faint magnitudes, like that carried out by Hubble at the Mount Wilson Observatory, seemed more advantageous than a comprehensive survey of the whole sky extending to smaller distances; Hubble's survey showed indeed few signs of larger scale irregularities in nebular density.

SPECTRAL TYPES AND DISTRIBUTION OF SPECIAL OBJECTS

By B. Lindblad

(Abstract)

The importance of spectral classification for the study of stellar distribution was already shown by E. C. Pickering in 1891, when he demonstrated the variation of the apparent galactic concentration of the stars with the spectral type. The great

dispersion in the luminosity function for all stars taken together and the probable deviations of this function from a Gaussian error curve make it very difficult to obtain safe results concerning the distribution of stars in space without a division of the material into groups which have a small dispersion in absolute magnitude. For the early spectral types the classification in the Harvard sequence means, as is well known, a grouping with respect to absolute magnitude with comparatively small dispersion in the groups. For the later spectral types we need above all, in addition to the classification in the ordinary Harvard sequence, a division of the stars into giants and dwarfs.

The most important statistical material of spectral classification is still the Draper catalogue. The extensive investigations based on this material are well known. In addition to the material of the Draper catalogue, we have at present above all the spectra of the Henry Draper Extension classified by Miss Cannon at Harvard and the extensive works of spectral classification in the Selected Areas by F. Becker at Potsdam, Humason at Mount Wilson and Schwassmann at Hamburg-Bergedorf. Considerable information concerning the distribution in space of the stars of various spectral types has been derived from these sources. Among the results derived from the recent material I may mention here the discussion by Becker for regions close to the Milky Way, and the investigations by Oort and by van Rhijn and Schwassmann on the density distribution in high galactic latitudes.

At the Uppsala and Stockholm Observatories methods have been developed which are based on spectrophotometric measurement of certain marked features in spectra of low dispersion. Some of these features depend intimately on the spectral type, whereas some depend rather intimately on the absolute magnitude of the stars. On the basis of these measurements it is possible to make a two-dimensional arrangement of the stars according to spectral type and absolute magnitude. A characteristic feature of the method is that it is based on quantitative measurements and not only on estimations of types. Each spectrum image is registered in a self-registering microphotometer and the tracings are measured and classified in a certain routine.

The most important quantities measured are the cyanogen absorption in the late types, which as a whole is strong in the giants and weak in the dwarfs, and the intensity of the lines of hydrogen in the early types, which for types earlier than A2 increases with decreasing luminosity. In the very late types there are further certain criteria of the absolute magnitude associated with the line $\lambda 4227$ of calcium. Between this line and the G band there is an absorption continuum which is strongly developed in the dwarfs of the M type. Ramberg has shown that there is an intimate relation between the intensity of the line and the absolute magnitude for dwarfs of the K5 and M types. Other criteria based on the intensity of the MgH and CaH have been developed by Öhman. He has further investigated the absorption in the Balmer continuum in the early types. Öhman and Iwanowska have found that on the low temperature side of the Balmer maximum, especially in the F type, the strength of the continuum is intimately connected with the absolute magnitude. The importance of these effects is that they enable a fairly accurate determination of the absolute magnitude in spectra of very low dispersion, at least sufficient for a division into giants and dwarfs, without taking into account geometrical data like the proper motions.

In this connection we are mostly interested in the applications of the methods to the study of the Milky Way structure. In addition to earlier works by Lindblad, Schalén, Petersson, Öhman, and others, a few rather extensive investigations have been performed recently, and other works are approaching completion. Stenquist has investigated the stars of the Cambridge regions for which proper motions have been determined by Smart. Using the distances computed from the spectrophotometric criteria he has converted the angular motions into absolute motions, and has studied the resulting velocity distribution in its dependence on distance. He derives in this way the probable amount of space absorption in various directions. It seems that this way of proceeding, in order to derive the space absorption as a foundation for a study of the density distribution, points in a direction which may be followed with advantage in future work when a greater material of accurate proper motions will be available. A great deal of information may be expected by the spectrophotometric work in fields of very accurate proper motions, especially close to the Milky Way.

Gratton has investigated a region around the Pleiades cluster using methods similar to those described above. From the relation between cyanogen absorption and the absolute magnitude inferred from the proper motions determined by Hertzsprung he derives a coefficient of absorption of 1·8 magnitudes per 1000 parsecs, practically the same as the average value derived by Stenquist. He then determines the density distribution for stars of successive absolute magnitudes in the direction of the Pleiades. The density is almost uniform for small distances. A slow decrease for greater distances may be due entirely to increasing distance from the galactic plane.

The regions of the Hyades and Praesepe clusters are at present under investigation by Ramberg, in order to study the members of the clusters as well as the field stars.

Extensive work on short objective-prism spectra is further carried out at Uppsala by Wallenquist, who examines 9000 stars in the Sagittarius and Ophiuchus regions on plate material assembled by him at Lembang, and by Johansson, Wernberg and Dyfverman in investigations of the Cygnus and Cepheus regions of the Milky Way.

An important application of the spectrophotometric methods has been made recently by Malmquist, who has applied the analysis to the regions near the north galactic pole, where he has previously carried out extensive determinations of photographic magnitudes and colour indices. His spectral investigation reaches about the photographic magnitude 13·5, and his material appears to contain practically all the giant stars in this direction in the region considered.

The general importance of investigating the distribution vertical to the galactic plane has been widely recognized in recent years. Oort has determined the vertical component of force at various distances z from the galactic plane, by co-ordinating the frequency distribution of the velocity components in the z-direction with the observed density distribution of the stars in z. A very direct way of determining the force should be possible if we knew more exactly by direct observation the variation in the velocity dispersion in the z-direction for a certain spectral group of stars with the distance from the galactic plane.

It may be shown that under very general conditions the law of force in the neighbourhood of the galactic plane will obey the relation

$$\frac{\partial^2 V}{\partial z^2} = -4\pi G\rho + 2\,(B^2 - A^2),$$

where ρ is the total density, and A and B are Oort's coefficients of differential galactic rotation. If B is numerically nearly equal to A, the second term in the right-hand member practically vanishes. In this form the relation has been applied to the A-type stars. A slightly more specialized relation has been used by Oort for estimating ρ. The present results indicate for ρ about $\frac{1}{10}$ of a solar mass per cubic parsec. Whether this is essentially more than the average density provided by the stars themselves seems still to be uncertain.

Studies of the space distribution of special objects of high internal velocity dispersion, like the globular clusters, the cluster type variables, and the planetary nebulae should be mentioned in this connection. The increasing extension at right angles to the galactic plane with increasing velocity dispersion and the decrease in the speed of rotation around the galactic centre, as shown by the phenomenon of the asymmetrical drift in the space velocities, give immediate connection with the ideas concerning the rotating "sub-systems" of the Galaxy, and further studies of the space distribution of special objects, especially in high galactic latitudes, should be of great importance for the development of our knowledge concerning the dynamics and the probable evolution of the galactic system.

Concerning the space distribution in low galactic latitudes the following points may be mentioned. According to a certain theory of star-streaming the matter of the star-streams has been ejected in asymptotic orbits from a discoidal central system, and we may expect the matter of the streams to form something like a ring around the central system. Here is a point where a further study of the especially bright objects, Cepheids, open clusters, etc. should be important. The objects adhering closely to the galactic plane should be expected to show a certain void region between our point of space and the central system.

In this connection the well-known spiral nebula NGC 7217 appears to offer some peculiarly interesting points for a better understanding of the dynamics of our own system. This nebula shows plainly a multiple spiral structure, namely an outer ring of matter surrounding an inner spiral structure, which evidently acts as central system for the asymptotic spiral whorls forming the outer ring. This ring might correspond to the possible ring formation in our own system which has just been mentioned above.

Carrying the analogy one step further, without arguing any quantitative correspondence between NGC 7217 and the Galaxy, it seems possible that in our system the main spiral structure occurs inside our point of the system, and that for instance the great star clouds of the Sagittarius-Scutum region form part of one of the mighty arms of this formation. This great spiral structure plays the part of a central system for another, from the outside of the system far less conspicuous, spiral structure in which the local cluster of B stars forms part of a diffuse arm. The majority of the stars in our neighbourhood are members of a wide ring of matter around the large spiral, and in this ring the various phenomena of star-streaming occur in approximate dynamical equilibrium.

Upon request of Mr Bok, Mr Oort was invited to say a few words on the question in how far present observations give evidence of spiral-like structure in our own stellar system.

Dr Oort: The possibility that the galactic system might have a spiral-like structure has been mentioned by Dr Lindblad and Dr Bok.

This question seems certainly to be one of the most interesting by which we are faced in the investigation of the galactic system. Is there a structure analogous to spiral arms; or is our system shaped like a strongly flattened elliptical or irregular nebula; or does it represent a type which has not yet been observed among extra-galactic systems?

There is a strong indication that the galactic system resembles the first type mentioned, and that the sun is situated between two arms. This may be illustrated by graphs exhibiting the density distribution within about 2000 parsecs from the sun in different layers north and south of the galactic plane. In each of Kapteyn's Selected Areas the ratio between the density in the area and the average density at the same distance from the galactic plane in the region immediately surrounding the sun has been derived in a geometrical manner, involving no knowledge of the luminosity function. The calculations have been restricted to areas outside the Milky Way proper, and the corrections to be applied for the absorption of light have been deduced from Hubble's counts of extra-galactic nebulae in regions immediately surrounding the Selected Area investigated.

The main uncertainty affecting these results concerns the assumption that the absorption found from the nebular counts takes place in front of the faint stars considered; the colour determinations in the Selected Areas published by Seares and Parkhurst give direct evidence in favour of this assumption, and so also does the separate investigation of areas in regions where the nebular counts indicate great transparency.

It would appear that a satisfactory investigation of the structural features indicated could most effectively be promoted by an extension of the region studied. As the structure appears to be limited to the regions within about 500 parsecs from the galactic plane, such an extension should primarily be undertaken for the lowest latitudes in which nebular counts can still be used to estimate the absorption. A rough estimate shows that if the investigations are limited to the more transparent part of the zone between 4° and 10° latitude average distances of about 4000 parsecs might be reached, thus making possible the survey of a very considerable part of the galactic system.

The Chairman said that as Dr Becker was present, who was so largely responsible for the discussion of the Potsdamer Spektral-Durchmusterung, he wished to invite him to address the meeting.

Dr Becker: Die kürzlich vollendete Potsdamer Spektral-Durchmusterung gibt die Spektren und genäherten photographischen Helligkeiten von rund 68,000 Sternen bis zur 12. Größe und schwächer in den Selected Areas des Südhimmels. Die Helligkeiten liegen im System der Harvard-Groningen-Durchmusterung und haben einen wahrscheinlichen Fehler von $\pm 0^{m}\cdot 12$ bis $\pm 0^{m}\cdot 15$. Die durchschnittliche Unsicherheit der Spektral-Klassifizierung beträgt etwas weniger als 0·2 Spektralklasse. Es wurde auch versucht, durch Schätzung der Intensität der Cyanbande bei $416\mu\mu$ in den Klassen G und K die Riesen und Zwerge zu trennen, aber die hierbei erzielten Ergebnisse befriedigen nicht, weil die Schätzungen in den schwachen Spektren zu unsicher sind.

Teilergebnisse zur sphärischen und räumlichen Verteilung der Sterne verschiedener Spektralklassen sind im Laufe der Arbeit von Dr Brück und mir veröffentlicht worden; eine zusammenfassende Diskussion des ganzen Materials ist im Gange. Einige Ergebnisse seien hier kurz erwähnt.

1. Beim Übergang zu schwächeren Sternen ändert sich am stärksten die prozentuale Häufigkeit der Klassen A und G. Im Durchschnitt über den ganzen Südhimmel nimmt bis zur 12. Größe der Anteil der A-Sterne auf 12·3% ab,

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während der Anteil der G-Sterne auf 42·0% steigt. Eine starke Abnahme zeigen auch die B-Sterne.

2. Die hauptsächlichsten Erscheinungen im Verteilungsbild der Spektralklassen lassen sich qualitativ auf drei Ursachen zurückführen, nämlich (a) die bekannte Häufigkeits-Zunahme der Sterne längs der Hauptserie von B nach M; (b) die abgeplattete Form des Sternsystems; (c) eine (auch in der Milchstraße) in gewisser Entfernung beginnende stetige Abnahme der räumlichen Sterndichte, sei sie nun reell oder durch interstellare Absorption verursacht.

3. In höheren galaktischen Breiten, etwa von $\pm 30°$ an, ist die Verteilung der Spektralklassen sehr einförmig. Der durchschnittliche Spektraltypus aller Sterne eines jeden Feldes schwankt zwischen den einzelnen Feldern nur etwa von G0 bis G3 bei wenig veränderter Streuung.

4. In der Milchstraße sind die Unterschiede zwischen den einzelnen Feldern größer. Der Prozentsatz der A-Sterne bis zur 11·5. Größe schwankt in den galaktischen Feldern von 17·9% bis 52·8%, der Prozentsatz der G-Sterne von 10·4% bis 48·0%.

5. In der südlichen Milchstraße gibt es zwei Gebiete von besonderem Interesse, nämlich erstens die große Sternanhäufung zwischen 250° und 280° Länge (Carina) und zweitens eine starke Depression der Sterndichte zwischen 290° und 340° Länge (Scorpio, Sagittarius). An der Häufigkeits-Zunahme in Carina sind die Sterne aller Spektralklassen beteiligt; von der Depression in Scorpio-Sagittarius werden die durchschnittlich näheren Sterne (Klasse G) relativ stärker betroffen als die entfernteren (Klasse A). Allgemein zeigen in der Milchstraße die A- und die G-Sterne in ihrer relativen Häufigkeit entgegengesetztes Verhalten; in Feldern, in denen die eine groß ist, ist die andere klein und umgekehrt.

Zum Schluß sei noch bemerkt, daß für die Untersuchung der Verteilung der Sterne in der galaktischen Ebene die Selected Areas offensichtlich zu wenig zahlreich und zu ungünstig angeordnet sind. Es wird notwendig sein, neue Felder einzuschalten und dabei mehr als früher auf die verwickelte Struktur der Milchstraße Rücksicht zu nehmen.

The President next invited Dr Malmquist to speak on the subject of his recently finished spectrophotometry of stars in high galactic latitude.

Dr Malmquist: In his introductory talk Prof. Lindblad has mentioned my investigations on the stars in high galactic latitudes. The third part of this work embraces a spectrophotometric analysis of about 2800 stars down to the photographic magnitude 13·5 within an area of about 70 square degrees. The instrument used is the 40 cm. astrograph of the Stockholm Observatory in conjunction with an objective prism which gives a dispersion on the plate of 1·7 mm. between $H\gamma$ and $H\epsilon$. The spectra were registered in a self-registering Koch-Goos photoelectric microphotometer. Altogether 11,000 registrograms were measured for the classification. From type G0 on a distinction between giants and dwarfs was made, mainly from the cyanogen bands.

Fig. 1 shows the relation between spectral type and colour index. The distinct difference in mean colour index between giants and dwarfs of the same spectral type is clearly demonstrated.

Concerning the proportion of the giants and dwarfs of types G and K the following results are obtained. Brighter than the eighth magnitude I have five giants and no dwarfs, between 8^m and 9^m 68 per cent are giants, between 9^m and 10^m,

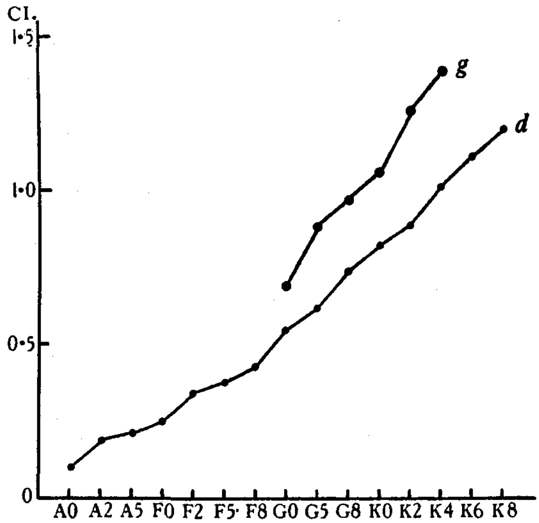

Fig. 1. The relation between spectral type and colour index for giants (g) and dwarfs (d).

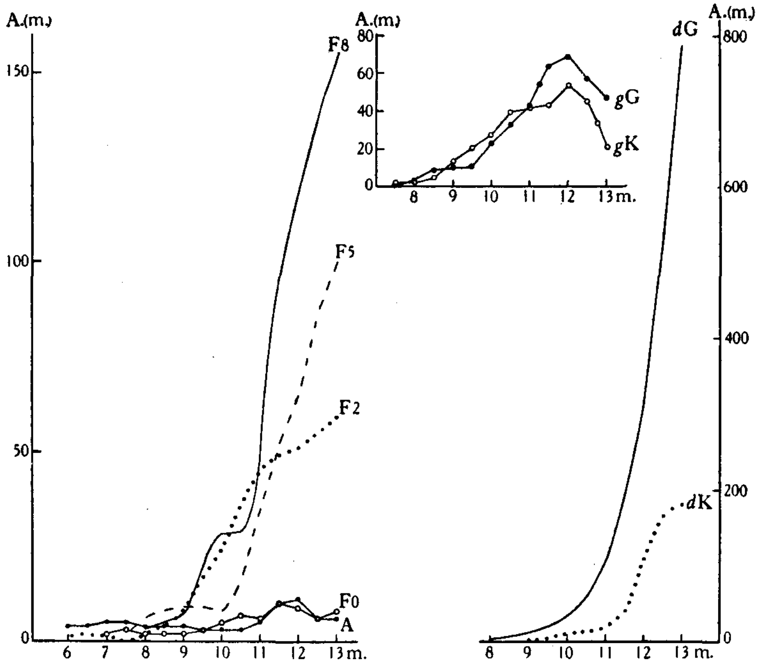

Fig. 2. The apparent magnitude curves of the different spectral types.

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56 per cent, between 10^m and 11^m, 50 per cent, between 11^m and 12^m, 32 per cent, between 12^m and 13^m, 13 per cent and between 13^m and $13^m\cdot5$ I have found 4·5 per cent giants only.

Fig. 2 shows the apparent magnitude curves of the different spectral types. The curves for the G- and K-giants (in the upper part of Figure 2) rise to a maximum at about the twelfth magnitude, after this magnitude the numbers decrease rapidly with the magnitude. The A-stars (at the bottom of the figure) show a somewhat different distribution; the number of stars of each magnitude is practically constant from the sixth to the eleventh magnitude with an indication of a small maximum at about the twelfth magnitude. It is evident from this distribution that the A-stars have a much stronger concentration towards the galactic plane than the late giants. The Fo-stars show a distribution similar to that of the A-stars, for the F2-stars we have not reached the maximum at our limiting magnitude, and passing on to the other types F5, F8, dG, dK the maxima become more and more remote.

I hope in the near future to be able to get spectra down to about the fifteenth magnitude. At this magnitude I suppose that no more giant stars will be present in the material (except some faint cluster type variables), so that the remaining stars belong to the main series and to the white dwarfs. These faint stars we may classify by the aid of colour indices for some additional magnitudes.