GALAXIES — PRESENT DAY PROBLEMS

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In the 25 years which have elapsed since the extragalactic nature of the spiral nebulae was established the center of interest in this field of research has shifted in a most remarkable manner. It all started normally enough. Through the discovery of Cepheids in these systems their stellar composition became firmly established, and subsequent investigations showed that like our own galaxy, star clusters, gas, and dust are mixed with the stars of these systems.

But hardly had the first provisional data for a few of the nearest galaxies been obtained, when a great discovery, the red shift in the spectra of the nebulae, diverted the inquiry into new directions. You all know what followed. The cosmological problem became the dominant question and a tremendous effort was made towards its solution. We know today that this bold first attempt ended in failure. The reasons for this failure are in part of a technical nature, as for instance the provisional character of the photometric scales used in this first attempt. There is no doubt that with the means now at our disposal reliable photometric scales will be available in the near future, although the requirements demanded by theory in order to distinguish between possible types of universes remain uncomfortably stringent. We are not so certain any more, however, whether certain basic assumptions underlying this first attack are justified. Thus it was assumed that the galaxies as a group were sufficiently homogeneous to justify the introduction of a standard model which would permit us to compute the changes in bolometric brightness caused by the red shift. We know today that this simplification is not permissible and that, in order to correct properly for the influence of the red shift, it is necessary to divide up the galaxies into type I systems, type II systems, and mixed systems. Even more threatening is the recent discovery of Stebbins and Whitford that the early-type nebulae — and presumably all type II systems — show, in addition to the reddening caused by the red shift, an intrinsic reddening increasing with distance. If the proposed explanation of the Stebbins-Whitford effect is correct, one of the fundamental assumptions made thus far, the constancy of the absolute magnitude of a galaxy, will go overboard, at least for all type II systems. Altogether, there are good reasons to believe that solution of the cosmological problem is much more difficult than was thought some 15 years ago and that it may well lie beyond our present powers. Certainly, we will need much wider and better-secured foundations than at present before we can hope to erect big superstructures.

In the following discussions I shall, therefore, leave the cosmological problem entirely aside and restrict myself to questions concerning the galaxies as individuals. Present knowledge is still very sketchy in this regard, but with the 200-inch now in operation a rather detailed study of all galaxies within 2.5 megaparsecs should be possible. The volume thus defined includes, besides the local group of galaxies, the group associated with the well-known spirals M81 and M101. It should, therefore, provide a much larger and more representative sample of galaxies than was previously at our disposal.

The Luminosity Range of Galaxies: Let us start with a very simple but fundamental question: what are the ranges in luminosities and diameters of the galaxies? To answer these questions we must restrict ourselves to systems of well-determined distance moduli; that means our local group of galaxies and nearby groups like those associated with the nearby spirals M81 and M101. Because the galaxies thus defined are nearby systems, their apparent diameters are large and an accurate determination of their integrated magnitudes presents great difficulties. Up to now we have had to rely on values which were hardly better than estimates. In recent years these estimated integrated magnitudes have become more and more subject to suspicion, because they led to results which could not be reconciled with data obtained independently. Putting too much reliance on such estimates, some investigators in recent years have stoutly maintained that the brightest globular clusters of our galaxy are quite comparable in luminosity with the smallest galaxies of our neighborhood and that they may even surpass them. What they overlooked entirely is the fact that some of these dwarf galaxies have their own globular clusters and that a simple look at their photographs provides convincing evidence that the luminosities of the dwarf galaxies are entirely outside of the range of the globular clusters. A first attempt to obtain reliable integrated magnitudes of nearby systems with large angular diameters was made some 12 years ago by Whitford with a photocell mounted at the Mount Wilson 10-inch refractor.

Quite recently Holmberg made another attempt to obtain accurate integrated magnitudes for the members of the local group and the groups associated with M81 and M101. Holmberg,[1] working at Mount

[1] Lund Medd., Ser. II, No. 128, 1950.

Wilson, used photographic photometry, exposing one half of the plate to the nebula in focus and the other half to the Polar Sequence out of focus. Through photometric tracings the total light of the nebula is integrated, the Polar Sequence stars providing the standard intensities. This method is free from objections but very tedious. On the average, Holmberg measured for each nebula 3 plates in the photographic and 3 in the photovisual region. The accuracy of either a final photographic or photovisual nebular magnitude is very high, with a mean error of only $\pm 0^{m}.04$, which testifies to the care with which the measures have been made. As Figure 1 shows, the agreement of Holmberg's results with Whitford's earlier measures is excellent, so that we can be confident that we have now reliable and accurate integrated magnitudes for this particularly difficult group of the nearest galaxies. The diagram also shows the comparisons with the Shapley-Ames Catalogue and with Holetschek. It is obvious that between 3^{m} and 11^{m}, which is the range covered by the local group of galaxies, the magnitudes of the Shapley-Ames Catalogue are systematically too faint by a whole magnitude. For the Holetschek

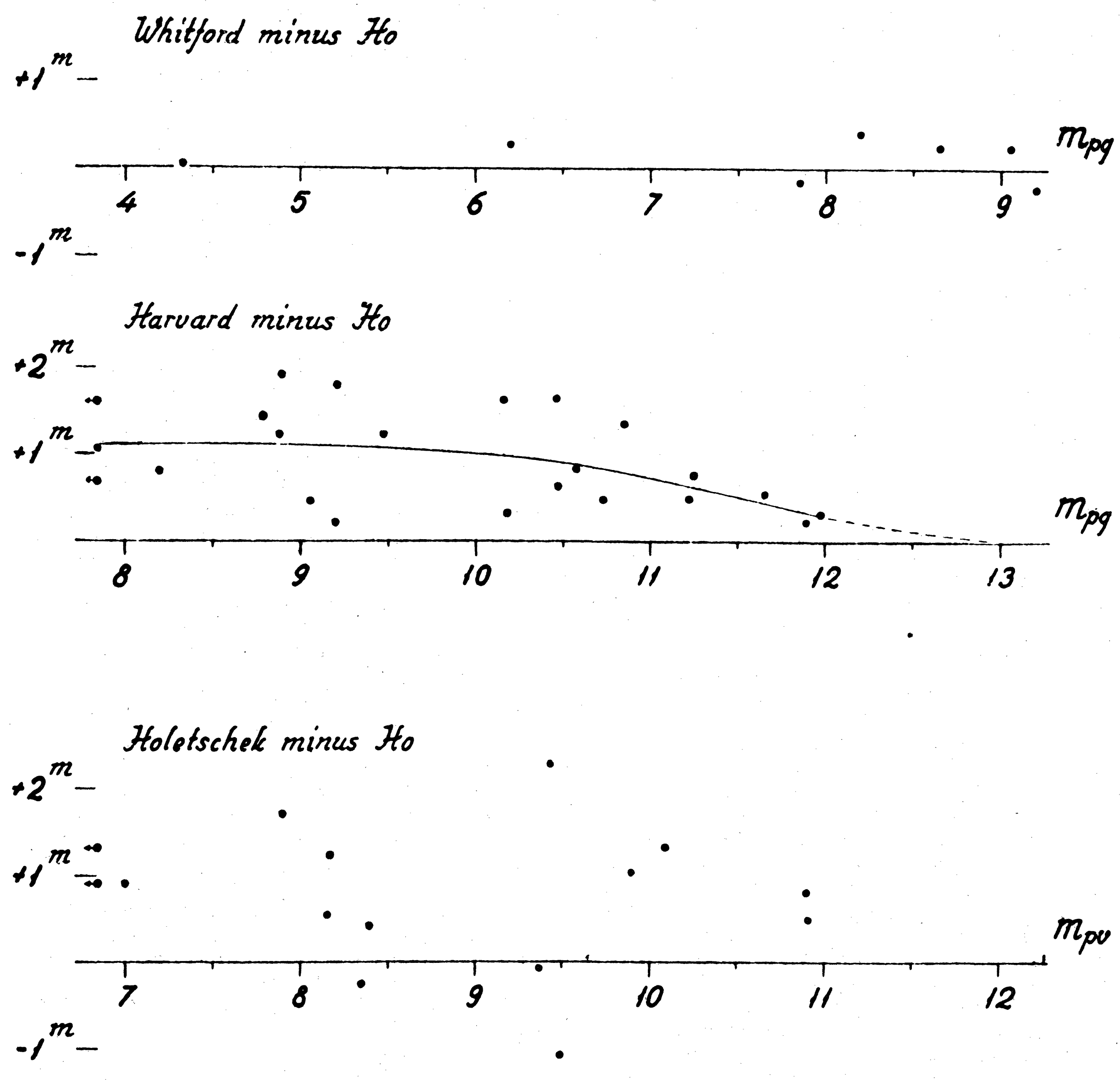

Fig. 1. Comparison of Holmberg's integrated magnitudes of nearby nebulae with those of Whitford, Shapley-Ames, and Holetschek.

Catalogue, the scatter of the individual observations is so large that it is better to disregard them entirely from now on.

The galaxy with the largest absolute photographic magnitude in Holmberg's list is the Andromeda nebula of $M_{pg} = -18^{M}.1$; the faintest is NGC 147, one of the distant companions of the Andromeda nebula, of $M_{pg} = -11^{M}.9$. Although NGC 147 is one of the poorest galaxies known, it is quite possible that specimens like the Sculptor system may be somewhat fainter. But all available evidence now suggests that galaxies with luminosities much below -12^{M} are exceedingly rare, if they occur at all. This puts a clear-cut gap of about 3 magnitudes between the faintest galaxies and the brightest known globular nebula leave no doubt that globular clusters are subunits of galaxies.

Figure 2 shows the frequency function of the luminosities of galaxies, as derived by Holmberg from the local group and the groups associated with M81 and M101. You will notice that the new luminosity function is strongly asymmetrical on account of the high percentage of dwarfs in these groups. There is every indication that the asymmetry of the luminosity function has come to stay. For one thing, we are steadily picking up on our 48-inch Schmidt survey plates dwarf systems which are resolvable at this instrument and hence belong to our close neighborhood, say systems with moduli $\leqq 24.0$. For the other, surveys of the Virgo cluster by Shane, with the Lick

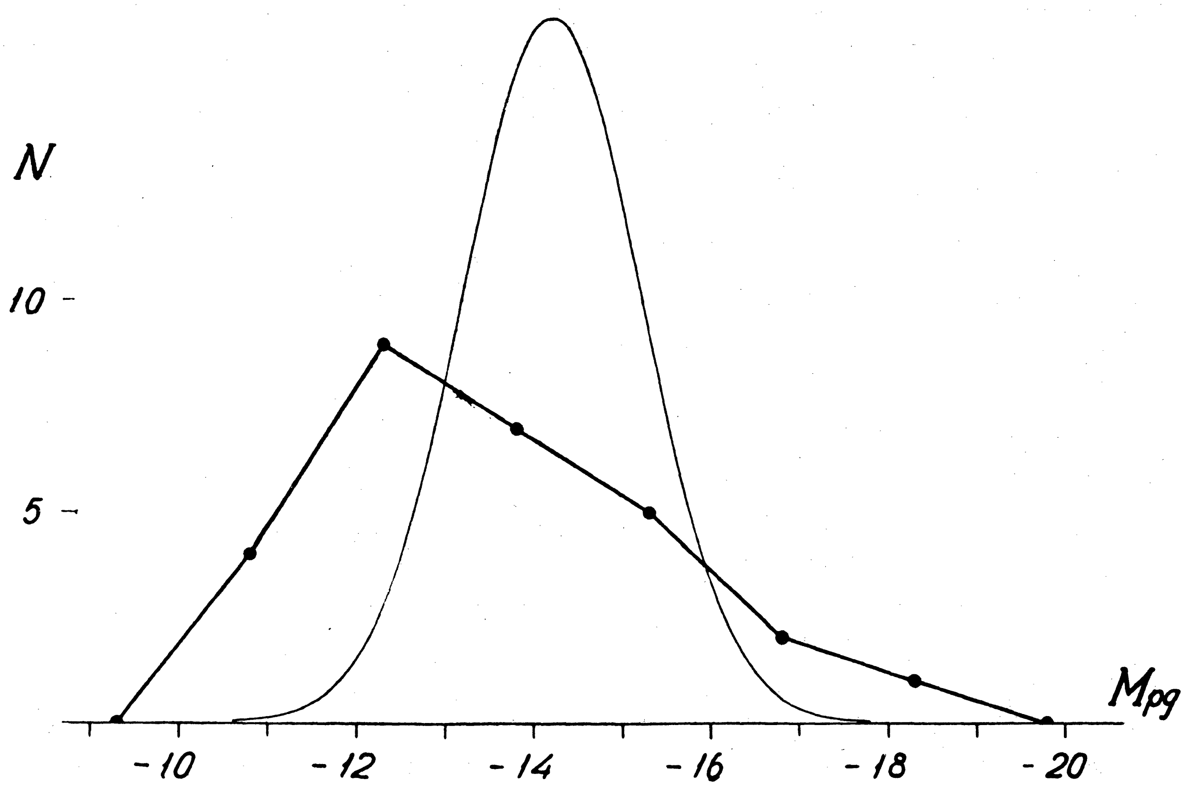

Fig. 2. Holmberg's luminosity function for galaxies (broken line). The smooth line represents Hubble's luminosity function.

clusters. The gap in the linear dimensions of the globular clusters and dwarf galaxies is even more pronounced, the linear diameters of the largest globular clusters are of the order of 100 parsecs, whereas those of the smallest galaxies are of the order of 1000 parsecs. As things stand at present, there is nothing to support the view that there is a steady transition from galaxies to globular clusters. Besides, the systems of globular clusters associated with our own galaxy and the Andromeda

20-inch refractor, and by me, on 48-inch Schmidt plates, show that dwarf galaxies are also abundant in this cluster. As a result of the asymmetry of the luminosity function the mean absolute magnitude for galaxies has to be lowered from Hubble's original value of $-14^{M}.2$ to $-13^{M}.5$. At the same time the dispersion of the nebular magnitudes has to be doubled. Holmberg finds $\sigma = 1^{M}.85$ compared with Hubble's $0^{M}.85$. In the diagram is also given Hubble's old luminosity function. It is obvious that it represents the new material poorly. This example shows clearly how primitive our present knowledge still is, and that in this field we are not yet in a position to tackle more ambitious problems.

The Composition of Galaxies: Let us turn next to the composition of galaxies. The recognition of fundamental types of stellar populations has led here to a great simplification, because it enables us to divide the galaxies into 3 classes: type I systems, type II systems, and mixed systems. A close correlation exists between this division according to stellar content and Hubble's classification of nebular forms. All early nebular types, from E0 to S0, are pure type II systems; the early and intermediate spirals Sa and Sb are mixed systems, the percentage of type I stars gaining steadily as one goes from the Sa's to the Sb's. Population I makes its greatest display in the Sc spirals and in the irregular systems of the Magellanic Cloud type, and there is good reason to believe now that pure type I systems exist. The large Magellanic Cloud, is a system of this kind as I shall show later on.

Closely correlated with the division of galaxies into 3 broad classes is another feature, the presence or absence of dust in these systems. Pure type II systems such as the E and S0 nebulae are free from dust; only when dust is present do the stars of population I show up.

Let me quote 2 striking illustrations. We know that the elliptical companion of the Andromeda nebula, NGC 205, is a typical type II system, as its resolution into stars a few years ago has shown. But it is one of the few known type II systems in which the presence of dust is indicated by 2 absorption patches in the central region. Now what happens? When one photographs NGC 205 (Figure 3) in the ultra-violet, which suppresses the red giants of the population II, about a dozen bright B stars of absolute magnitudes around $-2\overset{M}{.}5$ stand out in the central region. Even on ordinary blue plates they are a conspicuous feature, if one does not overexpose the central region, and they were noted as probable members of NGC 205 by Hubble some 25 years ago. There is a similar situation in NGC 185, one of the more distant companions of the Andromeda nebula. Again we are dealing with a type II system in which some weak absorption patches indicate the presence of dust. Using the same technique as in NGC 205, we find scattered through this galaxy about a dozen B stars between photographic magnitudes 20^m and 21^m; that means of absolute magnitudes $-2\overset{M}{.}5$ to $-1\overset{M}{.}5$. Per contra NGC 147, a type II system which forms a pair with NGC 185, shows no trace of absorption patches and is apparently transparent up to its very center, because extragalactic nebulae shine through it. Not a single one of the kind of B stars appearing in NGC 205 and NGC 185 was found in this system, when it was treated with the same technique. Numerically, these few normal B stars which are representatives of the type I, are of course quite unimportant compared with the hundreds or thousands of type II red giants in these systems, and we are justified in treating them as impurities in a predominantly type II population. But these examples show in a striking manner the intimate relation between the presence of dust and the appearance of type I stars. No dust, no population I, particularly no B and O stars.

This absence of dust in type II systems, except for small impurities, is a very agreeable feature, because it guarantees that neither the observed luminosities nor the integrated colors of such systems are affected by internal absorption. Moreover, since we have every reason to believe that the stellar composition of these systems is exceedingly homogeneous, for they are all controlled by the same Russell diagram, we should expect a remarkable constancy of the integrated colors of all type II systems. In order to test this, I induced Stebbins a few years ago to observe photoelectrically the colors of a list of nebulae, which were as representative of the types of galaxies as we could make them.

Table I gives the results.

TABLE I

Photoelectric Color Indices of Nebulae

Type	$CI_{intern.}$	n	σ_{CI}
E.	$+0\overset{m}{.}87 \pm 0\overset{m}{.}01$	31	$0\overset{m}{.}06$
S0	0.88 ± 0.04	9	0.12
Sa	0.83 ± 0.05	5	0.12
Sb (central regions). . . .	0.92 ± 0.02	9	0.07
Sc (integr.). . . .	$+0\overset{m}{.}45 \pm 0\overset{m}{.}04$	13	$0\overset{m}{.}11$

Note that the observed color indices fall into 2 groups, the one clusters around the value $+0\overset{m}{.}87$ and the other around the value $+0\overset{m}{.}45$. It may also be seen that the larger of the 2 values, $+0\overset{m}{.}87$, refers to type II population. The E and S0 systems need no comment in this respect. In the Sa spirals there are besides the population II, incipient spiral arms with their population I, but in the cases represented here the contribution of the spiral structure to the total light is negligible, so that the color index refers to the dominating population II. In the Sb spirals the measures were restricted, as indicated in the table, to the central regions, which are free of spiral arms and, hence, again are representative of the population II. The table shows convincingly that the color index is very closely the same for all type II systems, $+0\overset{m}{.}87$ on the International System. For systems in which population I dominates, the Sc spirals in the table, the integrated color index is $+0\overset{m}{.}45$, about half as large as for type II systems. The remarkably small dispersion in the color of pure type II systems is probably best indicated by the group of E nebulae, which are numerically the strongest sample in the table. Stebbins and Whitford recognized at once that this constancy of the colors of type II systems

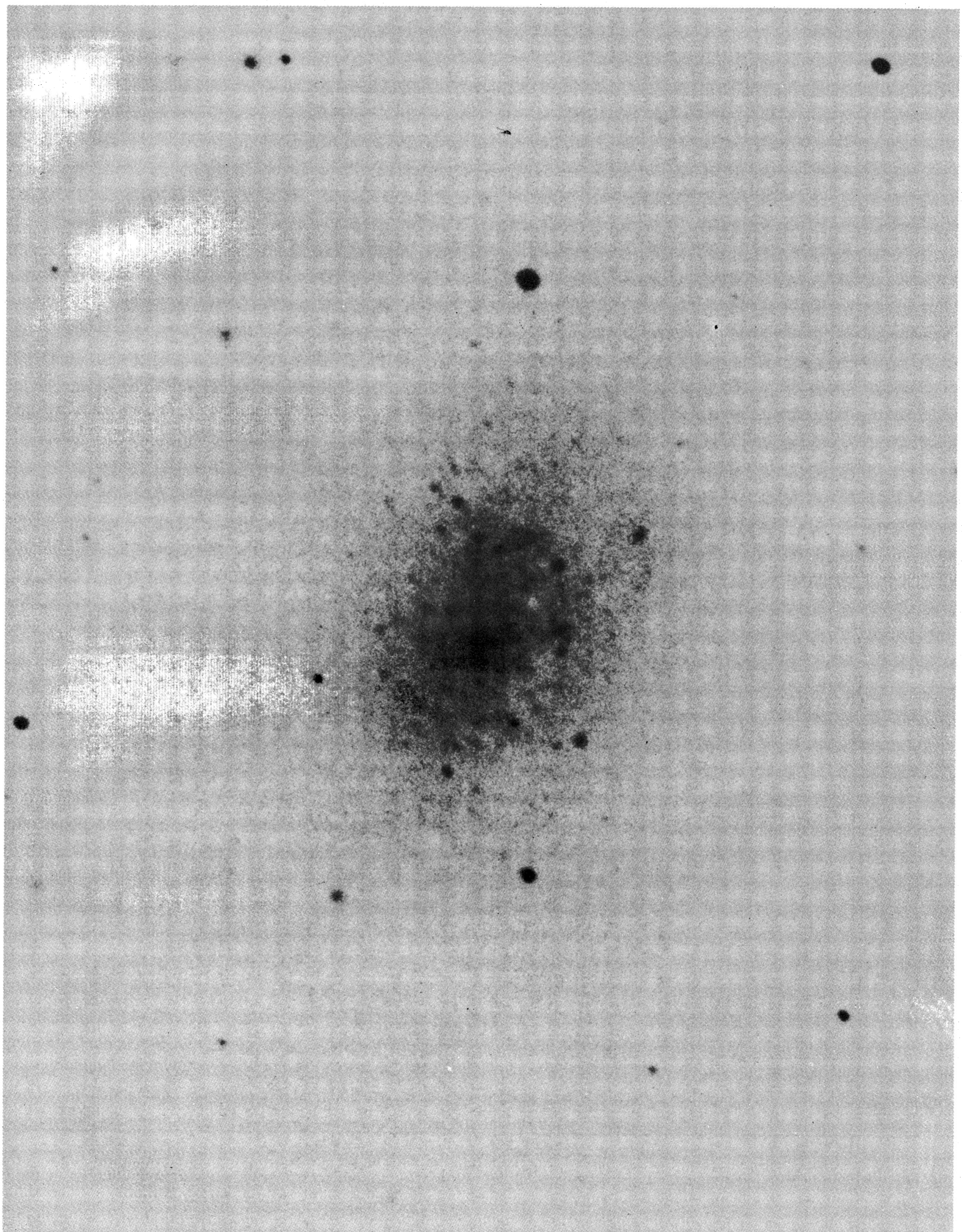

Fig. 3. Central region of NGC 205, photographed in ultra-violet light (λ3500-λ3900) at 100-inch reflector. Note the absorption areas north and south of the center.

provided a powerful tool in probing the change of color with the distance of the nebulae. They set out, if I remember correctly, to replace, for very distant type II systems, the radial velocity measures by color measures and ended up with the discovery of the Stebbins-Whitford effect.

Type Indicators for the Population II: I mentioned earlier that if we try to classify the galaxies according to their stellar populations, a division into type II systems, mixed systems, and type I systems would appear most logical. But we have to overcome some practical difficulties before we can apply this scheme even to the nearest galaxies. The segregation of the pure type II systems is easy enough, since they coincide essentially with Hubble's types E and S0; the absence of supergiants is a very characteristic feature, and finally their color index should conform to the standard value. Nor do the mixed systems represented by the Sa and Sb spirals offer any difficulties; a mere inspection of the photographs reveals the 2 populations at a glance, the population I with its bright supergiants along the spiral arms and the population II in the extended central lens. But in the Sc spirals and the irregular systems of the Magellanic Cloud type the situation becomes really complicated. The type I supergiants are spread over the entire face of such a galaxy and dominate the picture to such a degree that the observer is at a loss in deciding whether he is dealing with a pure type I or with a mixed system. What is obviously needed in such cases are type indicators of the population II, objects which are easily recognized and which are so characteristic of the population II that they identify it beyond doubt. Such type indicators are the variable stars associated with the population II, and the best known are the cluster-type variables, which serve admirably as indicators of the population II because they occur with great abundance. Their only drawback, if we want to use them as indicators of a population II in nearby galaxies, is their relatively low absolute magnitude, M = 0, which puts them, even in the Andromeda nebula, close to the limiting magnitude of the 200-inch.

Fortunately, we can fall back in such cases on the long-period Cepheids associated with the population II. That Cepheids with periods $> 1^d$ occur in the population II has been long established by their presence in globular clusters. But in several respects these type II Cepheids differ from their classical counterparts. First, while in our galaxy and in the Magellanic Clouds the number of Cepheids increases with decreasing length of period, with a maximum frequency around 2 to 4 days, the Cepheids in the globular clusters have a maximum frequency between 13 and 19 days, the frequencies dropping on either side of this interval. Second, the Cepheids which fall into this interval have light curves totally different from those of the classical Cepheids of the same periods. Whereas the latter have narrow sharp maxima, the former show a pronounced halt after the maximum, which lasts for several days. Since the prototype of this type of Cepheid in our galaxy is the well-known high-velocity star W Virginis, these type II Cepheids are often called the W Virginis Cepheids or, according to their mean period, the 16-day Cepheids. Spectroscopically, they have long been known as the only Cepheids which show emission lines at certain phases, and recent work by Sanford[2] with high dispersion has added to this the remarkable feature that shortly after maximum all lines in the spectrum are double, one set representing the old pulsation cycle, the other the new one. Probably no other fact emphasizes so pointedly the fundamental character of the 2 stellar populations as these differences in their Cepheids. What interests us here is that the most frequent group of Cepheids in the population II, the W Virginis variables, are easily recognized by their light curves and, since they are 2.5 magnitudes brighter absolute than the cluster-type variables, they can serve as indicators of the population II, when the former are already beyond reach. One of the results of the Harvard variable-star survey covering the galactic center region was the unexpected high frequency of what Shapley termed the 16-day Cepheids, and he interpreted this as due to a concentration of the more massive Cepheids in the galactic center. Since the few published light curves of these 16-day Cepheids clearly indicate W Virginis character, another interpretation is more to the point; namely, that a strong population II occupies the center of our galaxy. To the W Virginis Cepheids should be added the RV Tauri variables as typical population II objects. They have about the same absolute magnitude as the W Virginis Cepheids but may be too rare to be of practical importance.

Another group of variables which probably will become increasingly important within the next few years are the long-period variables. Red exposures taken with the 100-inch suggest their presence in systems like NGC 185 and NGC 205, and we intend to examine them more closely with the 200-inch. What we should expect is indicated in Figure 4.

Plotted are the giant branches of the 2 populations I and II. I have also put in the location of the Me or Mira variables, according to the determinations by Gerasimovič, by Wilson and Merrill, and by Oort and van Tulder.[3] In order to make everything more familiar I have plotted visual absolute magnitudes against spectral type. The whole diagram is of course schematic, although based on the best available data. The diagram shows that, of the Me variables, those of shorter period — around 200 days — should be prevalent in population II, whereas those of long period — 350 days and more — should be a

[2] R. S. Sanford, Pub. A.S.P., 61, 135, 1949. [3] B. P. Gerasimovič, Proc. Nat. Acad. Sci., 14, 963, 1928. R. E. Wilson and P. W. Merrill, Mt. W. Contr., 658; Ap. J. 95, 248, 1942. J. H. Oort and J. J. M. van Tulder, B. A. N., No. 353, 1942.

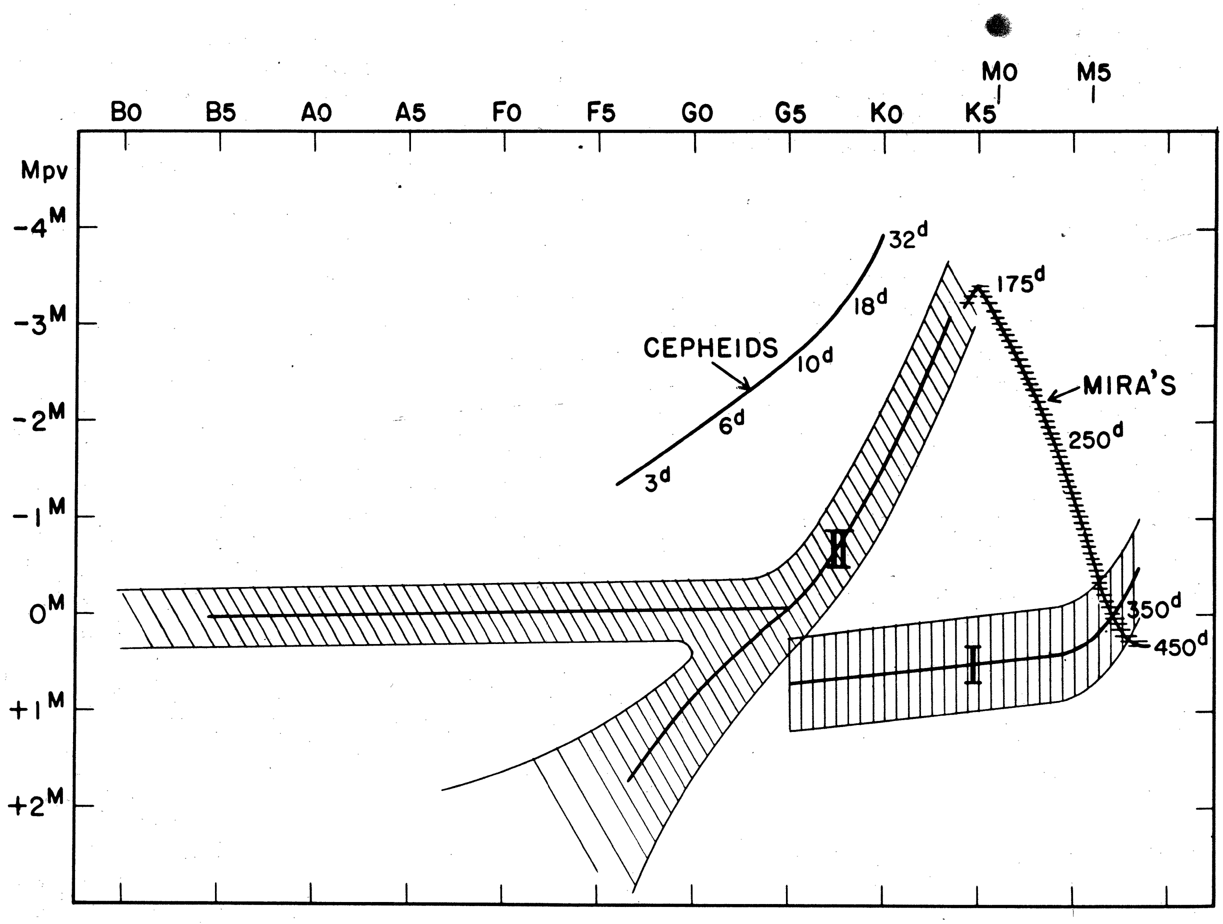

Fig. 4. The place of the long-period variables in the Hertzsprung-Russell diagrams of the populations I and II.

characteristic feature of the population I. Furthermore, the Me variables of the population II should at maximum belong to the very brightest stars occurring in this population, surpassing the cluster-type variables visually by about 3 magnitudes, or photographically by about 1.5 magnitudes. Particularly on red exposures they should, therefore, be valuable as type II indicators, when the cluster-type variables are beyond our reach. There is good reason to believe that the schematic and somewhat oversimplified picture which I have drawn is essentially correct. For one thing, it is well known that the Me variables of our galaxy with periods $< 250^d$ contain a high percentage of high-velocity stars, whereas those with periods around 350 days belong essentially to the slow-moving stars. This is just what we should expect, if we identify the high-velocity stars of our galaxy with the population II; the slow-moving stars with the population I. For the other, Shapley reported as one result of his surveys of the galactic center region, that the long-period variables in these fields, with a mean period around 220 days, surpass in brightness the numerous cluster-type variables by just about the amount predicted here; namely, 1.2 magnitudes photographically. Please keep in mind that these remarks about long-period variables in their relation to the 2 populations refer strictly only to the Me variables or the Mira type. There are other long-period variables, with periods between 120^d and 200^d, which differ from the standard Mira type by their much smaller amplitudes. There are strong indications that their luminosities are the same as those of the Mira variables of corresponding period, but the matter needs further investigation.

So much about our present methods of identifying the 2 stellar populations, particularly in mixed systems. Let me give 2 examples. First, in the reasoning which led to the concept of the 2 populations the Sculptor system played an important role. It is the nearest of the spherical galaxies, in fact near

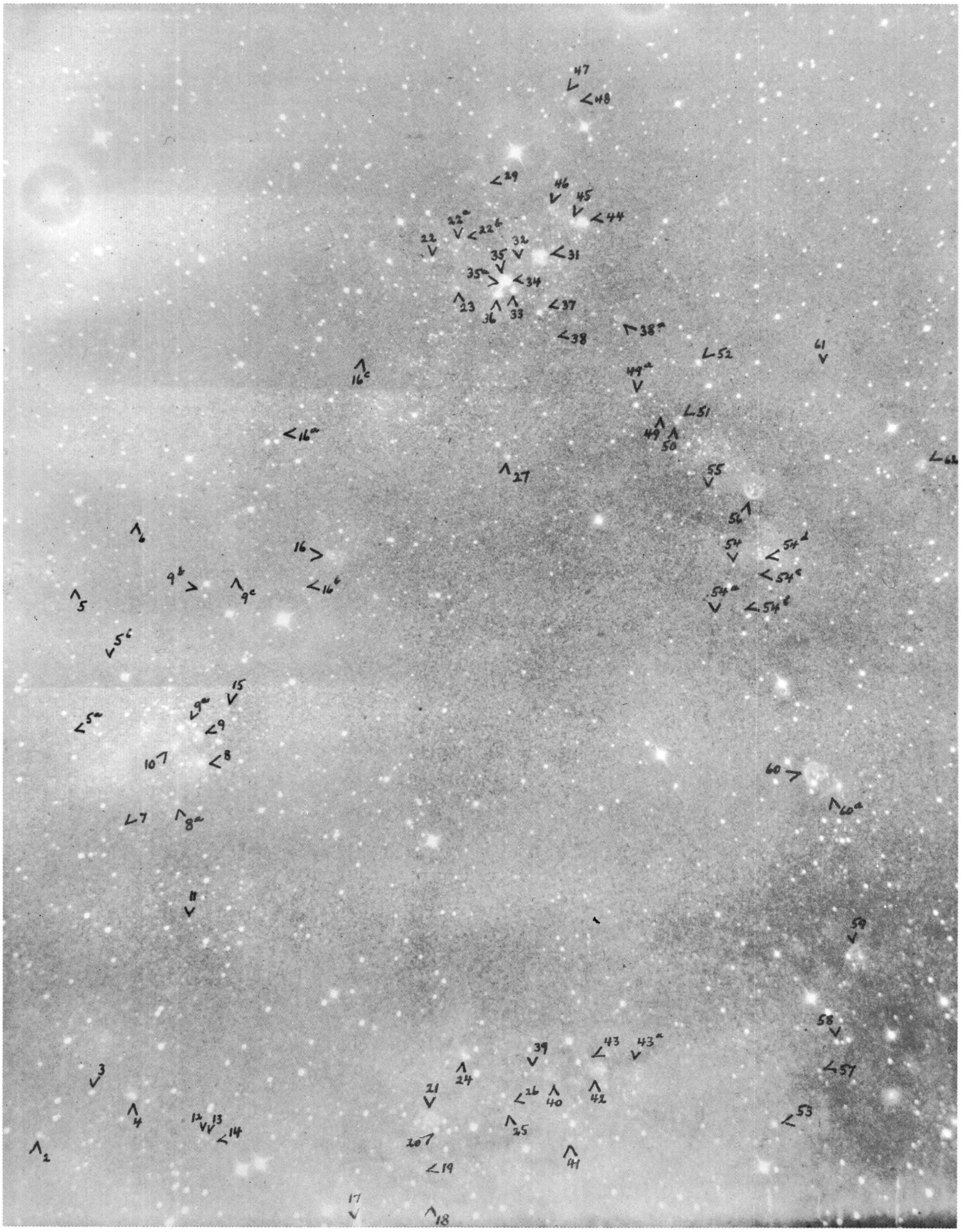

Fig. 5. Emission nebulosities in one of the outer spiral arms of the Andromeda nebula (north-following half). Hα photograph at 100-inch reflector.

enough to study its variable stars. On a few plates obtained at the 100-inch some 12 years ago Hubble and I discovered some 50 variable stars, and we concluded, from their variations from one night to the next, that they were probably cluster-type variables. The small scatter in their luminosities supported this view. There the matter rested, because the Sculptor system is too far south for profitable observations from our latitude. But in the intervening years I often felt uneasy as to whether we had guessed right that these variables in the Sculptor system actually are cluster-type variables. All these doubts have recently been removed by A. D. Thackeray, who is studying this system with the 74-inch Radcliffe reflector at Pretoria, where the Sculptor system passes through the zenith. According to a recent letter, Thackeray has thus far discovered 216 variables in the Sculptor system, and he expects to more than double this number before he is through with his search. Light curves have been derived for 39 variables. With the exception of 2 or 3 Cepheids they are all cluster-type variables, with periods ranging from $0^{d}.28$ to $0^{d}.92$ and with Bailey's types A and C clearly recognizable. Since the brightest stars in the Sculptor system are photographically about 1.4 magnitudes brighter than these cluster-type variables and, judged by their color, are of special type K, we have convincing proof now that the nearest spherical galaxy is in fact composed of a pure population II. And, although probably the poorest galaxy on record, it still beats the richest globular clusters in our galaxy in the number of variables by a large margin, another proof that there is a decided gap between galaxies and globular clusters. There is also convincing proof now that the high frequency of the cluster-type variables in the Sculptor system is not accidental. When this spring the sky survey with the 48-inch Palomar Schmidt led to the discovery of 2 more members of the local group of galaxies, both of the spherical type, they were put at once on the observing program of the 200-inch. Intercomparison of the plates obtained thus far has demonstrated beyond any doubt that these 2 spherical galaxies, like the Sculptor system, are rich in cluster-type variables.

Second, I would like to discuss the composition of the Large Magellanic Cloud. We know that there are many galaxies of the pure type II. We also know that in the Sa and Sb spirals the 2 populations occur side by side. But do pure populations I occur? The answer seems to be Yes, for there is now very strong evidence that in the large Magellanic Cloud we are dealing with a pure population I. What forces us to this conclusion is the fact that in spite of extensive searches made by Harvard Observatory, including special series of plates with the southern 60-inch reflector, not a single cluster-type variable belonging to the Large Magellanic Cloud has been found. Since cluster-type variables are a very common product of the population II, this result is very striking. Most instructive is perhaps a comparison with our own galaxy which, to use a conservative estimate, certainly contains between 10^4 and 10^5 cluster-type variables. Even if we make the widest allowance for the fact that our galaxy as a giant system surpasses in stellar content the Large Magellanic Cloud, we would still expect the cluster-type variables by the hundreds if they were present in the Cloud. Since none were found we conclude that there is no population II in the Large Magellanic Cloud and that we are dealing with a pure population I. But how shall we then explain the occurrence of globular clusters in the Large Cloud? The answer is obvious. If there is no population II in the Cloud, there should be no globular clusters in the sense in which we define them in our own galaxy. And the accepted definition of a globular cluster in our galaxy is that its stars obey the Hertzsprung-Russell diagram of the population II. In fact, we have been forced to this definition in order to distinguish in concrete cases between poor globular clusters and so-called open or galactic clusters. The question which we have to decide is, therefore, the following: Is the Hertzsprung-Russell diagram of these so-called globular clusters in the Large Magellanic Cloud of the type II or not? Fortunately, it can be easily settled without practically any photometry. The brightest stars in a globular cluster are K-type giants, and they are photographically more than a magnitude brighter than the brightest occurring blue stars, those which occupy the horizontal branch in the region of the cluster-type variables (see Figure 4, but keep in mind that it was plotted on the photovisual and not the photographic scale.) The test as to whether the Hertzsprung-Russell diagram of a cluster is of type II is therefore obvious. Take 2 plates of such a cluster; one in the blue, the other in the red. By intercomparing the 2 plates pick out the brightest red stars in the cluster which you can find; similarly the other extreme, the brightest blue stars. If the Hertzsprung-Russell diagram of the cluster is of the type II, the brightest red stars should also be the brightest stars photographically, and surpass on the blue exposure the brightest blue stars by more than a magnitude. At my suggestion Thackeray, using the 74-inch Radcliffe reflector, made this test a year ago on NGC 1866, the brightest of the so-called globular clusters in the Large Magellanic Cloud. The plates obtained show that among its brightest stars the cluster contains both blue and red giants. On the red exposure the red giants naturally stand out prominently, but on the blue exposure, that is photographically, these red giants are not a magnitude brighter than the brightest blue stars, as we should expect for a population II, but they are nearly a magnitude fainter. This proves conclusively that the Hertzsprung-Russell diagram of NGC 1866 is not of the type II. Hence, NGC 1866 is not a globular cluster of the sort with which we are dealing in our own galaxy. In order to apply every possible check, Thackeray later took the spectrum of NGC 1866 with the nebular spectrograph of the Radcliffe reflector.

In contrast to the F- and G-type spectra of the globular clusters of our own galaxy the spectrum turned out to be A3. Moreover, the radial velocity obtained from this spectrum leaves not the slightest doubt that NGC 1866 is a member of the Large Magellanic Cloud. Finally, Thackeray noted that NGC 1866 contains some classical Cepheids among its members, a result subsequently confirmed at the Harvard Observatory. That NGC 1866 is typical of the bright clusters in the Large Magellanic Cloud is indicated by the fact that plates of 2 or 3 additional clusters reveal the same state of affairs.

The results just mentioned confirm in a very striking manner our former conclusion, based on the absence of the cluster-type variables, that there is apparently no population II in the Large Magellanic Cloud. They indicate, moreover, that present ideas regarding star clusters are in need of some revision. Since in our galaxy the very rich and highly concentrated star clusters — and the original term globular cluster meant just that — occur only in the population II, with nothing to compare with them among the "galactic" clusters of the population I, we were led to believe that "globular" clusters and population II somehow went together. Objects like NGC 1866 in the Large Magellanic Cloud show that star clusters indistinguishable from globular clusters, as far as stellar content (luminosity) and general make-up (strong concentration toward the center) are concerned, occur also in populations I and that, evidently, the findings in our galaxy present a special case. It would seem, therefore, that we had better drop the term "globular cluster" for the star clusters of the population II and distinguish in the future simply between type I and type II clusters. In recent years the term globular cluster has become an anomaly anyhow, since it describes only the rich clusters of the population II and turns into a bad joke when applied to one of the poor members of this class.

Structure and Composition of the Andromeda Nebula: In my preceding remarks I have several times alluded to the intimate relationship between the composition of a galaxy and its structure. This relationship stands out clearest in the Sb spirals of which the Andromeda nebula and M81 are typical examples. Since I have made in recent years a special study of the Andromeda nebula I would like to mention briefly some of the results which illustrate this relationship between content and structure.

First, it is thoroughly established now that the population II, which is the dominating feature in the central region of the Andromeda nebula, actually pervades the whole flattened disk and extends far beyond the outermost traces of the spiral structure. It was in fact one of the great surprises of this investigation to discover, on the long red exposures with the 100-inch, everywhere within the confines of the nebula the dense sheet of population II stars, just above the limits of the plates. It is also certain now that the large extent of the Andromeda nebula, as inferred from the photoelectric measures of Stebbins and Whitford and the photometric tracings here at Ann Arbor by Williams and Hiltner, refers to the population II, since on red exposures with the 200-inch the sheet of type II stars is easily traced along the minor axis up to 45 minutes of arc from the nucleus.[4] This point corresponds to the Stebbins-Whitford isophote, 27 magnitudes per square second of arc, that marks about the limit to which the photocell was able to trace the extent of the nebula. If we combine with the large extent the high density of the population II in the Andromeda nebula, it becomes obvious that the main substance of this galaxy is made up of type II stars.[5]

Imbedded in the disk of type II stars is the spiral structure of M31 with its O and B stars and other supergiants of the population I. The Andromeda nebula is an excellent example in which to study the 2 stellar populations side by side, since its spiral arms are well separated from each other and the branching of the arms, which finally leads to a spreading of the population I through the whole system, is absent. The clear-cut restriction of the population I to the spiral arms is beautifully illustrates by the emission nebulosities in M31. In Figure 5 are marked the emission nebulae in one of the outer spiral arms, which has a turning point at about 70 minutes of arc from the nucleus, in the north-following half of the nebula. At the bottom of the picture a part of the preceding spiral arm is visible. The space between the 2 spiral arms is filled on long red exposures with the dense sheet of type II stars, which slowly decrease in numbers as we go outward. No emission nebulosities occur in this area, since the ingredients for a bright emission nebula are a hot star of high luminosity and gas spread through its neighborhood. Figure 5 illustrates the restriction of the O- and early B-type stars to the spiral arms, for there is no reason to believe that the interstellar gas is restricted to the spiral arms. Direct evidence from the area between the 2 spiral arms (Figure 5) confirms this interpretation. No O- and B-type stars occur in this area and no emission nebulosities were found.

I pointed out earlier the striking role which the

[4] These data refer to the south-following side of the minor axis. On the north-preceding side the outlying population II of the Andromeda nebula becomes mixed with the stars of NGC 205. It is interesting to note that the overlapping, resolved populations II of the 2 systems are indistinguishable from each other by their brightness. Only their different gradients indicate that we are dealing with 2 superimposed systems. [5] This has been quantitatively confirmed by E. Holmberg, who recently concluded from photometric data that 80 per cent of the total light of the Andromeda nebula comes from the population II (Lund Medd., Ser. I, 175, 1950).

presence of dust plays in a galaxy. Only when dust is present do the supergiants of the population I make their appearance. Since in the Andromeda nebula the supergiants are restricted to the spiral arms, it seems difficult to escape the conclusion that the dust is congregated there. There are a number of facts which support this conclusion. First, the density of the dust in the spiral arms must be high, because we observe a general reddening of the emission nebulosities in the Andromeda nebula. Only a few emission patches were known in this nebula as long as blue-sensitive plates were used in the explorations. They emerged by the hundreds when red-sensitive plates, covering the Hα region, were tried. There can be no doubt that the efficient technique[6] by which the emission objects were picked out is mainly responsible for this sudden increase. But that does not explain why the largest and brightest emission nebulosities of the Andromeda nebula were among the new discoveries or why it was difficult to identify them on the blue plates even after we knew where to look for them. It soon turned out that we are dealing with reddening, because Mayall was able to show that the spectra of these nebulosities are perfectly normal and similar to those of well-known emission nebulae in our own galaxy. Moreover, in a number of cases the exciting stars can be identified and their colors leave no doubt that these emission nebulosities of spiral arms are affected with strong reddening.

Outside the spiral arms the density of the dust must be much lower, because there are no obvious signs of reddening among the globular clusters of the Andromeda nebula. Since one half of them are located on the farther side of the nebula, their light on its way to us passes through the disk and reddening should result if the absorption in the disk were sufficiently strong. As already stated, no such reddening was noted among the globular clusters, when their colors were examined on standardized blue and red exposures. There are a few heavily reddened globular clusters in the Andromeda nebula, but they prove our point because they are located in the spiral arms and probably shine through them.

The most striking illustration of the relation between dust and spiral structure is provided by one of the inner arms of the Andromeda nebula. Farther away from the nucleus, it is densely studded with supergiants. As we move inwards their number gradually decreases and rather suddenly gives out altogether, but the spiral arm continues as a dust lane into the central region.

It seems, therefore, that the basic feature of the spiral structure is the dust and its congregation into spiral arms, the subsequent appearance of supergiants representing a secondary phenomenon. This would mean that systems, otherwise resembling spiral nebulae, but without dust, cannot develop spiral structure. Curiously enough, such systems exist. Hubble assigns them, with others, to his class S0. The particular group which interests us here represents a sequence of forms which runs parallel to the standard series of Sa, Sb, and Sc spirals. These S0 systems are true counterparts of the Sa, Sb, and Sc spirals as far as flattening (angular momentum) is concerned. Furthermore, just as in the standard series, the central lens of these systems shrinks with increasing angular momentum and is reduced to a "semistellar" nucleus in the most flattened systems. But these systems appear to be free from dust, because no absorption features are found in them and neither spiral structure nor population I make their appearance. In fact, the integrated colors of these systems leave no doubt that we are dealing with pure populations II. Systems of this kind are not very frequent among the field nebulae, but they predominate in rich condensed clusters of nebulae, like the Coma and Corona clusters, where we observe them not only in large numbers but also in all kinds of orientation. Two of their characteristics strike the observer at once. First, although systems of all degrees of flattening are present, spiral nebulae are rare if they occur at all in these clusters. In fact, the few present may well be field nebulae. Second, no absorption bands are visible in the numerous systems seen edgewise or nearly edgewise. These S0 nebulae must, therefore, be remarkably free of dust. This is confirmed by another observation. In all highly flattened systems seen edgewise the semistellar nuclei are visible, a very uncommon occurrence in the case of normal Sc spirals, where intervening absorption blots out the nucleus. The rich collections of S0 systems in the Coma and Corona clusters of nebulae, therefore, thoroughly confirm their main characteristics. They seem to be free of dust and show no spiral structure, although otherwise they are closely related in their make-up to the normal Sa, Sb, and Sc spirals.

When I discussed these S0 systems in one of my Princeton lectures last spring, Spitzer pointed out at once that the prevalence of dust-free systems in dense clusters of nebulae is not so surprising after all. The number of collisions in such clusters is so high that each of their galaxies must have suffered several during its lifetime. Now a collision of 2 galaxies is harmless as far as the stars are concerned, on account of their large free paths. The 2 systems simply penetrate each other and move apart again with only minor changes in their structure. But for the dust and gas of the 2 systems such an encounter means a real collision with the result that they are left behind when the 2 galaxies move away from each other after the encounter. Collisions thus provide a mechanism by which the galaxies in rich clusters of nebulae are stripped of their dust and gas. According to this concept the S0 systems

[6] This consists in photographing a field on 2 plates; the first covering the wave-lengths $\lambda 6400$ - $\lambda 6700$, the second the adjacent region $\lambda 6800$ - $\lambda 7200$. The first contains Hα; the second is free from emission lines of any strength.

of rich clusters of nebulae are stripped Sa, Sb, and Sc spirals which have lost their dust and gas in collisions and are, therefore, unable to develop spiral structure. Only in the general structure of their remaining populations II, that is the flattening of the systems and the extent of their central lenses, is there a hint that, normally, they would have been Sa, Sb, or Sc spirals.

Our Galaxy as a Spiral Nebula: Let me conclude with a few remarks about our own galaxy and how it fits into the wider picture which we have discussed. We know that our galaxy is a strongly flattened, rotating system. Both stellar populations are present and we are also certain that we are dealing with one of the largest galaxies. Together these data leave little doubt that our galaxy belongs to the group of spirals, and more specifically to the late-type spirals.

We have, I think, convincing evidence now that our galaxy is an Sb spiral, because it has a nucleus similar to that of the Andromeda nebula and not to that of M33. As I pointed out a few years ago, the different character of the nuclei of Sb and Sc spirals should lead to a decision in the case of our galaxy, because the small nucleus of a Sc spiral would certainly be blotted out by the wide band of heavy obscurations which hide the central region of our galaxy. The situation is much more favorable if our galaxy is an Sb spiral, because the central lens in these systems rises far above the main plane and forms a bulge, which is a well-known feature of Sb spirals seen edgewise. Since the outer regions of such a bulge may well stick out above the layers of dust which hide the center itself, we would get at least partial access to the nucleus of our galaxy.

Now probings with red exposures at the 100-inch suggested strongly that our galaxy possesses such a nuclear bulge and that the well-known Sagittarius Cloud is a part of it. The further steps were obvious. Since the nuclei of Sb spirals are made up of a pure population II, cluster-type variables should be abundant in the bulge and dominate all other types of variables. Moreover, their distance should confirm that we are really dealing with the nucleus. In order to settle this question, I have investigated during the last years with exposures at the 100-inch the variables in a field of the Sagittarius Cloud, which was centered on the globular cluster NGC 6522. This choice was made for the following reason. Tests in the blue and red showed that everywhere in the Sagittarius Cloud reddening is present and that all photometric data have to be corrected for absorption. For our field the color excess of NGC 6522, determined by Stebbins and Whitford, should provide this information, since there are good reasons to believe that the cluster is actually imbedded in the bulge.

Thanks to the active collaboration of Dr. Sergei Gaposchkin, who made the estimates and derived the light elements for all the variables, this investigation is nearly finished. Here are a few of the main results.

First: As was to be expected the number of variable stars in this nuclear field is exceedingly high. In a preliminary note I stated that the number of variables per square degree is about 400. We know that this was an underestimate and that the true number is 1000 variables per square degree, if not larger.

Second: The cluster-type variables are indeed the most frequent type among the variables. In Figure 6 their distribution according to brightness is plotted. Only variables within 16 minutes of arc of NGC 6522 were used, since outside this area local absorption patches disturb the uniformity of the field. The striking concentration around the frequency maximum at $m_{pg} = 17.5$ leaves not the slightest doubt that we have actually reached the nucleus and passed beyond it. It is also obvious that this frequency distribution is in no way affected by limitations of the observing material, since the plate limit for the variable star series was close to $m_{pg} = 20.0$.

Third: NGC 6522 contains 4 cluster-type variables of its own, which give for its apparent distance modulus $m - M = 17.77$, thus confirming that this globular cluster is imbedded in the nuclear bulge.

Fourth: We can therefore, use the photographic absorption $\Delta m = 2.8$ magnitudes, derived from the color excess of NGC 6522, to compute the true distance of the cluster-type variables of the bulge and obtain $m - M = 17.5 - 2.8 = 14.7$, corresponding to a distance of D = 8.7 kpc.

These results show that the bright Sagittarius Cloud is a part of the nuclear lens of our galaxy, that this lens is made up of a population II and that its great extent leaves no doubt that our galaxy belongs to the Sb spirals like the Andromeda nebula, and not to the Sc spirals like M33.

The figure which I gave for the distance of the nucleus can be considerably improved. The photometric scale used in this investigation should be entirely satisfactory, since it rests on intercomparisons with S.A. 68, which is at the same zenith distance as our field shortly after the latter has passed the meridian. Whitford's new magnitudes for S.A. 68 were used throughout, which insures that we are on the International System. The weak point at present is the amount of absorption which lies in front of our field. Color excesses of globular clusters are certainly not the best measure for absorption and we are planning to determine photoelectrically the color excesses of some of the brighter cluster-type variables in the bulge itself.

Another problem which we should be able to attack now is that of the spiral structure of our galaxy. The procedure in this case is obvious. Since the supergiants of the population I are restricted to the spiral arms, we have to study their spatial arrangement in the solar neighborhood. The most promising stars for a first test are undoubtedly the O and early B stars, on account of their high frequency in spiral arms. But we will need for each star accurate data on the following, in order to determine its position

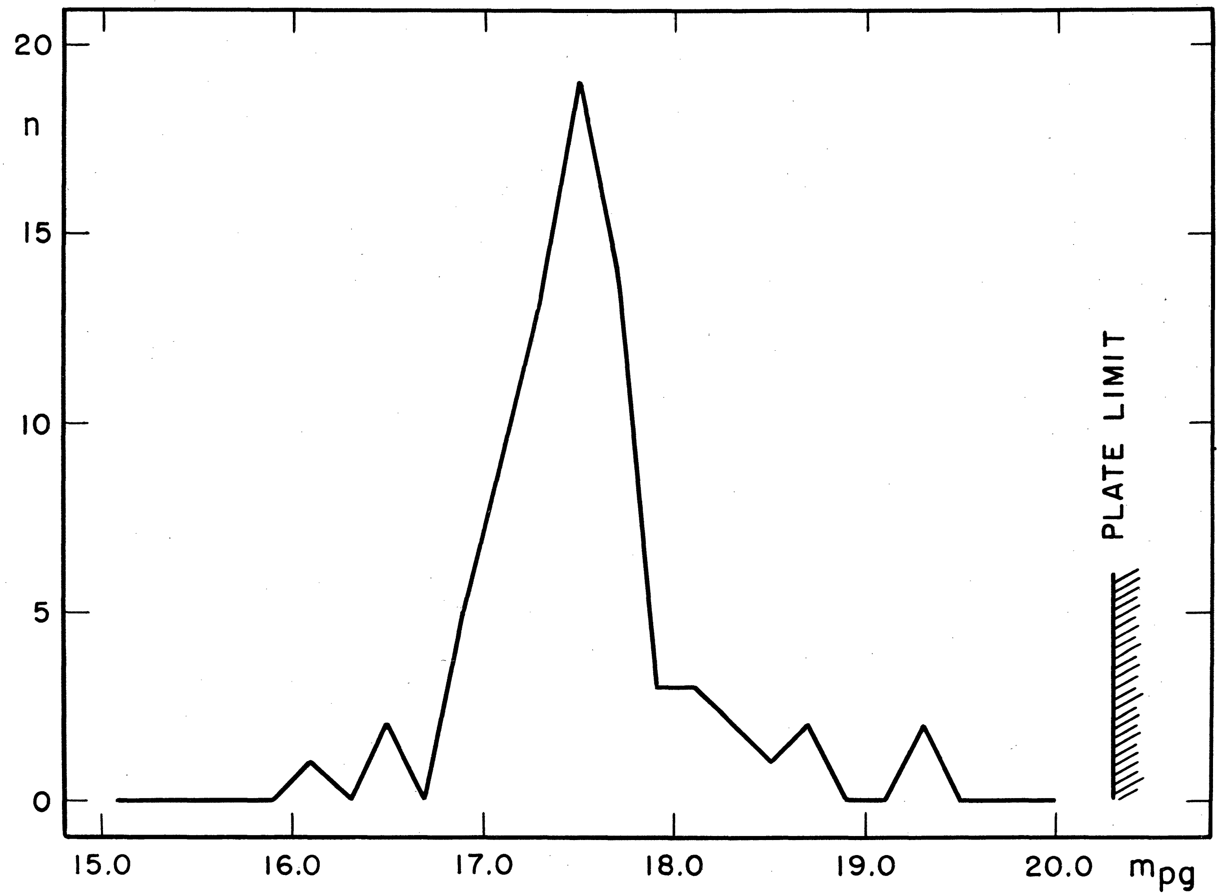

Fig. 6. Magnitude-frequency diagram for 76 cluster-type variables in the Sagittarius Cloud (ℓ = 328°.2, b = -4°.3). Abscissae are observed median magnitudes; ordinates are numbers of variables in intervals of 0.2 magnitudes.

relative to the sun: apparent magnitude, absolute magnitude, and color excess. Since apparent magnitudes and color excesses of most of the O and early B stars brighter than 7.5 visual and north of declination -30° are already known, their individual absolute magnitudes are the only remaining desideratum. W. W. Morgan's spectroscopic luminosity criteria for O and B stars should fill this gap and it is, I think, no secret that Morgan and Nassau are now engaged in a large program of determining the absolute magnitudes of O and B stars by this method. The near future should therefore bring the answer to the much debated question: whether the spiral arms of our galaxy sweep through that limited part of its disk which we can observe from our sun? Of one thing we can be certain: on account of the heavy obscurations in the plane of the Milky Way we will at best get only a glimpse of short pieces of such spiral arms. And one guess we can probably safely make, that our sun is located in a spiral arm, because the brighter B stars and the dust surround our sun in all directions along the Milky Way. I know that this argument will not overly impress you and that you would like to see the arm or a piece of it demonstrated ad oculos. So would I.

I think these examples show that we are finally coming to grips with significant structural features of our galaxy and that we know how to attack these problems, thanks to insights which we gained from studies of the galaxies at large.

We are here today to celebrate the dedication of the Heber D. Curtis telescope. Let me conclude with the sincere wish that in the able hands of our Michigan colleagues this instrument will play a leading part in unraveling the mysteries of our galaxy and of the wide universe which lies beyond it.