III

THE LOCAL SYSTEM AND THE HENRY DRAPER EXTENSION

FOR more than a century astronomers have been systematically examining the distribution of both naked-eye and telescopic stars, recording their numbers in different parts of the sky, and determining their increasing frequency with decreasing apparent brightness. Important and laborious catalogues have been compiled of the radial velocities, the proper motions, the magnitudes, the positions, and the spectra of thousands of stars. Although it was realized that the stars extend in great numbers beyond the limits of available telescopic power, it was generally felt a generation ago that current studies were dealing with a very considerable part of the stellar system. In recent years, however, we have come to the realization that our catalogues pertain to a localized bit of the sidereal universe and that the major part of even our own Milky Way system is comprised of stars fainter than the tenth magnitude, and is more than ten times as remote as the average catalogue star.

Analyses of the data of our catalogues, especially the study of positions, numbers, and spectra, long ago showed structural detail in the arrangement of the stars; they indicated not only the galactic concentration, and the falling off in star numbers with increasing distance (in certain directions), but also local irregularities. And the studies of star motions revealed to Kapteyn and his successors a remarkable complex of systematic motion which is not yet satisfactorily interpreted.

The refinement of the star counts and their extension to faint magnitudes, especially at the Mount Wilson and Groningen observatories, has carried far our knowledge of stellar distribution in the solar neighborhood. But the study of the distribution of the brighter stars of each spectral type has done more to bring to light the existence of a "local system." Formerly this local star cloud was not distinguished from the general galactic system, and its boundaries are so poorly known that we cannot now feel entirely sure of its distinctness from surrounding galactic clouds or even of its organization as a separate stellar system.

Nevertheless, the common opinion is that a local star cloud surrounds the Sun; its diameter is a few thousand light years; its population is probably numbered in millions of stars; its membership includes most of the naked-eye stars and many of the conspicuous clusterings such as the Pleiades, the Hyades, and the constellations of high temperature stars in Orion, Scorpio, and Centaurus. Less common is adherence to the provisional view of the writer that the motions of stars within the local system, and the motions of the system as a whole with respect to other star clouds of the Milky Way, give rise to the phenomenon frequently interpreted as galactic rotation. Our studies of the proper motions and radial velocities of stars deal with such a localized region near the Sun that I feel it incautious to extrapolate from a meager amount of material and form the hypothesis that the galactic system rotates as a single unit. The galactic system is perhaps a thousand times as large as the region so far explored for stellar motions.

But it may be well for the present to postpone consideration of the incompatibility between simple galactic rotation and the existence of localized star clouds. We proceed rather to an account of a method of measuring and dissecting the section of the stellar universe which, though within a few thousand light years of the Sun, nevertheless lies beyond the range of easy trigonometric survey or measurement by means of spectroscopic parallax.

Some twenty years ago the construction of the Henry Draper Catalogue of stellar spectra was begun at the Harvard Observatory, after two decades of analyzing and classifying the spectra of the brighter stars. Professor Pickering and Miss Cannon undertook in this catalogue to list the positions and magnitudes for stars over the whole sky to approximately the ninth magnitude. The six thousand naked-eye stars were included along with about two hundred and twenty thousand telescopic objects. The catalogue, in nine volumes, was published in fifteen years. A study of the results showed that the catalogue was practically complete in the northern hemisphere for stars to the magnitude 8.25, and in the southern hemisphere to 8.75; but more than a hundred thousand stars fainter than those limits were also included. Six major groups were established in the classification of spectra, the sequence of classes bearing the letters B, A, F, G, K, M, in the order of decreasing surface temperature. Including the aberrant types and the subdivisions of the major classes, Miss Cannon has differentiated approximately fifty kinds of spectra.

The average number of stars per square degree to magnitude 8.75 for the whole sky is shown for the six major classes in Figure 1 (cf. Shapley and Cannon, Harvard Reprint 6, 1924). The conspicuously different distribution among the spectral types for fainter stars in the Milky Way is shown for localized regions in Cygnus, Figure 2, and in

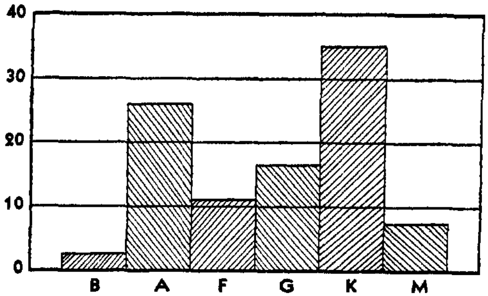

FIGURE 1. Number of stars per square degree in each spectral class, down to visual magnitude 8.75, in the Henry Draper Catalogue.

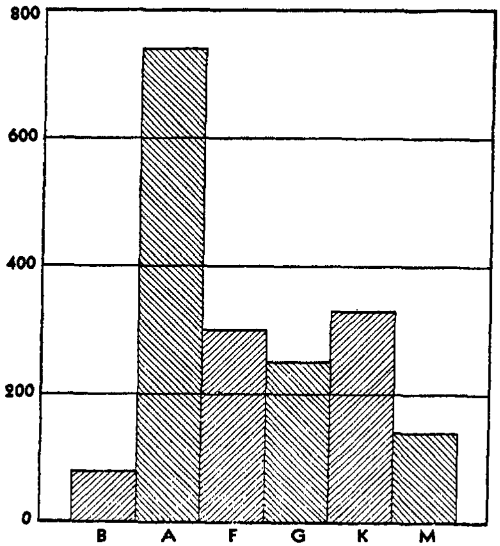

FIGURE 2. Distribution in spectral class of stars between magnitudes 10.1 and 11.0 in the Cygnus region.

Taurus, Figure 3. Further analysis of the material of the Henry Draper Catalogue shows the well known phenomenon of high concentration to the Milky Way for stars of

Classes B and A, and a more even distribution through all galactic latitudes for the cooler spectral classes.

The division into giant and dwarf stars for the classes from F to M, a highly important phenomenon early emphasized by Hertzsprung and Russell, has a bearing on the

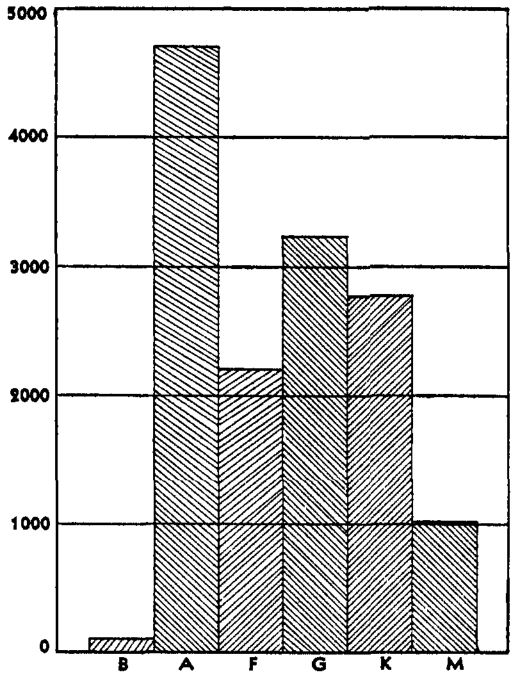

FIGURE 3. Distribution in spectral class of stars between magnitudes 10.1 and 11.0 in the Taurus region.

galactic concentration; giant K stars, for instance, are more concentrated to the Milky Way than the dwarf K stars. It is not expedient, however, to deal further here with the intricacies and peculiarities of the distribution of stars of various types. For the present purpose it need only be pointed out that whether we are considering giant stars or dwarfs, hot stars or cool, the Henry Draper Catalogue does not get us very far into space. Eighth magnitude stars of Class A are, on the average, less than a thousand light years distant. In fact, a large majority of the stars of the statistically complete part of the catalogue are within twelve hundred light years of the Sun.

Before the catalogue was entirely published, with its valuable spectral information for the regions most com-

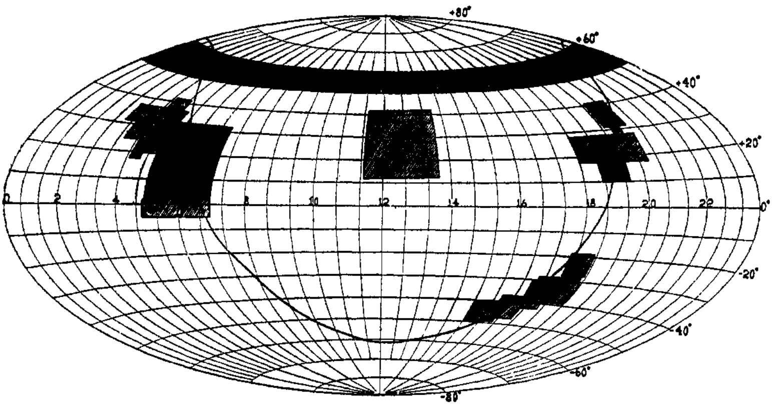

FIGURE 4. Regions covered by the Henry Draper Extension. Cross-hatch indicates classifications already published. Equatorial system of coördinates, with galactic circle superposed.

monly explored by astronomers, the studies of globular star clusters and faint variables had shown the importance of getting deeper into space, even in the analysis of the local system. An extension to the Henry Draper Catalogue was suggested, to be based on new photographs showing spectra of fainter stars and involving new determinations of apparent magnitudes. Miss Cannon and her associates immediately undertook the Henry Draper Extension, directing attention mainly to the rich and important fields in low galactic latitude (Milky Way regions). An Aitoff chart of the sky is reproduced in Figure 4 showing the progress made up to the present time in this supplementary survey, which will extend the Henry Draper Catalogue in certain regions down to magnitude 11.5 or 12. The increase of

TABLE II

REGIONS COVERED BY THE HENRY DRAPER EXTENSION

Region	Approximate Center		Number of Stars	Approximate Area (square degrees)	Remarks
	h	°			
1. Cygnus	20	+37	4,000	80	Published
2. Cygnus	19.2	+23	13,082	220	Unpublished
3. Aquila	19.1	+14.8	2,800	130	Published
4. Cambridge catalogue	...	...	4,200	1,090	Published; Gesellschaft
5. Helsingfors-Gotha catalogue	...	...	4,200	940	Published; Gesellschaft
6. Sagittarius	16.8	−33	15,269	400	Unpublished
7. North Galactic Pole	12.6	+27	4,351	975	Unpublished
8. Taurus, Orion, Monoceros, Gemini, Auriga	6	+18	28,100	900	Published
9. Orion	6	− 1.5	8,138	210	Unpublished
10. Taurus	4	+30	12,095	215	Unpublished
11. Large Magellanic Cloud	5	−69.5	2,100	35	Unfinished
			98,335	5,195	

more than three magnitudes beyond the previous limit of completeness corresponds to an extension of the survey to four times the distance.

To accompany the chart of progress, Table II has been compiled. It shows that nearly one hundred thousand stars have been classified by Miss Cannon during the past eight years. The determination of the photographic magnitudes lags far behind, however, so that only half of the new spectra are published. The present state of photographic photometry is such that the determination of the magnitudes of these faint Milky Way stars is a more serious problem than the classification of their spectra; but we hope to have remedied within a few years these photometric deficiencies.

Items 4 and 5 in Table II indicate zones, extending through all right ascensions, which were especially studied at the request of Professor Schlesinger of the Yale Observatory in order to assist in his work on stellar motions. The magnitude limit for these zones is much higher than for other regions of the Henry Draper Extension, since the object in view was merely to get spectra of stars of accurately measured positions.

Until large representative areas in different parts of the Milky Way have been completed, it would be premature to analyze in detail the accumulating data on the spectra and magnitudes of faint Milky Way stars. As an illustration, however, of the manner in which the Henry Draper Extension contributes to our knowledge of the structure of the local system, I give herewith a series of diagrams illustrating the distribution of the stars of different spectral classes on the surface of the sky throughout the "Taurus" region, and also for different parts of this region curves illustrating the frequency of Class A stars of successive intervals of brightness.

Figures 5 to 10 give plots of the positions in equatorial coordinates of stars between magnitudes ten and eleven in

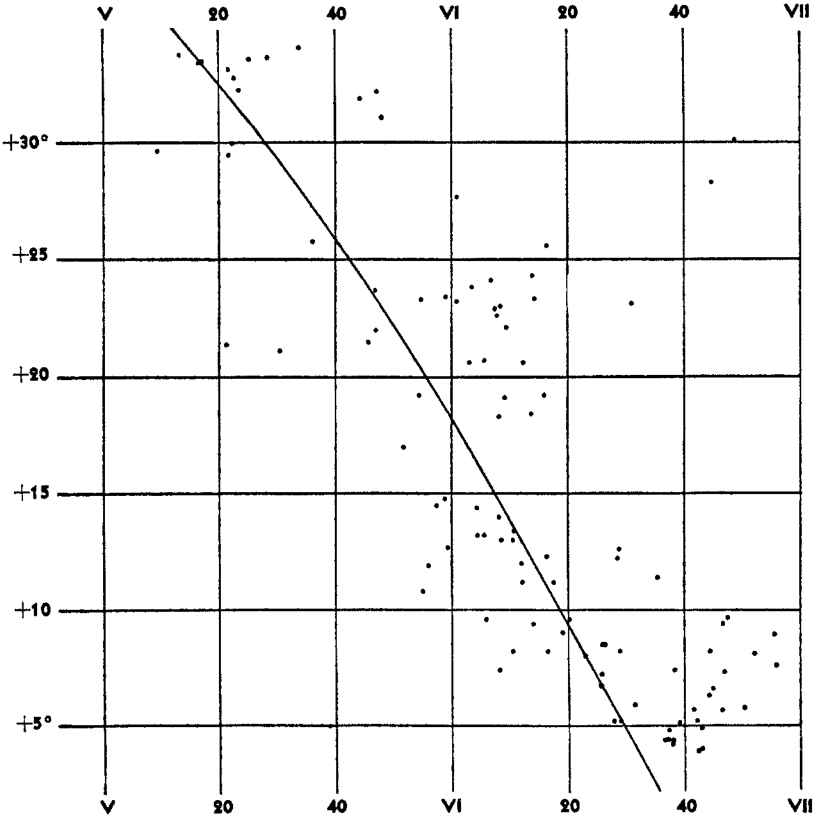

FIGURE 5. Class B stars of magnitudes 10.1 to 11.0 in the Taurus region of the Henry Draper Extension. Coördinates are right ascension and declination. The heavy curved line represents the galactic circle.

the Taurus region, which extends over about nine hundred square degrees and includes sections of several of the neighboring constellations. The course of the galactic circle through the region is indicated.

The relative infrequency of Class B stars, already shown in Figure 3, is well illustrated in Figure 5. For a first approximation we can consider the Class B stars in this in-

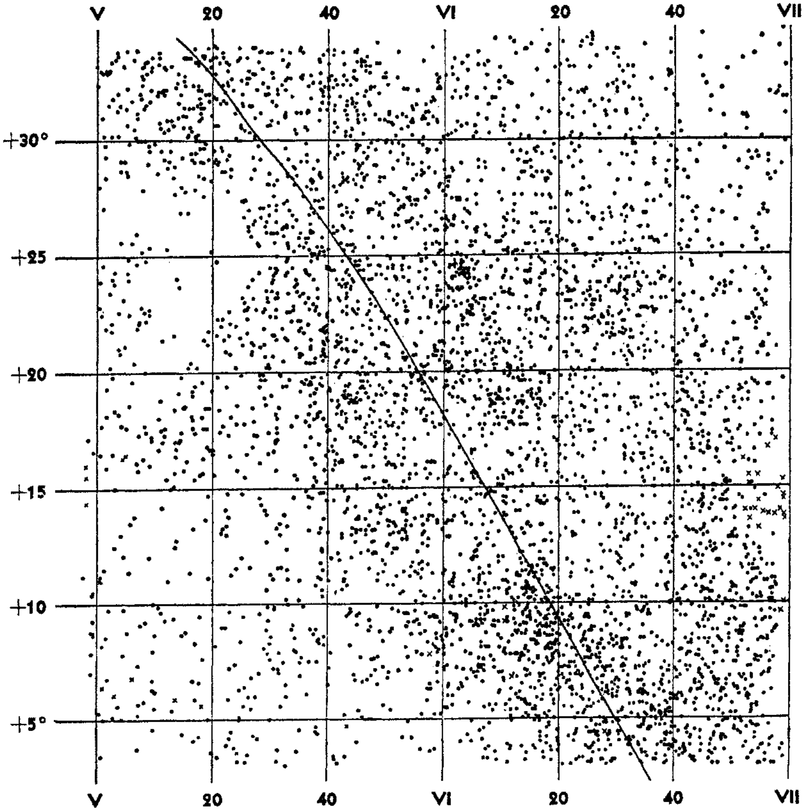

FIGURE 6. Class A stars of magnitudes 10.1 to 11.0 in the Taurus region of the Henry Draper Extension. In this and the four following diagrams the crosses indicate stars taken from the Henry Draper Catalogue.

terval of apparent magnitude as approximately five thousand light years from the Sun; brighter Class B stars are of course generally nearer, and those fainter than the eleventh magnitude more remote. Similarly for the other classes the respective plots present the distribution throughout a definite, relatively small, interval of distance from the observer. What this distance is varies from class to

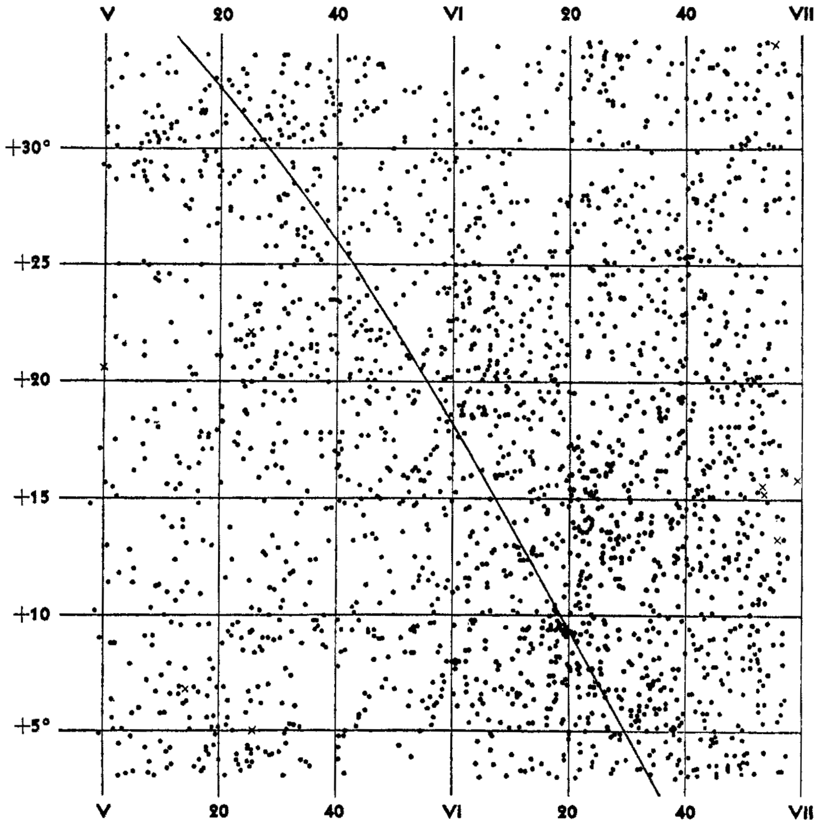

FIGURE 7. Class F stars of magnitudes 10.1 to 11.0 in the Taurus region of the Henry Draper Extension.

class, depending of course on the absolute luminosities of the different types of stars. For Classes G, K, and M, in which giants and dwarfs are mixed, two intervals of distance are represented.

A general consideration of the distribution figures shows least concentration to the galactic circle for solar type stars (Class G); they are probably largely dwarfs. A higher concentration is shown by stars of Class A, and also a dis-

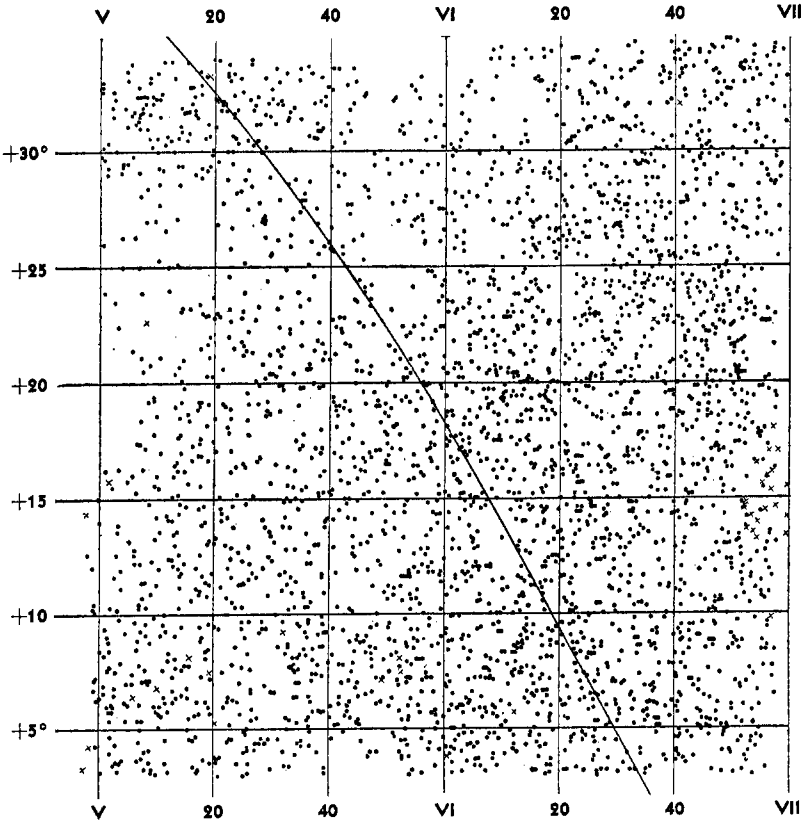

FIGURE 8. Class G stars of magnitudes 10.1 to 11.0 in the Taurus region of the Henry Draper Extension.

tinct unevenness in their frequency throughout the field. The most important deficiency for the Class A stars is at right ascension $5^h\ 20^m$, declination $+25°$. The same "hole in the sky" is shown clearly for some of the other classes;

it undoubtedly indicates the presence of an obscuring dark cosmic cloud, and it is in the discovery and location in space of such obscurations that the Henry Draper Extension may be most useful.

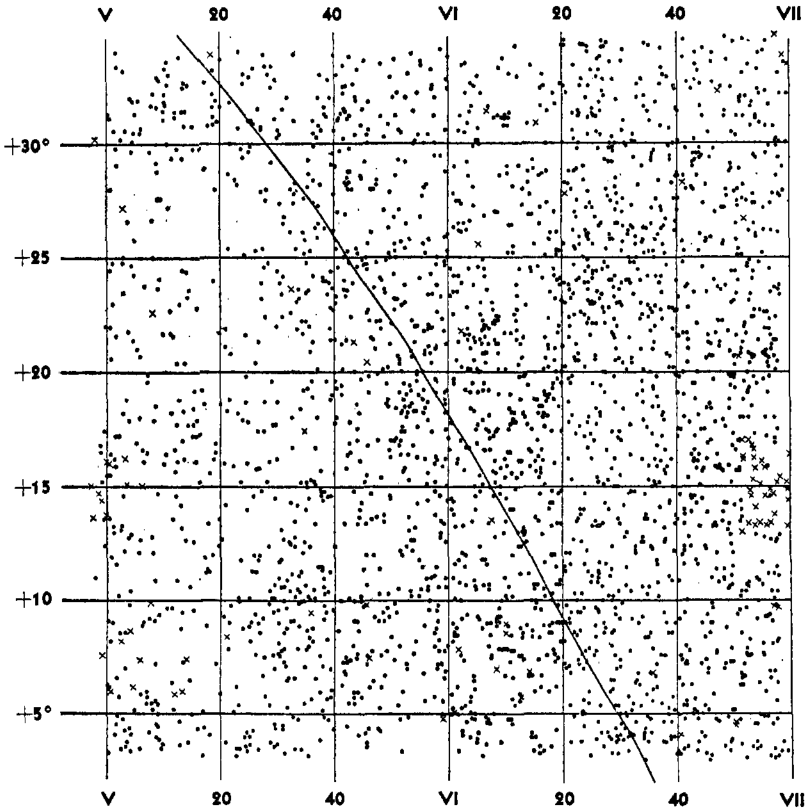

FIGURE 9. Class K stars of magnitudes 10.1 to 11.0 in the Taurus region of the Henry Draper Extension.

To look further into the form and effect of the obscuration at $5^h\ 20^m$, $+25°$, and also in the field fifteen degrees further south, I have presented in Figures 11 and 12 a series of distribution plots of Class A stars. All the Class A stars from the sixth to the eighth magnitudes are shown in Figure 11a, the data being taken from the Henry Draper Catalogue. For magnitudes eight to nine the star positions are plotted in Figure 11b; for nine to ten in Figure 12a;

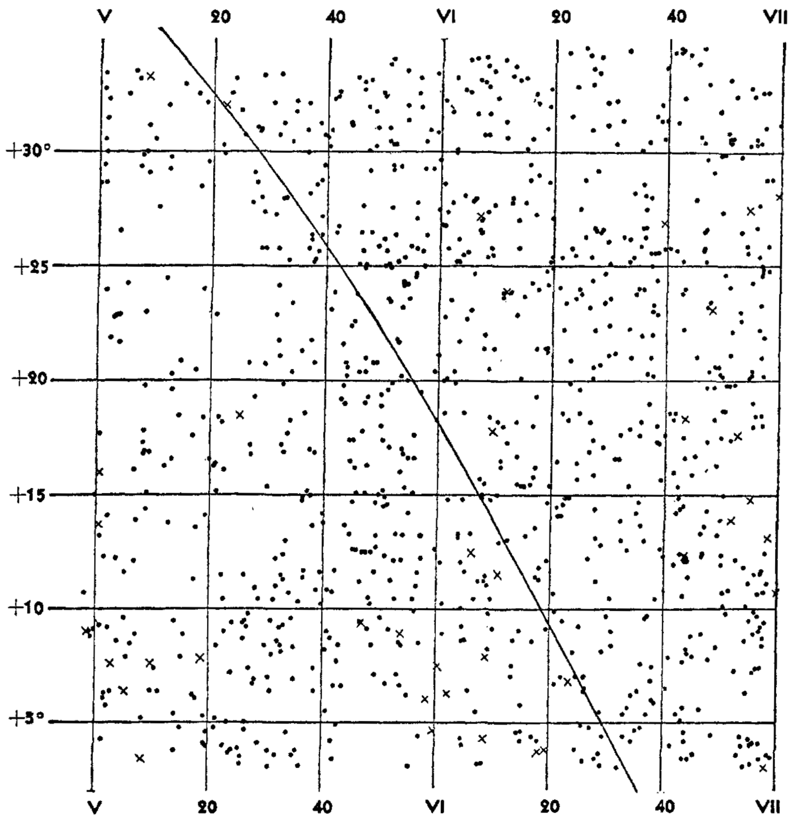

FIGURE 10. Class M stars of magnitudes 10.1 to 11.0 in the Taurus region of the Henry Draper Extension.

for ten to eleven in Figure 6; and for stars fainter than the eleventh magnitude, as far as data are available, in Figure 12b. This last plot shows a number of stars appearing in the region that is nearly void of brighter stars. I believe

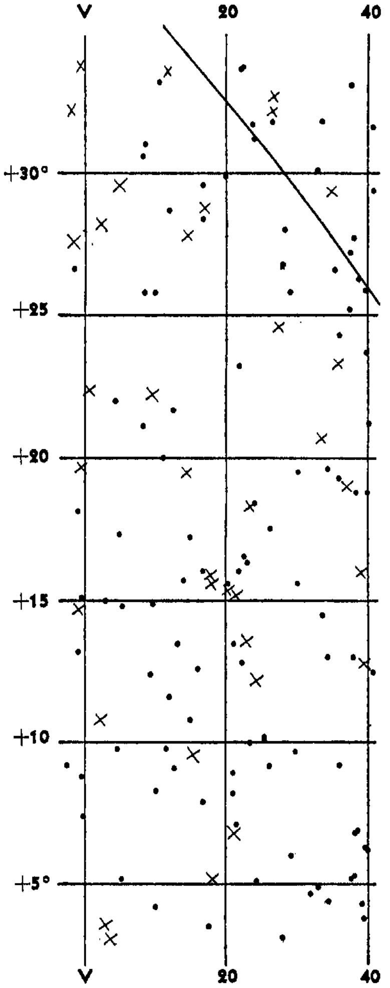

FIGURE 11a. Class A stars in the first forty minutes of the Taurus region. Crosses indicate stars of magnitudes 6.1 to 7.0; dots, those of magnitudes 7.1 to 8.0. These stars are in the Henry Draper Catalogue.

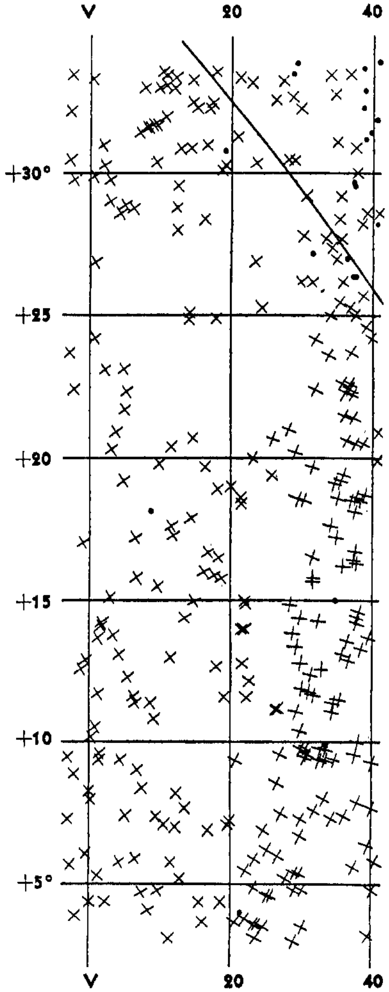

FIGURE 11b. Class A stars, in the Taurus region, of magnitudes 8.1 to 9.0. Crosses indicate stars in the Henry Draper Catalogue; dots, stars in the Henry Draper Extension.

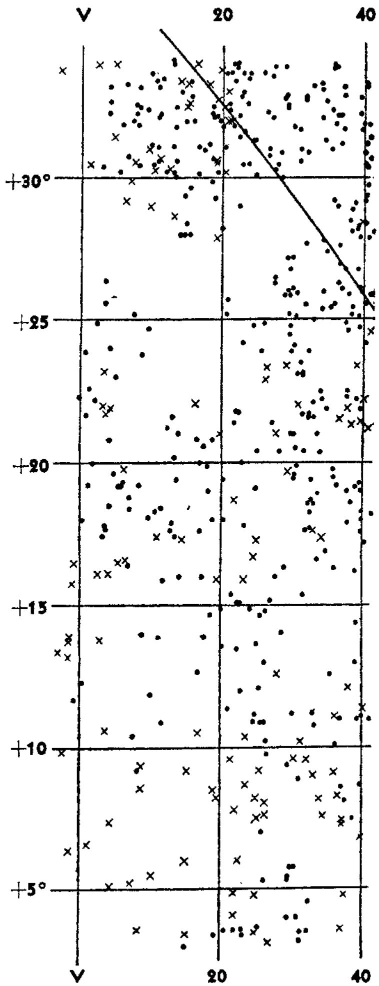

FIGURE 12a. Class A stars, in the Taurus region, of magnitudes 9.1 to 10.0. Crosses indicate stars in the Henry Draper Catalogue; dots indicate stars in the Henry Draper Extension.

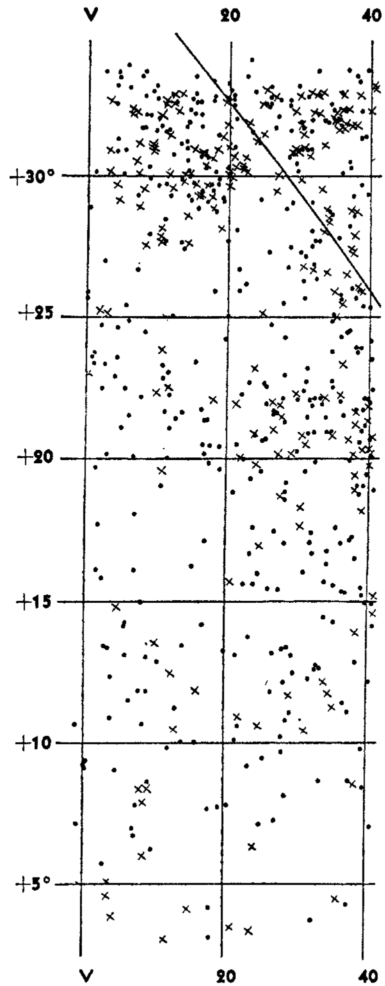

FIGURE 12b. Class A stars, in the Taurus region, of magnitudes 11.1 and fainter, in the Henry Draper Extension. Crosses indicate stars from 11.1 to 11.5; dots indicate stars fainter than 11.5.

this indicates that the obscuring cloud is not completely opaque, but merely cuts down the light of the more distant stars by two or three magnitudes.

The obscuring nebulosity of the Taurus region extends northward and westward for many degrees, beyond the

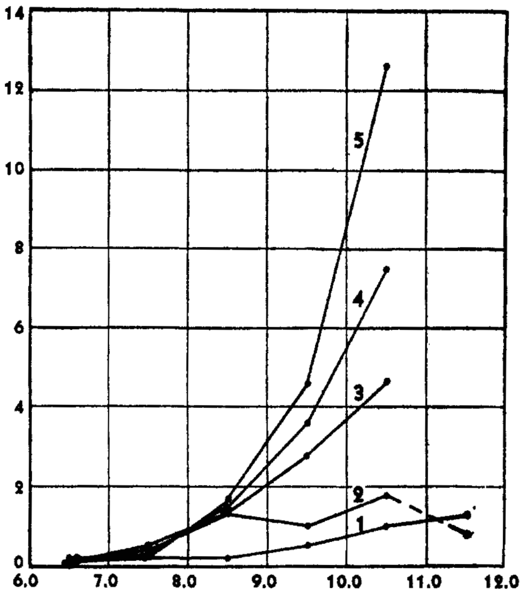

FIGURE 13. Frequency of A stars in five areas in the Taurus region. Ordinates are numbers per square degree. Abscissae are photographic magnitudes.

limits of the plots here given. In order to investigate further its extent and its distance from the Sun, the Henry Draper Extension is being spread over the whole region affected. When the material is available we shall be able to consider thoroughly the position of the Taurus nebulosity; and perhaps by making special spectroscopic studies of the various classes of stars in or beyond the nebulosity we may be able to learn more concerning the nature of the materials of which such cosmic clouds are composed.

It is clear from Figures 11 and 12, with the addition of Figure 6, that the number of Class A stars increases with decreasing brightness at different rates in different parts of the sky. In heavily nebulous regions the increase is slow; in transparent regions where the remote A stars are not lost by intervening nebulosity the increase is rapid. I have selected five different areas in the Taurus region for which the frequency curves are tabulated in Table III and plotted

TABLE III

NUMBER OF CLASS A STARS PER SQUARE DEGREE IN TAURUS

Area	Number of Square Degrees	Photographic Magnitude					
		6–7	7–8	8–9	9–10	10–11	11–12
1	35	0.1	0.2	0.2	0.5	1.0	1.3
2	99	0.1	0.4	1.3	1.0	1.8	0.8
3	50	0.1	0.5	1.3	2.8	4.7	...
4	75	0.2	0.3	1.5	3.6	7.5	...
5	62	0.2	0.3	1.7	4.6	12.6	...

in Figure 13. The areas are arranged in order of increasing richness in stars between magnitudes ten and eleven; Area 1 is the most heavily obscured, Area 5 is nearly if not quite free of obscuration. Although there is little difference in the number of Class A stars per square degree brighter than the eighth magnitude, at the tenth magnitude Area 5 is thirteen times as rich as Area 1. Obviously the form of the frequency curve of apparent magnitude depends on the area observed.

The average giant star, with a luminosity a hundred times that of the Sun, is about five thousand light years distant when of apparent magnitude 11.5, which is the working limit of the Henry Draper Extension. This means that the completion of the Extension all around the Milky Way will give us most of the giant stars throughout the local system and, out to distances of two or three thousand light years, some hundreds of thousands of less brilliant bodies. Although distances of the individual stars will not be obtained, the material should be of considerable value in statistical investigations of the structure of the local star cloud.

Useful though it may be for the analysis of the local system, the Henry Draper Extension will deal very little with most of the star clouds that make up the Milky Way. Except for their supergiant stars, the clouds are composed of objects fainter than magnitude 11.5. We may be able to get some rather uncertain information concerning their structure from undifferentiated star counts; some rather better knowledge from surface photometry of the Milky Way. But a more direct way of investigating the distances and structure of the Milky Way star clouds is described in the next section. Leaving the local system, we enter the fourth territory of our sidereal explorations and tackle the difficult problem of measuring directly the dimensions of the galactic system.