B. OPTICAL OBSERVATIONS

33. LOCAL STELLAR DISTRIBUTION AND GALACTIC SPIRAL STRUCTURE

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Abstract. Aside from the well-known spiral arm tracers such as the OB associations, young galactic clusters, WR stars and possibly the long-period classical cepheids, the more common stars in the neighborhood of the sun within 2 kpc show little or no relationship to the local spiral structure of the galaxy.

1. Introduction

The role played by primary spiral arm tracers in delineating the galactic structure in our region of the galaxy is well known. Intrinsically bright young stars such as the OB stars and early Be stars, the Wolf-Rayet stars and possibly the brightest Cepheids seem to be distributed in localized sections of spiral arms. Concentrations of these objects in the O-associations, the galactic clusters having early O and B stars, and in association with ionized hydrogen regions strengthen the probability that in our neighborhood we see the following well established features as summarized by Bok (1967):

Region	*Galactic Longitude* l^{II}	*Distance*
Perseus	90–140°	2–3 kpc
Local	60–210°	Sun on inside edge
Sagittarius	330–0–30°	2 kpc
Carina (section)	280–310°	1.4–5.5 kpc
Centaurus (link)	310–330°	2 kpc (weak)

To these the radio astronomers have added the Norma-Scutum spiral arm extending broadly from $l^{\mathrm{II}}=30°$ to $l^{\mathrm{II}}=327°$ at about 4 kpc from the sun at its nearest point.

More recently Westerlund (1969) has investigated the OB associations in the filamentary nebulous regions of RCW 86 (Rodgers *et al.*, 1960) and RCW 103 at $l^{\mathrm{II}}=315°$ and 332° respectively. He finds distances consistent with segments of the Sagittarius spiral arm extending from $l^{\mathrm{II}}=328$–337°, the distance from the sun at these galactic longitudes being about 2.5 kpc and 1.4 kpc, respectively. The Norma arm is identified by the Ara grouping at $l^{\mathrm{II}}=337°$, distance 3.5 kpc and the RCW 103 association and Norma grouping at $l^{\mathrm{II}}=332°$, distance about 3.9 kpc.

Bok and associates are investigating photometrically in depth several other areas in the southern sky. These will be reported upon by him and will not be considered in detail here.

In the present paper my principal purpose will be to examine briefly the current status of any relationship which may be present between the general stellar population and the spiral structure in our neighborhood.

Becker and Contopoulos (eds.), The Spiral Structure of Our Galaxy, 189–198.

2. High Luminosity Stars

First we shall summarize a few of the facts concerning the well-known spiral arm tracers. The distributions of two principal stellar contributors, the *OB stars* and the *Wolf-Rayet stars*, have already been exhibited in a diagram by Klare and Neckel (1967) and one by Smith (1968). The first shows the space distribution of OB^+ and OB^o stars as a function of position in the galactic plane. The second indicates the positions of known Wolf-Rayet stars.

Although there is considerable scatter in the distribution of the WR stars, two concentrations of these stars coincide remarkably well with the local and the Sagittarius spiral arms as defined by the OB stars. The WR stars toward the galactic center from the sun are systematically about 0.6 kpc more distant than the greatest concentration of OB stars in this direction. At the same time a similar trend is evident in the grouping in the local spiral arm toward Cygnus. Here the difference is less clearly defined. If we were to assume that the OB concentration and that of the WR stars in the Sagittarius direction were equidistant, then an adjustment of 0.9 mag. in the mean absolute magnitude, M_v, in one group, or the other, or both in combination would be indicated.

While both the OB stars and the WR stars associated with the local spiral arm indicate a very low inclination of this structure to the line at $l^{II}=90°$, those outlining the Sagittarius arm convey the picture of a much greater inclination, something like 25°. The scatter in the distribution of the WR stars makes very uncertain their assignment to any spiral pattern at large distances from the sun.

It has been shown by Klare and Neckel (1967) that the OB^- stars (primarily main sequence B1–B3 objects) are not in general clearly associated with spiral structure. There is an elongated narrow concentration of these at $l^{II}=130°$ extending from 1.5 to 3 kpc from the sun. This is similar but much more elongated than a similar concentration for the OB^+ and OB^o stars. The reality of such an extended group and its existence for any length of time in a differentially rotating galaxy may be questioned.

This broad brush treatment of the OB stars must, of course, be ultimately supplemented by studies of their distribution from more precise photometric and spectrographic data. Space density functions have been calculated from more accurate data for several galactic longitudes in the northern hemisphere in an effort to see whether the Perseus spiral arm is evident at the galactic anti center and whether another spiral arm exists farther from the sun as suggested by the radio astronomers. These analyses give the space density, *stars per* 10^6 pc^3, as a function of distance for five northern galactic longitudes (Figure 1). At $l^{II}=129°$ the maximum density associated with the Perseus spiral arm is clearly apparent but no clear-cut maxima in space density occur beyond 3 kpc from the sun. Nor is there any perceptable indication of an extension of the Perseus spiral arm into the galactic anticenter region.

Emission B-stars of early type have been shown by Schmidt-Kaler (1964, 1966) to be distributed near the galactic plane in regions resembling parts of spiral arms. Behr (1965, 1966) has questioned this, pointing out that the dispersion in absolute magnitude of these stars is much larger than that found by Schmidt-Kaler. As a result many of the structural details shown by the latter are smeared out. Recent work by Wray (1966), however, concerning the distribution of Be stars in the southern Milky Way simply indicates a clumpiness in their distribution with an indication of possibly an inclined structure to the galactic plane.

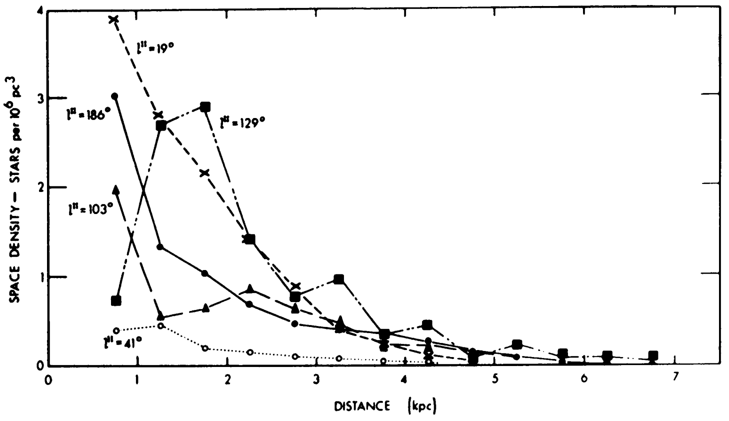

Fig. 1. Space density distribution of OB stars as a function of distance at five galactic longitudes.

The paper by Schmidt-Kaler (1964) contains a figure which illustrates well the indication of spiral structure among the Be stars. The mean absolute magnitudes for these stars are, according to Schmidt-Kaler, $M_v \sim -4.2$ for classes Bpe, B0(III–V) e to B 2 (III–V) e. A recent study by Crampton (1968) of the kinematics of Be stars essentially confirms these intrinsic luminosities.

Cepheid variables with $M_v < -4.3$ show some indication of concentrations along the currently recognized spiral structure. However, the recently published data by Fernie and Hube (1968) leave considerable doubt concerning this point. A plot of the positions on the galactic plane for those classical cepheids with periods longer than 10 days ($M_v < -4.3$) differs considerably from that shown by Kraft (1965), in which an association between the bright cepheids and the recognized spiral structural details of the galaxy was more marked.

Fernie (1968) has pointed out that with a foreknowledge of the spiral structure one can see that the classical cepheids do show a weak association with the structure indicated by other types of objects. The sun appears to be on the *outer edge* of a local spiral arm, however, rather than on the inner edge as indicated by other spiral arm tracers. Incompleteness in the data may have a strong influence on the apparent distribution of these objects.

3. The Common Stars

In this grouping we include the vast majority of stars, constituting the main sequence from B 5 to F 5 and the normal giant stars from F 8 to M. Because progress on detailed spatial analyses of these groups is slow and since a recent summary (McCuskey, 1965) has not been seriously changed by added material, we summarize briefly the present state of affairs.

Space density contours on the galactic plane indicate large concentrations of B 5 stars at $l^{II} = 165°$ between 500 and 1000 pc from the sun; of B 8–A 0 stars at $l^{II} = 100°$ and 135° within 500 pc of the sun; of a high concentration of B 8–A 0 stars near $l^{II} = 300°$ at a distance of 1 kpc and another at $l^{II} = 200–220°$ between 1.5 and 2.0 kpc. This clumpy distribution of stars of moderate age ($1–5 \times 10^8$ yr) shows little correlation with the large-scale spiral structure. It should be emphasized, however, that these detailed analyses based on spectral classifications and photometry carried out at the Warner and Swasey Observatory are far from complete. At present five areas of the Milky Way in the southern sky are under study. When these are finished a better picture of the local stellar system can be obtained.

Among the older stars similar local groupings are evident. The most conspicuous of these is the group of F 0–F 5 stars around the sun. It has been pointed out before (McCuskey and Rubin, 1966) that these appear to form a local concentration near the sun. An average decrease in space density of 65% in the first 600 pc from the sun occurs. A recent study by Rydgren (1969) indicates that this is not due to a statistical fluctuation of randomly distributed stars. Rydgren's analysis of the space motions of 96 nearby F-stars places a maximum age of 2×10^7 years for the local concentration. He suggests that epicyclic resonance may be responsible for the present grouping, and that the grouping is a transient phenomenon.

The G 8 III–K 3 III stars appear to be rather uniformly distributed in the region of the sun. One concentration at $130° < l^{II} < 150°$ in the range $r = 100–500$ pc coincides approximately with the B 8–A 0 and A 2–A 5 groupings here.

The local concentrations and the rather high population densities near the sun shown by these studies are very much influenced by uncertainties in the evaluation of the interstellar absorption. On the face of it, however, the localization of intermediate age stars within 250–500 pc of the sun may indicate their preference for the inner part of the local spiral arm. But any striking evidence of association between them and the spiral structure is not present.

Analyses of the stellar distribution toward the galactic center (unpublished) and toward the galactic anticenter (McCuskey, 1967) have permitted the construction of space density profiles showing the variation of the number of stars per 1000 pc^3 over a range of 4 kpc centered on the sun. These have been constructed for several spectral groups: B 5, B 8–A 0, A 1–A 5, A 7–F 5, G 8 III–K 3 III and F 8 III–M 5 III. The profiles (Figures 2 and 3) show:

(a) A steeper decline in space density of B 8–A 0 stars toward the galactic center than toward the anticenter – another indication of a possible concentration of these stars near the inner edge of the local spiral arm.

(b) The concentration of late A and the F stars near the sun, mentioned above.

(c) A marked steady decrease in space density of giant G 8–K 3 stars from the galactic center direction toward the anticenter.

(d) A remarkably constant space density of F 8 III – M 5 III stars over the entire span of distance included.

No indication of major connections between these groups and the local spiral structure is apparent.

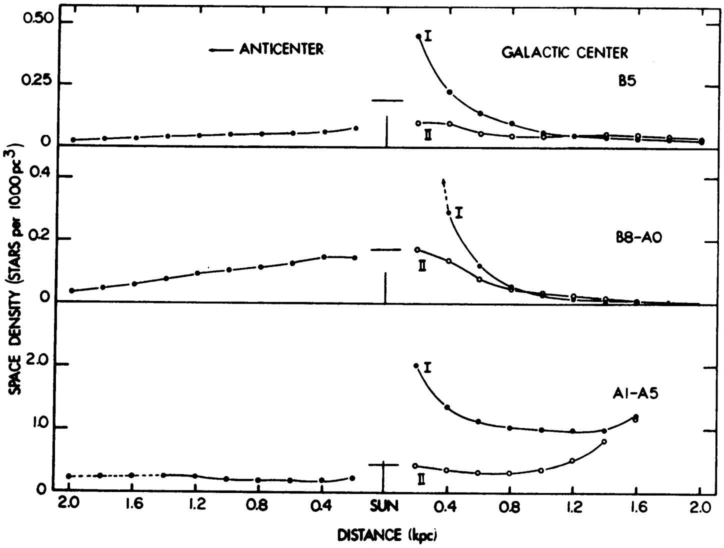

Fig. 2. Space density profile for early-type stars from galactic anticenter to center directions through the solar neighborhood. Curves I and II refer to calculations using high and low estimates of interstellar absorption, respectively. Bars at the solar position refer to space densities for the region within 100 parsecs of the sun.

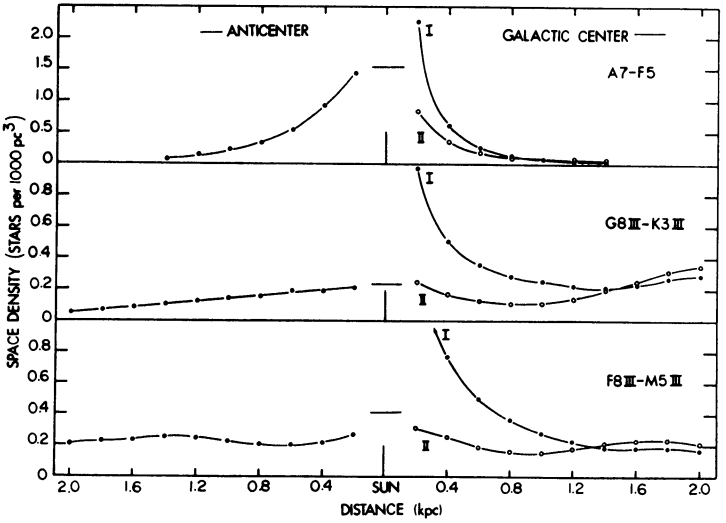

Fig. 3. Space density profiles for main sequence F and late-type giant stars. See caption to Figure 2 for details.

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4. New Survey of B 8–A 3 Stars

In a further attempt to associate in some detail the early A-stars with the local spiral structure a comprehensive survey of the entire galactic belt visible from Cleveland was begun three years ago. The use of a thin 1°.8 ultraviolet transmitting prism (dispersion 1100 Å/mm at Hγ) attached to the Burrell-Schmidt telescope and Kodak IIa O plates with exposure times of 20 min yield clearly identifiable spectra for B 8–A 3 stars brighter than $V \sim 13$ mag. Galactic clusters provide a magnitude calibration for the survey. By studies of overlapping plates the counts of A-stars are reduced to a reasonably uniform system. Dr. Nancy Houk and I have collaborated on the identification and counting of these objects. Independent counts and reductions for overlap, etc. were finally combined into the accepted *number of* B 8–A 3 *stars per square degree brighter than* $V=13$.

At present the data for galactic longitude ranges $95° < l^{II} < 150°$ and $55° < l^{II} < 75°$ are complete. In galactic latitude the range varies. Our present discussion will be limited to $-3° < b^{II} < +3°$. The data, however, extend somewhat farther from the galactic plane but not uniformly. One region embraces the local spiral arm and the other is an interarm region.

To supplement the data for the faint A-stars we have classified the stars in this group for the magnitude range $V=7$–10 from plates taken some years ago with the 4° prism attached to the Burrell-Schmidt telescope (dispersion 280 Å/mm at Hγ). Furthermore we have used the counts made years ago by Seydl (1929) from the Henry Draper Catalogue. Thus we have available for analysis values of log $N(7)$, log $N(10)$ and log $N(13)$, where $N(V)$ is the *number of A-stars per square degree brighter than magnitude* V, for each square degree, or combinations of square degrees, in the regions of the Milky Way outlined above.

The data on interstellar reddening published by Neckel (1967) and by FitzGerald (1968) have been used to obtain the interstellar absorption as a function of distance in small sub-areas of the regions. A ratio $A_v/E_{B-V}=3.1$ was used to convert the color excesses into total absorption. The absorption data for the distance range 0–2.5 kpc from the sun was evaluated for areas of 1 sq deg or combinations thereof.

The total numbers of A-stars, adjusted for overlaps, magnitude differences, etc. counted in these two sections of the survey are:

Local spiral arm – 34731 in 581 sq deg.
Interarm – 8802 in 382 sq deg.

Thus we find 2.6 times as many stars per square degree in the local arm region as in the interarm region. At the same time we find that the average absorption, $\langle A_v \rangle$ at 1 kpc is somewhat less in the latter as compared to the former. At 0.5 kpc the same result prevails. The bulk of the interstellar absorption is within 1.5 kpc of the sun in both regions.

It is clear from the surface distributions of the 13th magnitude A-stars that large fluctuations occur from point-to-point along the galactic plane within distances of

1 to 1.5 kpc of the sun. A large part but not all of this is attributable to variations in the interstellar absorption. At $l^{\mathrm{II}}=130$–$140°$ above the galactic plane and at $l^{\mathrm{II}}=98$–$108°$ below the galactic plane, for example, excesses in the counts of A-stars are difficult to explain by a lack of obscuration there. On the other hand most of the variation in the numbers of these stars in the interarm region seems to be due to fluctuations in absorption.

The star-count and absorption data have been used in a standard way (McCuskey, 1966) to compute space densities for the A-stars. As parameters we have used $M_0=+0.9$ and $\sigma_0=0.7$ mag., for mean absolute visual magnitude and dispersion respectively. These refer to unit volume of space. The calculations were performed on the Univac 1108 of the Jennings Computing Center at Case Western Reserve University. We are indebted to Mr. W. H. Wooden for carrying out these calculations. *There results the number of* B 8–A 3 *stars per* 10^3 pc^3 as a function of galactic longitude at distances of 250, 500, 750, 1000, 1500 and 2000 pc from the sun for three zones of galactic latitude, $-3°<b^{\mathrm{II}}<-1°$, $-1°<b^{\mathrm{II}}<+1°$, and $+1°<b^{\mathrm{II}}<+3°$.

From the space density analysis we draw the following conclusions:

(a) A definite density gradient in $-1°<b^{\mathrm{II}}<+1°$ seems to exist across the local spiral arm, the number of A-stars at 250 pcs and at 500 parsecs at $l^{\mathrm{II}}=95°$ being about 5 times the number at $l^{\mathrm{II}}=150°$. A similar trend is evident for the zone $-3°<b^{\mathrm{II}}<-1°$ but it is not as pronounced. For the region above the galactic plane this trend is not evident.

(b) This density gradient has largely vanished at $r=1500$ and 2000 parsecs, and at $l^{\mathrm{II}}=145$–$150°$ there is some evidence for another high concentration of A-stars at these distances.

(c) At $l^{\mathrm{II}}=133°$ and around $l^{\mathrm{II}}=105°$ there are distinctly delineated maxima in the space density of A-stars, resembling large clusterings. These appear to be rather elongated regions, some 50 pc wide and 300 pc long. The reality of such 'cigar-shaped' high density regions may be questioned. But they do appear, not only in the distributions of A-stars but in those of other spectral classes. It has been suggested to us by Dr. V. C. Reddish that perhaps a cloud of relatively large particles, non-reddening, is embedded in the stellar distribution in such a way as to produce the elongated structures. This remains to be investigated.

(d) A large clustering of A-stars occurs at $l^{\mathrm{II}}=52$–$62°$ in the interarm region at $r=250$ pc. It persists at $r=500$ pc but has essentially disappeared beyond that distance. The general decrease of space density with distance is much more rapid in the interarm region than in the region of the local spiral arm.

(e) If we assume that the B 8–A 3 stars are associated, albeit loosely, with the local spiral structure then we might interpret the above results in the following way:

(i) If the sun is situated toward the inner edge of the local spiral arm (LSA), the heavy concentrations of A-stars at $r=250$–500 pc near $l^{\mathrm{II}}=95$–$105°$ and $l^{\mathrm{II}}=132$–$135°$ imply their predominance also toward the inner edge of LSA.

(ii) The end of the space density decrease at $r\sim800$–1000 pc around $l^{\mathrm{II}}=100°$ implies vaguely a boundary to LSA here.

(iii) The most rapid density decrease occurs at $l^{II}=115–125°$, the radial extent of LSA here being 500–600 pc. This is about one-half of the width of the LSA as defined by other stellar populations.

(iv) If the sun is near the inner edge of LSA the distributions of the A-stars as noted above would indicate an angle of inclination to $l^{II}=90°$ of some 25–30° for LSA. This is in conformity with the structure defined by other stellar objects but much larger than the inclination angle of the spiral structure indicated by the concentrations of H I.

It should be re-emphasized, however, that vagaries in the evaluation of the interstellar absorption enter the analyses strongly.

5. Giant M, S, C Stars

Blanco (1965) and Mavridis (1966) have summarized in considerable detail the information obtained from infrared surveys concerning the galactic distribution of these late-type giant stars. Briefly it may be said that:

(a) *The early-type M stars*, spectral classes earlier than M 5 III, are distributed somewhat irregularly along the galactic equator with concentrations at $l^{II}\sim 60°$ and $l^{II}\sim 240°$ suggestive of membership in the local spiral arm population.

(b) The giant stars of classes M 5–M 6.5 are more uniformly distributed between spiral arm and interarm regions but show an appreciable increase in numbers toward the galactic center.

(c) The very late M-stars, classes M 7–M 10, appear to be confined more or less uniformly to a thin disk centered on the galactic plane. The thickness of the disk is about 400 pc. These stars do not seem to be as concentrated toward the galactic center as do those of the M 5–M 6.5 group.

(d) The *S-type stars* are very rare in space. It has been shown by Westerlund (1964) that their distribution in the southern Milky Way is similar to that of the OB-associations. They are, therefore, probably spiral arm objects. On the other hand, there may be two types of S-stars (Keenan, 1954; Takayanagi, 1960) one of which is *not* associated with spiral structure. Much more needs to be done to determine distances for these objects before any definitive conclusions can be drawn.

(e) The *Carbon stars*, particularly those classified as N in the *Henry Draper Catalogue*, exhibit some tendency toward concentrations in spiral arm regions. Westerlund (1964) has examined in detail the surface distribution of these in the southern Milky Way. There is a preponderance of carbon stars toward Carina at $l^{II}=290–300°$ and these appear to be distributed fairly uniformly along the spiral structure in that direction. Blanco (1965) has shown that these stars are more numerous toward the galactic anticenter than toward the galactic center. And Westerlund's (1964) survey of the southern sky does not indicate any penetration of the Sagittarius spiral arm in this direction. There is considerable evidence for clustering and pairing among the carbon stars.

(f) Space density analyses for the late-type giant stars are not available for a great many regions in the galactic plane. For the stars M 5 III and later, however, the space density, *number of stars per* 10^6 pc^3, has been calculated as a function of distance for several areas (Figure 4). These data have been taken from the work by Westerlund (1959a, b, 1965), Albers (1962), McCuskey and Mehlhorn (1963), Blanco (1965), Hidajat and Blanco (1968), and McCuskey (1969). A relatively uniform space distribution of these stars (0.3–0.4 stars per 10^6 pc^3) for regions away from the galactic center is evident from these surveys. There is, however, a considerable increase in space density toward the galactic center and a slow decrease toward the anticenter.

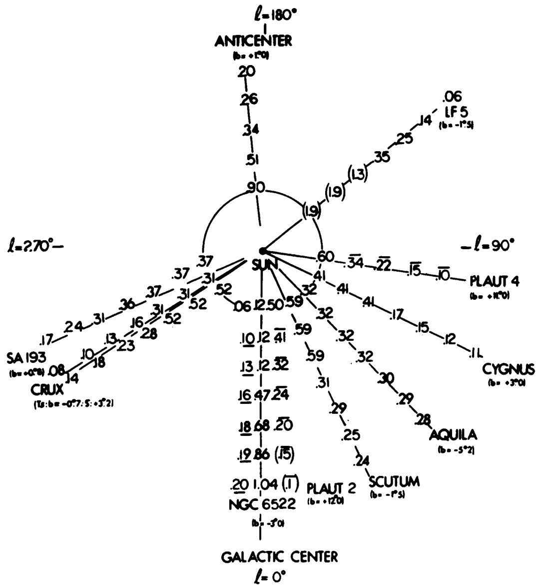

Fig. 4. Space density of late-type giant M stars near the galactic plane. See text for details.

At comparable distances greater than 3 kpc from the sun there appear to be 2–4 times as many late M-stars toward the galactic center as in the opposite direction. There is little evidence that these stars are associated with the spiral structure of the galaxy.

6. Summary

We conclude from this survey that among the *stellar groups* thus far studied in sufficient detail

(a) The OB^+ and OB^o stars, the WR stars, the Be stars of early type, the O-associations, some of the S-stars and the N-stars (carbon), appear to be linked to the spiral structure of the galaxy in our neighborhood.

(b) The B 5 and the B 8–A 3 main sequence stars, the classical cepheids, the early M-giant stars (including those that are variable) *possibly* are associated with the local spiral structure, although the evidence is not strong.

(c) The remaining upper main sequence stars, earlier than F 8, the yellow-red giants,

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the M-giants later than M 5, some of the S-stars and the R-carbon stars exhibit no discernable relationship to the spiral structure.

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