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SPIRAL STRUCTURE IN THE VELA SECTION OF THE MILKY WAY

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RESUMEN

En base al análisis de la distribución espacial de estrellas Be (Vega 1982) se estudió la estructura espiral en la zona de Vela. Esta investigación se complementa con un análisis exhaustivo de los distintos indicadores de brazos espirales que han sido observados en la zona por otros autores.

Se establece la presencia de un brazo espiral (el brazo local) aproximadamente tangente a la visual en $\ell = 270^\circ$. La extensión de dicho brazo es considerable (probablemente alcance unos 6 u 8 kpc del Sol), presentando una pequeña ramificación como la propuesta por Vogt y Moffat (1975). Más allá de la distancia indicada habría una zona interbrazo y, finalmente, se hallan algunos objetos muy distantes que podrían pertenecer a una extensión del brazo +II hacia esas longitudes.

ABSTRACT

The spiral structure in the Vela region is studied through the distribution of Be stars (Vega 1982), and different spiral tracers which had been observed in this zone by other authors. We found that a spiral arm (the Local Arm), is running tangentially along the line of sight at $\ell = 270^\circ$. This arm extends probably in the direction of Vela up to 6 or 8 kpc from the Sun. In addition, it presents a small branch as proposed by Vogt and Moffat (1975). There might be an interarm zone somewhat farther away, and finally, there are some very distant objects that could belong to an extension of the +II arm toward these longitudes.

Key words: GALAXIES-STRUCTURE — SPIRAL STRUCTURE

I. INTRODUCTION

The Vela region, in the southern Milky Way, was one of the least studied zones in the past; it was not attractive enough to look for spiral structure, because as it was considered an interarm region. It also has the disadvantage of being a region of strong absorption which makes it difficult to observed at a large distance from the Sun in the optical range.

More recently, the presence of a spiral arm has been suggested by several authors, notably Herbst (1975), whose argument that at $\ell = 265^\circ$ we are seeing tangentially a spiral arm is based on the fact that the greater absorption is found at $\ell = 270^\circ$, just over the inner edge of the arm delineated by the reflecting nebulae. This would agree with the observations made by Lynds (1970, 1972) who showed that the dust in galaxies concentrates along the inner zone of the optical spiral arms.

One of the most comprehensive works carried out in the zone is perhaps that of Denoyelle (1977) who found that at $\ell = 268^\circ$ there is a relatively strong emission of the local arm up to at least 5 or 6 kpc from the Sun. However, the data he analyzed were not homogeneous. He used spectral types from different authors and he included in his sample stars much later than B2. Besides, he did not attempt to recognize stellar groups. Thus, his diagram of the spiral structure is biased by the distance errors of individual stars and his results might not be trustworthy.

The existence of a spiral arm running tangentially near $\ell = 270^\circ$ is still uncertain. Despite the presence of many tracers of spiral structure in the region, their number is lower than in other zones where spiral arms are known to be present. Among the authors that support this possibility we can mention Humphreys (1979) who proposed that the local arm extends in the direction $\ell = 240^\circ$, suggesting that it may be a branch of the Perseus arm. Georgelin, Georgelin, and Sivan (1979) locate no arm at all in the Vela zone, assigning even the Sun to an interarm zone.

As it can be seen there is great disagreement in relation to the existence of a spiral arm. While some authors suggest that it runs tangentially along $\ell = 270^\circ$, others consider instead this zone as an interarm region.

The present work aims to obtain a clearer picture of the local structure. To achieve this aim a sample of Be stars (Vega 1982) in the regions $266^\circ < \ell < 275^\circ$, $-2.5^\circ < b < 2.5^\circ$ was selected, and in order to include those results into a more general frame, a wider zone was adopted: ($260^\circ < \ell < 280^\circ$, $-5^\circ < b < 3^\circ$) to which observations from others authors were added. The pref-

1986RMxAA..13...33V

erence for the negative latitudes is due to the deviation of the optical (Bok, Hine, and Miller 1970) and radio (Kerr and Westerhout 1965) tracers encountered in this direction of the Galaxy.

The Vela region is particularly inadequate for the kinematic derivation of distances due to the slow change of radial velocity with distance. Besides, in view of the criticisms made during the last decade to the use of neutral hydrogen as a spiral tracer and, in particular, of the difficulties involved in the kinematic methods of distance estimation (Burton 1976), it was decided to limit this study to the optical range and to employ radioastronomical data only as an aid.

II. TRACERS OF SPIRAL STRUCTURE IN THE VELA ZONE

The ratio of total to selective absorption in the 260°-280° region was adopted as R = 3.1 (Barlow and Cohen 1977).

a) *Open Clusters*

The distribution of clusters in the Vela region was studied on the basis of the Janes and Adler (1982) catalogue. Seven clusters were selected with spectral types earlier than B2. This limit insures that the selected clusters are young enough to trace the spiral structure.

b) *OB Stars*

The OB stars in the Vela region were selected from the lists of spectral types of Garrison *et al.* (1977), and the *UBV* photoelectric photometry from Klare and Neckel (1977). For each luminosity class the spectral type was chosen so that the age would not exceed 1.2×10^7 years. This ensures that the stars we selected are young enough. The latest spectral types for each luminosity class are given in Table 1.

TABLE 1

LATEST SPECTRAL TYPE FOR EACH LUMINOSITY CLASS

V	IV	III	II	Ib	Iab	Ia
B2	B4	B5	B6	B9	all	spectral types

Seventy-seven OB stars were found within these limits. The absolute magnitudes given by Crampton and Georgelin (1975) were adopted for stars earlier than B4, and those of Schmidt-Kaler (1982) for the later types; intrinsic colors were taken from Schmidt-Kaler (1982).

Twenty seven OB stars with photoelectric data only were also selected from the lists of Klare and Nekel (1977); in this case only those having $(U-B)_0 < -0.84$ were considered, i.e. stars earlier than B2V according to Schmidt-Kaler (1982).

The results based on *UBV* photometry alone were derived assuming that the stars were of luminosity class V. Their intrinsic colors were obtained using the reddening path $E(U-B)/E(B-V) = 0.72 + 0.05\ E(B-V)$ and the calibration of Schmidt-Kaler (1982). The absolute magnitudes were derived from the intrinsic colors using the zero-age main-sequence calibration of Crampton and Georgelin (1975).

c) *OB Associations*

The new catalog of Ruprecht, Balazs, and White (1981) includes only three probable OB associations in the Vela region; Vela OB1, Vela OB2 and Vela OB3. As the first one is questionable we prefer not to regard it as a real association, but to deal with the H II region RCW 38 that could be the nucleus of the assumed association (Muzzio 1979). The two remaining ones are not very useful for this work since Vela OB2 at 460 pc is very near to the Sun according to Brandt *et al.* (1971). The distance of the other one is doubtful, 5000 or 6000 pc, according to Miller (1972 and 1973).

d) *Be Stars*

From the lists of Garrison *et al.* (1977) eleven Be stars were selected, for which we derived the intrinsic colors, and the absolute magnitudes from Schmidt-Kaler (1964*a*, 1964*b*).

Be stars with photometry and without spectral classification were also selected from the list of Klare and Neckel (1977). Their intrinsic colors were obtained in the same way as for the OB stars without spectral classification, but employing the Schmidt-Kaler (1964*b*) calibration for emission-line stars. The absolute magnitudes were taken from the relation derived by Schmidt-Kaler (1964*b*) for color indices $(U-B)_0 < -0.85$.

e) *H II Regions*

A selection of H II regions was obtained from the catalogue of Rodgers, Campbell, and Whiteoak (1960) and of thermal radio sources from the list of Shaver and Goss (1970). Eighteen H II regions were found, two of them, RCW 36 and RCW 38 related to thermal radio sources.

In some cases it was possible to obtain the radial velocities of H II regions from the work of Georgelin and Georgelin (1970). Their low absolute values show that these regions lie near the Sun according to the Schmidt model (1965). One exception is RCW 42, for which Georgelin and Georgelin (1970) using their exciting stars obtained the true distance modulus, $V_0 - M_V = 12.75$ mag.

f) *R Associations*

The three R associations found in the Vela zone were selected from the list of Herbst (1975).

1986RMxAA..13...33V

g) *Long-Period Cepheids*

From the lists of Madore (1975) five long-period cepheids (P > 15d) were selected in the Vela zone. Using the mean magnitudes and the periods given by him the color excesses E($B-V$) and the distance moduli were computed for each cepheid by means of the relations given by Tammann (1970).

h) *Wolf-Rayet Stars*

Four WR stars were selected in the Vela zone from the lists of Hidayat, Supelli, and van der Hucht (1981).

III. RESULTS

In what follows we make an analysis of the observations carried out in the Vela zone by different authors. Special emphasis was put on the results from the lists of OB stars of Garrison *et al.* (1977), since they offer the most complete source for the classification of these stars in the southern hemisphere. The open clusters, H II regions, cepheids, R associations, WR stars and the Be stars including those discovered by Vega (1982) will be also presented in § IIIa.

Only three H II regions have been taken into account for the present discussion: RCW 32, RCW 35 and RCW 38. Only for the last one it is available a well determined distance (Bassino *et al.* 1982) from the exciting stars (Muzzio and Celotti de Frecha 1979); RCW 38 is also a giant H II region which provides an excelent spiral tracer. In the remaining H II regions the exciting star is not well determined or, in some cases, the star assumed to be the exciting star is of very late spectral type. This is the case of RCW 42, where Georgelin and Georgelin (1970) assign a B2 IV type, which makes it difficult to believe that it could be the exciting star. For RCW 32 and 35 we adopt the exciting stars suggested by Georgelin and Georgelin (1970) and the spectral types assigned by Garrison *et al.* (1977). These regions have no measurements in the range of 5000 MHz, and perhaps they are not giant H II regions.

Our analysis will consider first the near spiral structure, that is less than 4 kpc, and later on the objects that are located at distances greater than 4 kpc. The former is best determined, but the latter is also of interest despite its inaccuracies.

a) *Spiral Structure up to 4 kpc in the Vela Region*

To begin with, the distribution normal to the galactic plane of all the selected objects was plotted in order to detect any preference for negative latitudes. Figure 1 shows the results from which it is clear that such a preference exists, so that our adoption of a greater interval for the negative latitudes was reasonable.

Figure 2 represents the distribution of the objects in the galactic plane. It shows that for distances less than 2 kpc there is a greater concentration of objects between $260° < \ell < 270°$ with a gap toward greater longitudes. Beyond 2 kpc the distribution becomes more homogeneous.

The distribution of all the objects in longitude and latitude has been represented in Figure 3*a*. It shows a strong concentration toward the range of galactic longitudes $260° < \ell < 270°$. However, if we draw a similar diagram but separating the objects by distance modulus we note that the concentration is more evident for distances less than 2 kpc (Figure 3*b*). At distances greater than 2 kpc there does not appear a tendency of stars to cluster at lower longitudes (260° – 270°), but their distribution looks somewhat more homogeneous (Figure 3*c*). It is then questionable whether this lack of objects between 270° and 280° at distances less than 2 kpc is caused by absorption or to a real lack of a spiral feature.

The plots of the color excesses versus the distance modulus allow us to answer the question mentioned above and to see which is the behavior of the absorption with longitude.

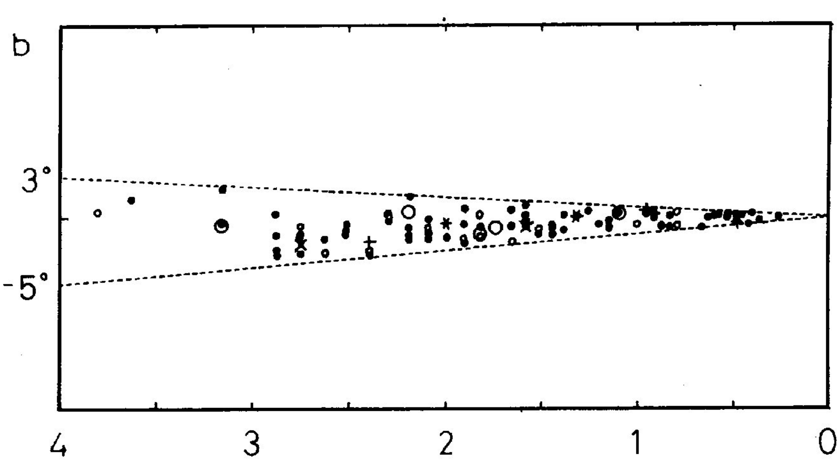

Fig. 1. Spatial distribution up to 4 kpc of: OB stars (dots), Be stars (small circles), H II regions (asterisks), R-Associations (plus signs), young clusters (large circles), Cepheids (crosses), and WR stars (triangles), displayed in a latitude versus distance diagram.

1986RMxAA..13...33V

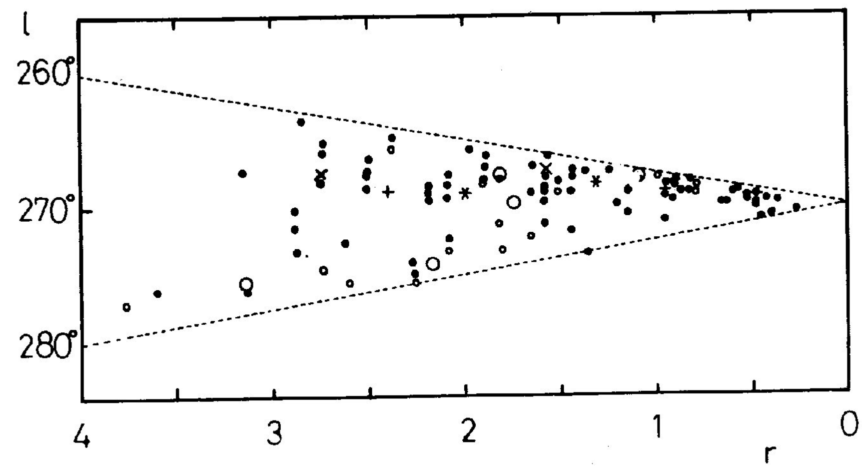

Fig. 2. Spatial distribution of the same objects as in Figure 1, but displayed in a longitude versus distance diagram.

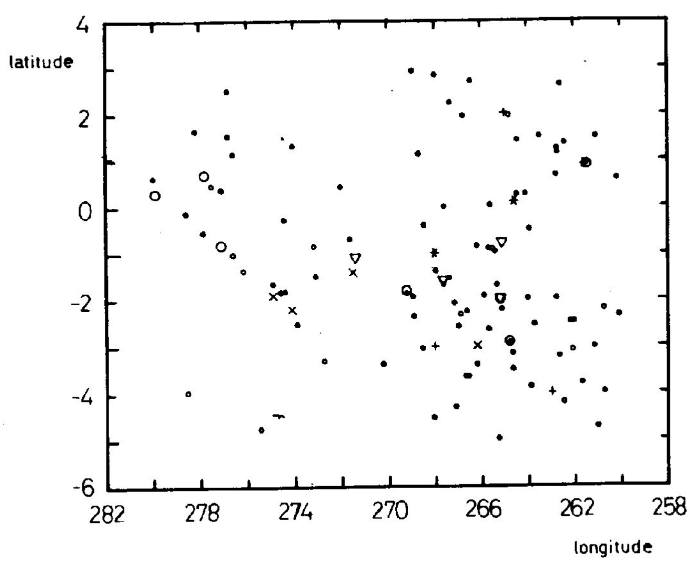

Fig. 3*a* The surface distribution of all the objects. Symbols as in Figure 1.

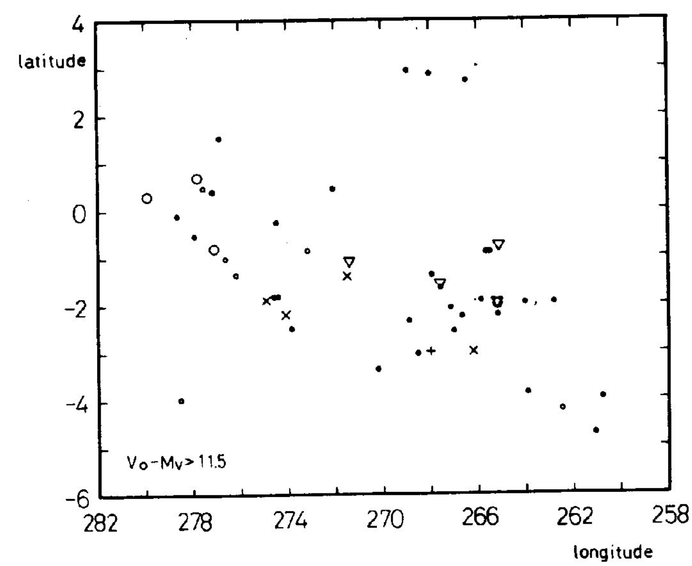

Fig. 3*c*. Same as Figure 3*a*, but for distances greater than 2 kpc.

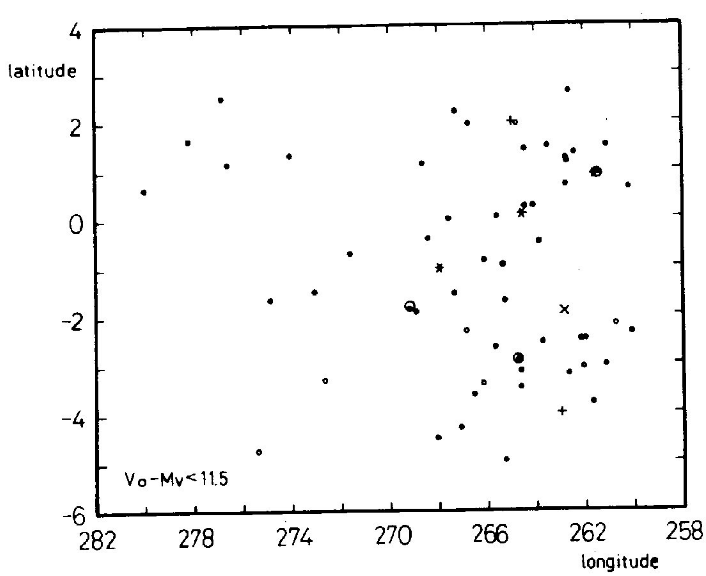

Fig. 3*b* Same as Figure 3*a*, but for distances less than 2 kpc.

The zone under investigation has been divided into four regions with longitude limits of 260°, 265°, 270°, 275° and 280°, and the results have been represented in Figures 4*a*,*b*,*c*, and *d*. In addition to the objects presented in the previous figures, there were also included the results from the OB stars of Klare and Neckel (1977), for which only minimum limits of distance can be given. It can be seen that in the region of $260° < \ell < 265°$ (Figure 4*a*) the greatest color excess reaches a value of 1.5 mag at less than 1 kpc from the Sun. At higher longitudes and greater distances there is an increase of the absorption. It is also noticeable that there is a real lack of spiral tracers between $270° < \ell < 280°$ at short distances from the Sun ($r < 2$ kpc).

The high absorption which appears in Figures 4*a*,*b* and *c* agrees with the results of Stegman and FitzGerald from the Sun. This larger value and the results derived by Lynds (1970), 1972) from other galaxies, suggest

1986RMxAA..13...33V

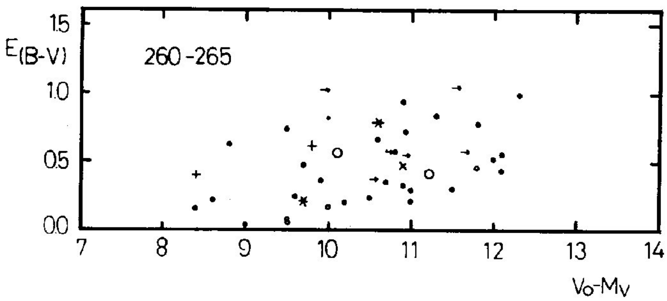

Fig. 4*a*. The diagram of $(B-V)$ color excess versus true distance modulus in the galactic longitude range 260° – 265° of OB stars with photometric data only, are represented with arrows.

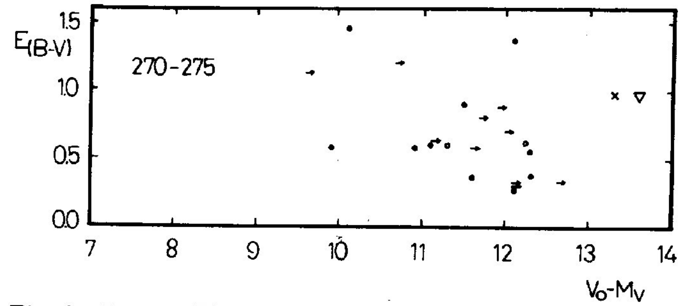

Fig. 4*c*. Same as Figure 4*a*, but for the galactic longitude range 270° – 275°.

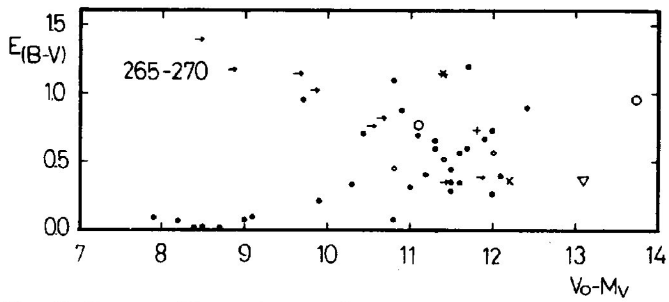

Fig. 4*b*. Same as Figure 4*a*, but for the galactic longitude range 265° – 270°.

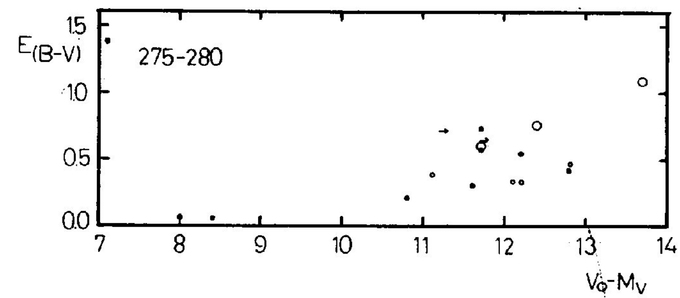

Fig. 4*d*. Same as Figure 4*a*, but for the galactic longitude range 275° – 280°.

that the absorption we found here could be related to the circumstance that we are looking towards the inner part of a spiral arm. This would be the Local Arm which at greater longitudes departs from the $\ell = 270°$ direction.

Bassino *et al.* (1982) carried out a photometric and spectroscopic study of OB stars in a zone between 267° and 272°. Their results confirm the presence of strong absorption relatively near the Sun. A detailed analysis of their own data led these authors to point out that near $l = 267.9°$, $b = -1.5°$, there is a group of stars physically related among them, as well as to RCW 38, an H II region. They derived a distance modulus of $V_0 - M_V = 11.5$ mag (r = 2 kpc) with a mean color excess $E(B-V) = 1.14$ mag. They also give some support to the presence of a farther group (Muzzio 1979) in the same zone, as well as to another one at about 2.5 kpc in the zone $\ell = 272°$, $b = -0.1°$.

The presence of optical tracers which start to be seen at greater distances larger than 2 kpc confirms the above results. This also agrees with our assumption that we are observing a tangent arm, with a dust zone in the inner part of the spiral arm, and with the stellar component behind it.

b) *Spiral Structure Beyond 4 kpc*

The Be stars selected from the lists of Vega (1982), in the zone of completeness (see § I), allow us to derive distances greater than 2 kpc. These stars are plotted in Figure 5 with dots, together with the young clusters, the H II regions, the R-Associations, the Cepheids and the

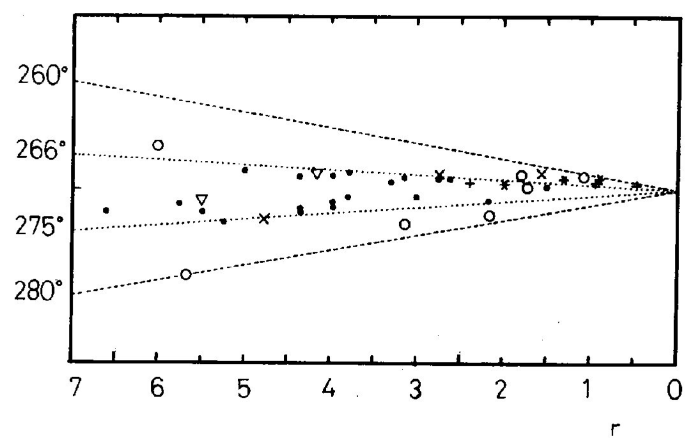

Fig. 5. Spatial distribution up to 7 kpc of: OB stars (dots) together H II regions (asterisks), R-Associations (plus signs), young clusters (large circles), Cepheids (crosses), and WR stars (triangles) displayed in a latitude versus distance diagram.

WR stars. Although, the sample is not very large and the longitude range is small ($267° < \ell < 273°$), it can be noticed that the spiral arm extends even farther away, showing some tendency to curve toward greater longitudes. If tracers up to 16 kpc are included (Figure 6) the Local Arm can be seen distinctly separated from still more distant tracers. The WR stars 12 and 13 and the EZ Vel Cepheid together with two Be stars discovered by Vega (1982), could belong to the extension of the +II arm (Vogt and Moffat 1975). However, it must be taken into account that at such long distances the errors are

1986RMxAA..13...33V

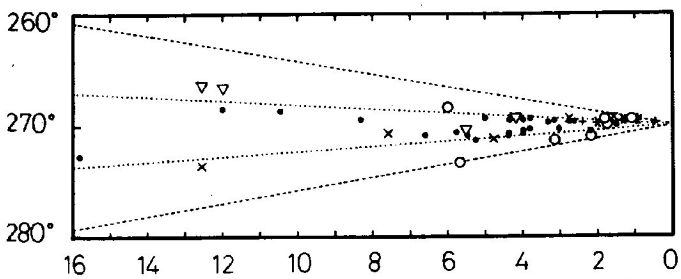

Fig. 6. Same as Figure 5, but for distances greater than 7 kpc.

very large, and our conclusions are thus doubtful. For instance, if we accept that the uncertainty of the distance for a cluster is 15 %, it would correspond to an error of 1.5 kpc at a distance of 10 kpc. On the other hand, we have already seen that the limit of completeness for our previous search of Be stars involves distances similar to the value mentioned above. So the gap could be simply caused by the incompleteness of the sample. Nevertheless, the fact that the gap and the appearance of more distant tracers occur also for other tracers, such as the WR and Cepheid stars, suggests the possibility that this phenomenon is real and not a consequence of the incompleteness of the data.

IV. CONCLUSION

The presence in the Vela zone of a spiral arm nearly tangential to the visual has been now well established. There are not only tracers of spiral structure but some of them, as region RCW 38, are conspicuous objects as seen also in other spiral galaxies. Our results show that at greater longitudes the optical tracers of spiral structure appear more distant. If we notice that the same happens with the absorption, which also reaches very high values at distances relatively near to the Sun, then it is reasonable to conclude that we are seeing the arm "from inside" and that it departs from $\ell = 270^\circ$ at greater distances. The extension of the arm is considerable, and it is probably seen in this direction up to about 6 or 8 kpc from the Sun. Because at such distance the arm either bends or ends, we found an interarm zone farther still and perhaps, at even greater distances, part of another arm.

At first sight our results seem to be opposite to some observed facts as well as inconsistent among themselves. Actually, we found an inclination of the arm in the opposite direction to the one observed in the other arms, since they are "open" with respect to a reference circle, while in our case the arm would have such an inclination that would be introduced into the circle. On the other hand, as the width of the arms is of the order of 1 kpc, a typical inclination of about 15° or 18° would imply that our view would not go along over the arm more than about 3.5 kpc at $\ell = 270^\circ$.

Vogt and Moffat (1975) have found at $\ell = 270^\circ$ a branch of the local arm between 1 and 2 kpc from the Sun which perfectly agrees with our conclusions. Since it is just a branch it is not significant that its inclination is opposite to that of the main arms. However, our results allow us to give a more complete model, since to obtain the extension of the spiral tracers found here, it is necessary to see a real arm tangent toward $\ell = 270^\circ$.

There are two reasons to explain why the existence of this arm has not been clearly established in the past. Undoubtedly, the main reason is the enormous absorption present in the zone, even very close to the Sun. Its presence not only prevents the study of the optical tracers, but also their discovery. However, it must also be recognized that the Local Arm, which is the one that extends in Vela, is not delineated by relevant tracers. It is considered by the same authors as a branch of another arm (Yuan 1969), or neglected completely (Georgelin *et al.* 1979) due to the lack of prominent H II regions. Although this last situation is obviously exaggerated in as much as it ignores other tracers different from H II regions, the real fact is that, besides the absorption, their scarcity in the local arm may also contribute to the lack of tracers in Vela.

In conclusion, from this investigation it is found that the Local Arm extends in the direction of Vela up to about 6 or 8 kpc from the Sun, with a small branch as the one proposed by Vogt and Moffat (1975). There would also be an interarm zone beyond that distance and, finally, there are some very distant objects that could belong to an extension of the +II arm toward these longitudes.

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