37. THE DISTRIBUTION OF HII REGIONS IN THE LOCAL SPIRAL ARM IN THE DIRECTION OF CYGNUS

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Abstract. The apparent shapes and orientations of optical nebulae in the Cygnus X complex provide possible evidence for the existence of a symmetry in the local spiral arm which may be related to the structure of the local magnetic field within the spiral arm. We have made a preliminary determination of the distances to about 90 nebulae in the Cygnus X complex by use of the values of interstellar absorption as a function of galactic coordinates. These values of absorption were determined from a comparison of optical and radio data for the nebulae. The more prominent nebulae are clumped at a distance of about 1.5 kpc. The total range in distances is from 1 kpc to at least 4 kpc. We have attempted to fit model spiral arms to this three-dimensional distribution of nebulae by approximating the spiral arm with a truncated cylinder. It has been possible to narrow the range of permissible orientations and sizes etc. for this local section of the Orion arm.

1. Introduction

Gaseous nebulae are intimately associated with spiral structure. Thus the distribution and physical properties of the gaseous nebulae in our local spiral arm should help to reveal the structure within the arm. We will present possible evidence for a symmetry about the axis of the arm and also some preliminary results concerning the orientation and geometry of the local region of the Orion arm as deduced from our study of the nebulae in the Cygnus X complex.

The Cygnus X region is approximately bounded by $l^{\mathrm{II}} = 70°$ to $90°$ and $b^{\mathrm{II}} = -8°$ to $+8°$. Most of the optically-visible nebulae of this complex are concentrated in the western side. So, we began our study by cataloguing 193 optical nebulae in this western section (Dickel *et al.*, 1969). We have followed two main lines of data analysis: the first has been to study the apparent shape and orientation of the optical features in our catalogue. The second aspect of the study has been to determine the distances to about half of these nebulae by use of the values of interstellar absorption as a function of galactic coordinates. These values of absorption were determined from a comparison of optical and radio data for these nebulae.

2. Shape and Orientation of the Nebulae

Let us first consider the shape of the nebulae. There are innumerable delicate filaments in addition to the prominent nebulae of IC 1318. One interesting feature of the nebulae is that 75% of those catalogued are highly elongated with axial ratios less than $\frac{1}{2}$ rather than the expected value close to 1. We see from Figure 1 that the axial ratio or

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Becker and Contopoulos (eds.), The Spiral Structure of Our Galaxy, 213–218.

eccentricity decreases with increasing galactic latitude above the plane. The indicated error bars show the extreme values within each latitude range. There are no extremely filamentary nebulae at low latitudes and no circular ones at high latitudes.

It should be pointed out that these highly elongated features that are so prevalent in the optical picture do not seem to appear in the radio data. Furthermore, although the main areas of the optical and radio emission overlap, the peaks of emission do not coincide too well which suggests that the optical appearance of the H II regions is governed to a high degree by the distribution of the absorbing material (Wendker,

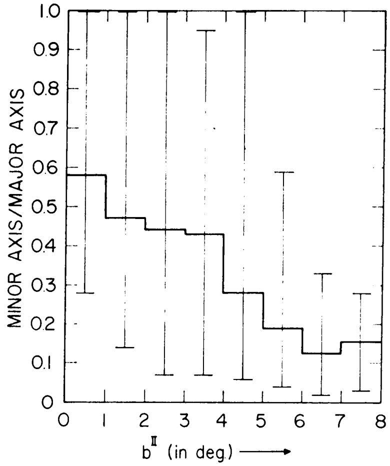

Fig. 1. The nebular axial ratio vs. galactic latitude.

1970). Thus in the following discussion on the apparent orientation of the optical emission features, probably one is dealing mainly with the orientation of the dust lanes. For this discussion on the orientation, we will consider the following four possibilities:

(i) The orientation of the minor axes of the nebulae is random.

(ii) The nebulae have their minor axes oriented to within $\pm 30°$ of being perpendicular to the galactic plane as suggested by the data.

(iii) The nebulae have their minor axes aligned to within $\pm 30°$ of the radius vector from the apparent center of the spiral arm. Since the center of the Cyg OB2 association lies conveniently nearly on the axis of the spiral arm, we have chosen it as the reference point in testing for symmetry.

(iv) This case is similar to the third except that the orientations are physically related to the Cyg OB2 association. However, this is unlikely to be the case since the nebulae are too strung out to be excited by this one association. Also, as previously mentioned, it is probably the dust which is aligned.

Thus we will consider only the first three orientations. Figure 2 shows a histogram of the number of nebulae within each 20° zone of orientation relative to the radius vector from the center of the arm which we will take as Cyg OB2. From the results of a χ^2 test applied to this histogram to test for deviations from randomness, we conclude that the apparent orientation of the optical nebulae is not random.

In considering the other two possibilities, orientation with respect to the galactic plane or with respect to the axis of the arm, we have grouped the nebulae into 20° sectors of the position angle of the radius vector from the center of the arm as shown in Figure 3. Then we considered the number of nebulae within each sector that have a particular orientation. The results of χ^2 tests applied to these data may be summarized as follows: There seems to be a natural dividing line at a position angle of 70°

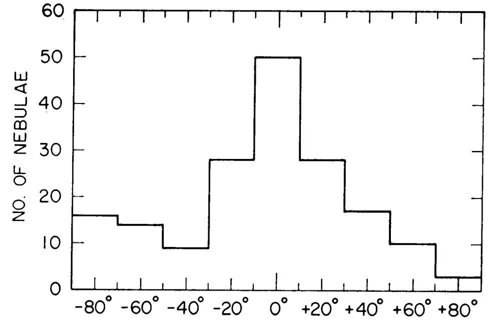

Fig. 2. The number of nebulae with various orientations relative to the radius vector from the arm center (taken as the center of the Cyg OB2 association).

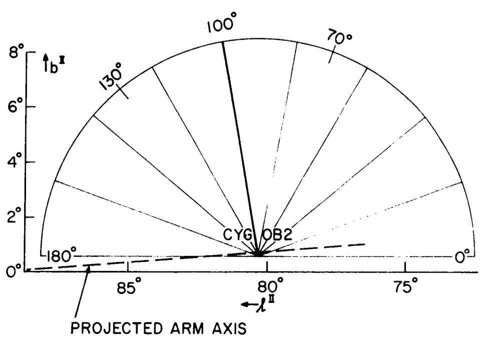

Fig. 3. Zones of position angles around the Cyg OB 2 association.

which separates a region of random orientations for position angles less than 70° from a region of nearly radial orientations for position angles greater than this value. Most of the large, nearby nebulae such as IC 1318 a, b, c, are at position angles less than 70°. In general the probability for orientation of the minor axis perpendicular to the galactic plane is lower than for orientation with respect to the arm-center. The most pronounced alignment occurs between position angles 100° to 130° which is in the right sense if the arm is tilted above the galactic plane. The projected axis of the arm for a 1° inclination is indicated in Figure 3. Near the axis and in the galactic plane where we can see to further distances along the arm, one might expect any

https://doi.org/10.1017/S0074180900000577 Published online by Cambridge University Press

alignment to be smeared out but above the plane at the edge of the arm, the filamentary structure and alignment should be more apparent as we have found.

Struve (1957) has also commented on the outer ring of filaments which seems to surround the main part of the Cygnus X complex (see Figure 4 of Dickel *et al.*, 1969). We applied the χ^2 test to the orientations of the nebulae on the outer ring. The orientations are not random but are again oriented with respect to the center of the arm. Here it may be the nebulae themselves that are so aligned.

In concluding the first part, the apparent orientation of the optical nebulae seems to indicate an alignment for the dust streamers which may be related to the helical structure of the local magnetic field of the spiral arm as given in the recent model by Mathewson (1968). The alignment we have found resembles that found by Hiltner (1951) for the planes of vibration of the polarized starlight.

3. Nebular Distances and the Local Spiral Arm

For any nebula, both the observed surface brightness in Hα and the observed radio brightness temperature are directly related to the emission measure by formulae involving known physical constants and the electron temperature. If we adopt a value of 6000 K for this temperature we can then compute the ratio of the observed brightness at the two wavelengths. The observed ratio will differ from that predicted, however, because of the absorption of the optical radiation by interstellar material. The amount of absorption as a function of distance in the Cygnus direction has been determined by Ikhsanov (1959) from measurements of the color excesses of stars. We have therefore used his curves to get the distances to the 90 nebulae for which we have both radio and optical data.

The optical data for the nebulae consist of an overlapping network of two dozen, calibrated plates of the Hα emission covering the western part of the Cygnus X complex. The grid of radio brightness temperatures for the region was obtained from Wendker's observations (Wendker, 1970) with a resolution of 11 min of arc at a wavelength of 11 cm. The microphotometry of all our plates is time consuming and thus we decided to do a preliminary calculation of the distances by estimating the surface brightnesses in Hα of the catalogued nebulae which appear on our plates. The results of these calculations were presented in our paper V (Dickel *et al.*, 1969) where we found that the nebulae are distributed from about 1 kpc to at least 4 kpc with the more prominent nebulae located around 1.5 kpc.

The next concern is where to place the main part of the Orion arm relative to this three-dimensional distribution of nebulae. From an examination of maps of the 21-cm emission it seems possible to approximate the local section of the arm as a truncated cylinder. The center of the arm can be fit reasonably well by a straight line which makes an angle of 77° with the line representing 0° longitude. This simple model gives a good fit from about 0.5 kpc from the sun to about 3.5 or 4 kpc beyond which the curvature of the arm becomes noticeable.

Figure 4 shows the model of the spiral arm which best fits our data. We have tried many models and have been able to significantly narrow the range of possible parameters for this section of the local spiral arm. Our results may be summarized as follows:

(i) The pitch angle – here defined as the angle which the axis of the cylinder makes with the line to the galactic center – lies between 75° and 80° with the best fit giving 77°.

(ii) The angle of tilt above the plane is less than 2° with a best fit of 1°. Putting the arm parallel and above the plane does not improve thc fit.

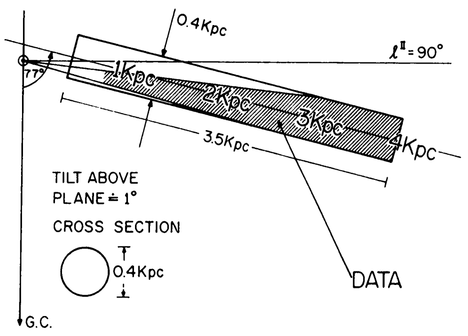

Fig. 4. Best-fitting model to the local Orion arm.

(iii) The sun is on the inner edge of the arm, roughly $\frac{8}{10}$ of the distance from the center to the edge of the arm.

(iv) The semimajor axis is found to be greater than 0.15 kpc and much less than 0.4 kpc with a best fit of 0.2 kpc.

(v) The ratio of minor and major axes of the cylindrical cross section is more than $\frac{1}{2}$ and close to 1.

4. Conclusions

In summary, the data on the apparent filamentary structure of the optical nebulae and of the interstellar absorbing material within the local Orion arm suggest the existence of a symmetry which may be related to the structure of the local magnetic field within the arm. Our preliminary analysis on the distances to the Cygnus X-nebulae indicates that with the refinements in the data and analysis which we are presently incorporating (such as the accurate Hα surface brightnesses, high resolution radio data, etc.) we should get distances to the nebulae which are reliable to within a few tenths of a kpc. The fitting of model spiral arms to these data is a promising technique for determining the geometry of our local arm as defined by the ionized gas. So, by a judicious combination of optical and radio data for the nebulae with stellar color excesses and perhaps additional measurements of polarization and radial velocities at both wavelength ranges, we are beginning to see a picture emerging for the spatial distribution of the components of the local spiral arm. Hopefully, the physical relationships between the gas, stars, dust and magnetic field in the arm will soon be revealed.

Acknowledgements

We wish to thank R. A. Avner, S. P. Wyatt and K. M. Yoss for helpful discussions and J. H. Cahn and J. R. Dickel for their help in the preparation of the manuscript.

This research has been partially supported by the National Science Foundation.

References

Dickel, H. R., Wendker, H. J., and Bieritz, J. H.: 1969, *Astron. Astrophys.* **1**, 270.
Hiltner, W. A.: 1951, *Astrophys. J.* **114**, 241.
Ikhsanov, R. N.: 1959, *Izv. Krym. Astrofiz. Obs.* **21**, 257.
Mathewson, D. S.: 1968, *Astrophys. J.* **153**, L47.
Struve, O.: 1957, *Sky Telesc.* **16**, 118.
Wendker, H. J.: 1970, *Astron. Astrophys.* **4**, 378.