Chapter 6

IRAS sources in the dark clouds in the Gum Nebula

6.1 Introduction

In this chapter we discuss the young stars embedded in dark clouds in the Gum Nebula as revealed by tlie Infra-Red Astronomy Satellite(IRAS) survey data. The aim is to study the locations of Young Stellar Objects(YSOs) inside the dark clouds with respect to the center of the distribution of the CGs in the Gum Nebula. If tlie star formation in the dark clouds in the Gum Nebula has been triggered by *external events*, the locations of the YSOs should reveal this as a tendency for the YSOs to lie towards (1) the periphery of tlic clouds, and (2) towards tlie side facing tlie center. There have been two such studies of IRAS sources in dark clouds in the past, between them, covering tlie whole of the sky (Emerson 1985; Parker 1988). They looked for enhancement in the density of IRAS sources towards edges of the clouds. In such whole-sky studies, since there is no obvious center for the processes possibly triggering star formation. the second effect mentioned cannot be stutlied. Both these studies conclude that there is no evidence for externally triggered star formation in dark cloutls. The first of these studies done by Emerson(1985) for the southern sky uses the Southern Dark Cloud(SDC) catalog compiled by Hartley *et. al.*(1986) from the ESO/SERC J Survey plates. This catalog gives in addition to the co-ordinates the major and minor axes of the ellipse which best approximates tlie cloud. Unfortunately it does not list the orientation of the ellipse making the interpretation of the IRAS source locations difficult. In other words, based on this information it is not possible to say reliably if an IRAS source lies towards the periphery of a cloud or not. This is a major drawback for any study which seeks to draw conclusions based on the distances of the IRAS sources from their respective cloud-centers as in Emerson's study. The second study done by Parker(1988) for the northern sky is based on the accurate shapes of Lynds dark cloutls and so can give reliable information about external triggering of star formation. The results of these studies indicate only that external triggering of star formation is not wide spread.

In tlie case of tlie dark cloutls in the Gum Nebula, there is already substantial evidence for external processes affecting them and also an apparent *center-of-influence.* We can take advantage of these circumstances and modify the method of analysis of the location of the IRAS sources. If the processes originating in tlie central region are important for triggering star forniation. then apart from expecting tlie IHAS sources to lie towards the edges of the clouds, one also expects that they be on the sides of the clouds facing the center as mentioned before. We use this second property of tlic exepectetl distribution of IRAS sources. The advantage of this method is that it is not affected by the exact shape of the cloud and its orientation.

In the next section we will describe the criterion we have used for selecting YSOs. In the third and fourth sections we describe tlie search and analysis procedures. Then the statistical method used to obtain tlie confidence level is described. The last section discusses tlie results.

6.2 Selection Criteria of the YSOs

The criteria used for selecting a YSO are the same as the ones used by Parker, along with those proposed by Emerson These are listed below:

1. Detection at 25μ and 60μ with [60-25] > 0
2. [25-12] > 0, if also detected at 12μ
3. Detection only at 60μ.
4. Detection at 60μ and 100μ only with [100-60] > OG
5. [100-25] > 0

Here [25-12] means the *25 to 12 micron color.* $\equiv \log[S_{25}/S_{12}]$, S_{25} being the IRAS catalog flux density in Jansky at 25μ wavelength. The fifth criterion, used by Parker is simple and picks up sources whose temperatures are less than $\sim$ 70 K, thus rejecting the more evolved stars. The first four criteria from Emerson are more detailed and were arrived at based on the regions occupied by known classes of objects in the IRAS *color-color plots.* Parker has shown that objects meeting criterion 5 fall in regions in the color-color diagram recognisecl by Emerson to be populated by T-Tauri stars, embedded cores and galaxies. If any one of these conditions is satisfied, the source is considered a candidate. *We take an IRAS source to be an embedded YSO if it meets one of the above criteria and falls within a specified distance from the center. of a dark cloud.* Emerson has shown that the number of IRAS sources so selected falls off as one goes towards the edge of the clouds implying that they are physically associated with tlie clouds. In other words, it is unlikely that there are many *galaxies* in the selected sample. Also, galaxies will be far outnumbered by galactic objects at tlie low latitudes of the dark clouds. The association with dark clouds makes it unlikely that the sources are galaxies.

6.3 The Search

The dark clouds are from the SDC catalog of Hartley *et. al.*(1986) We have chosen the distance limit from the center of the cloud to be the mean of the minor and major axes of the cloud. Since the analysis does not depend on the distance of the source from the center of tlic cloud, this larger area of search than what was used by both Emerson and Parker is not a handicap. On tlie other hand it takes care of errors in the co-ordinates of the cloud centers and tlie IRAS sources. The search was carried out over the RA range 7 hr to 9.5 hr and dec range $-53°$ to $-30°$. The total number of clouds involved is **1.500.** A total of 294 IRAS sources met at least one of the above criteria. Most of the sources (257) met the fifth criterion. A database of the search results was created with the following information:

1. IRAS source co-ordinates
2. associatetl dark cloud co-ordinates
3. major and minor axes of the cloud.
4. the IRAS fluxes at four wavelengths
5. the four flux qualities

This data base is used for carrying out the statistical analysis described in tlie next section.

6.4 Analysis

For each IRAS source meeting one of the criteria we calculate using plane geometry the angle θ shown in figure 6.1 from

$$\cos\theta = \left(a^2 - b^2 - c^2\right)/2bc \qquad (6.1)$$

where

$$a^2 = [(\alpha_{IR} - \mathbf{a,})\cos(\delta_{IR} + \delta_\circ)/2]^2 + (\delta_{IR} - \delta_\circ)^2 \qquad (6.2)$$

$$b^2 = [(\mathbf{a,} - \alpha_\circ)\cos(\mathbf{6,} + \delta_\circ)/2]^2 + (\delta_c - \delta_\circ)^2 \qquad \textit{and} \qquad (6.3)$$

$$c^2 = [(\alpha_c - \alpha_{IR})\cos(\delta_c + \delta_{IR})/2]^2 + (\delta_c - \delta_{IR})^2 \qquad (6.4)$$

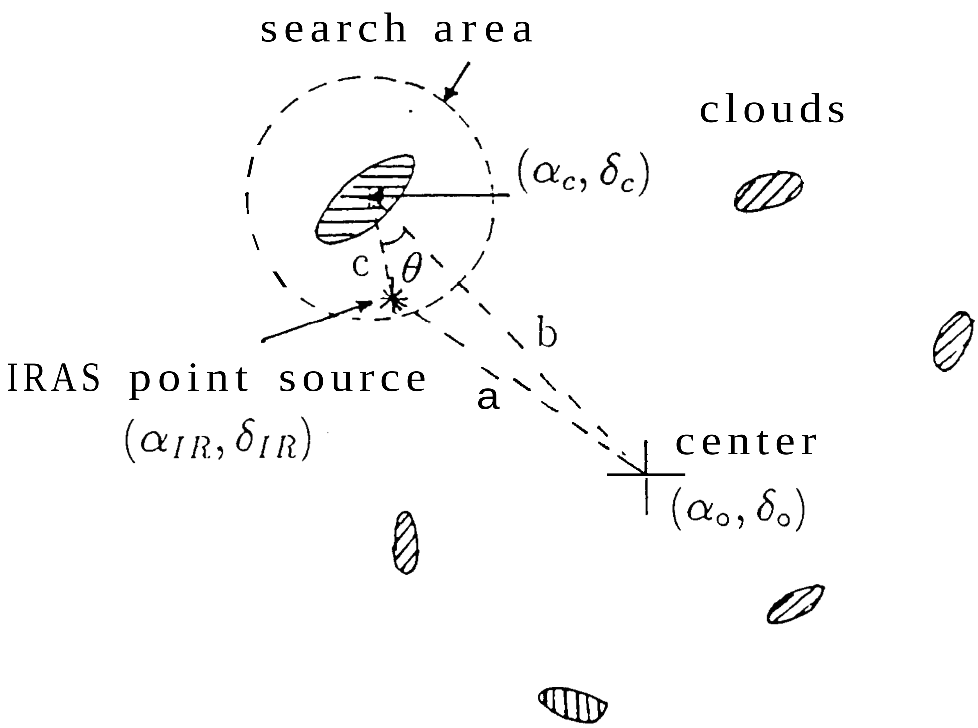

Figure 6.1: A schematic diagram showing the scheme for IRAS sources search. The search area is circular with radius equal to the mean of the major and minor axes of the cloud.

The angle θ simply represents the location of the source in the cloud with respect to the center of tlie distribution of the CGs regardless of tlic location of the cloud itself. If the YSOs arc located randomly throughout the dark clouds (with or without systematic radial dependence), one expects no dependence of their distribution on the polar angle in the cloud co-ordinate system with respect to any reference direction. On the other hand if the central processes arc important, one expects a dependence on the angle 0. We simply study the distribution of tlic YSOs as a function of the absolute value of θ with a coarse binning of 45°. We have plotted in figure 6.2 histogranis of this distributions for clouds of different sizes taking in each case sources falling within different fractional areas in the clouds. We have restricted this analysis upto a cloud size of $20'$. We see that in all these ranges the distribution peaks towards the side facing the center of the distribution of tlie CGs. In other words there seems to be a real tendency for the YSOs to fall on the side facing the center. To get a quantitative estimate for the confidence level of this conclusion we adopt a simple stastical method as explained in tlic following section.

6.5 Confidence Level

We first divide each cloud into two semi-circles, one facing tlie center and the other facing away from it. These partitions correspond to tlie ranges 0°-90° and 90°-180° in the absolute value of θ defined previously. We will call these ranges *the front arzd the back sides.* In the case where tlic locations of tlic YSOs are unaffected by the central processes, on an average we expect equal number of YSOs in these two ranges. The distribution is binomial with $p = q = 0.5$ and n = total number of YSOs. Here p and q are tlie probalilities that an IRAS YSO falls on the front or the back side. As mentioned in section 6.4 the histograms in figure G.2 peak on tlie front side (0" – 90°), i.e., there is an asymmetry in tlic distribution of YSOs. We now ask if tlie asymmetry seen is sufficient to indicate a deviation from $p = q = 0.5$ and hence a central origin. If X is the number of YSOs in tlie first range (0°-90°) then tlie confidence level for the hypothesis that the distribution is biased towards front side is equal to the $P(X > x)$, tlic area under the distribution curve upto x = X, where x is the binomially distributed random variable. To get this area we approximate tlie binomial distribution by a *normal distribution.* This is a good approximation when $p = 0.5$ as in our case with n around a few tens (theorem of De Moivre and Laplace: Kreyseig 1970). The mean and variance of tlie normal distribution are $\mu = np = n/2$ and $\sigma^2 = npq = n/4$. Then tlie confidence level is

$$P(x > X) = 1 - P(x < X) \approx 1 - \Phi((X - \mu)/\sigma) \qquad (6.5)$$

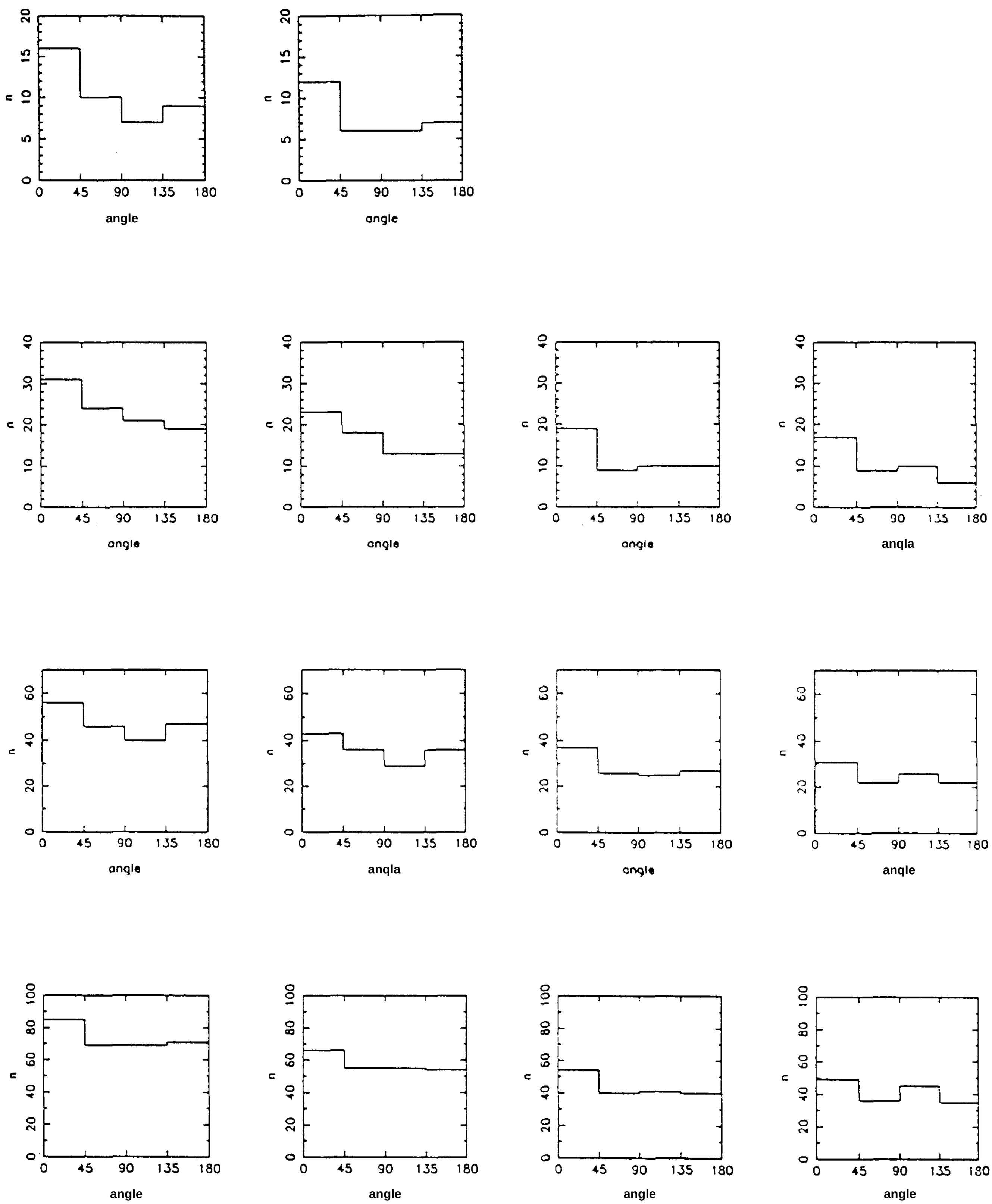

Figure 6.2: Histograms of distribution of IRXS sources in θ, the angle with respect to the center (see figure 6.1). Horizontally, the plots are for the effetctive area ranges 0-1,0.1-1,0.2-1 and 0.3-1. Vertically the plots are for the mean cloud ranges 0-5,0-10,0-15 and 0-20 arcminutes.

Table 6.1 Confidence Levels

size	fractional area			
arcmin.	0.0-1.0	0.1-1.0	0.2-1.0	0.3-1.0
0- 5	94	82		
0-10	94	97	87	94
0-15	86	87	85	69
0-20	79	79	84	65

where Φ is the area under the normal distribution curve. We have listed the confidence values in Table 1 for the different ranges of sizes and fractional area mentioned earlier.

6.6 Conclusion

From the above analysis it appears that there is a real tendency for the YSOs to fall on the front side rather than the back side. The confidence level for this conclusion is highest for clouds of sizes 0'-10'. This may be because in larger clouds the effects of external mechanisms get shadowed by normal star formation. Even among the smaller clouds it seems that external triggering is not the only method of star formation. It is to be remarked that not all the IRAS sources identified as YSOs are necessarily YSOs. Because of the larger search area the inclusion of sources not physically associated with the clouds at all is possible. But for this confusion the confidence level would have been even higher.

References

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