A CS SURVEY OF MASSIVE STARS EMBEDDED IN MOLECULAR CLOUDS

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ABSTRACT. The CS J=2→1 molecular line at 98 GHz, a normally optically thin line requiring high densities to be excited , has been detected with SEST (Swedish ESO Submillimeter Telescope) toward 294 IRAS point-like sources having the characteristic FIR colors of embedded stellar objects and apparently associated with the largest molecular cloud complexes in the southern Milky Way. We present here their Galactocentric radial distribution and a correlation between their FIR and CS luminosities.

1. FAR INFRARED EMISSION FROM GALACTIC MOLECULAR CLOUDS

Large scale CO surveys can be used together with the IRAS database to study the properties of FIR emission from large molecular clouds in the Galactic plane. Comparison of velocity-integrated CO intensity contour maps and corresponding IRAS surface-brightness images show substantial infrared counterparts for almost every CO concentration. Because the infrared data provides no information about the distance of the source and, at least in the inner Galaxy, there are several molecular clouds at different distances in most lines of sight, it is not easy to tell which fraction of the infrared emission is being produced by a particular cloud. Different methods developed to compare the diffuse FIR emission from IRAS with CO data (Mooney and Solomon 1988, Scoville and Good 1989) apply mostly to isolated clouds. Here we take a different approach, based on the observation of molecular lines toward selected IRAS point-like sources.

Molecular clouds, often associated with extended HII regions, are also associated with infrared point-like sources, very likely to be compact HII regions heated by embedded massive stars. Wood and Churchwell (1988; WC), using a two-color selection criterion for the IRAS point source catalog based on the FIR spectral characteristics of known ultracompact HII regions, identified 1,646 candidates to be massive stars embedded in molecular clouds in the Galactic plane. These stars provide a large fraction of the internal heating of molecular clouds and may play an important role in their fragmentation. We have observed now the CS J-2→1 line, normally optically thin and requiring high densities to be excited, toward embedded star candidates in the

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third and fourth Galactic quadrants and used the kinematic information from the CS line, together with our CO survey of the southern Galaxy, to calculate their distances and estimate the FIR luminosity of their surrounding dust.

A fully sampled CO survey of the fourth Galactic quadrant, covering from b=-2° to 2° at an angular resolution of 0°125, allowed us to derive the gross distribution of molecular gas and to identify the largest molecular cloud complexes within the solar circle (Bronfman et al. 1988a, 1988b, 1989). Molecular clouds outside the solar circle have been described by Grabelsky et al. (1988) and May et al. (1988).

2. CS OBSERVATIONS

Sources in the fourth Galactic quadrant, within 2° of the plane, were selected from the IRAS Point Source Catalog using WC criterion. From l=307°, near the tangent of Centaurus Spiral arm, to l=348°, the limit of the region presently analyzed of our CO survey, every source was observed in the CS line. Between l=280 and 308, candidates were observed first in the CO 1-0 line, and those with non-local velocities observed in CS. For the third quadrant, we observed in CS all IRAS point sources with non-local velocities from the CO catalog of Wouterloot and Brand (1989), plus those associated with molecular clouds recently discovered in a 0°125 resolution survey of the third Galactic quadrant (May et al. 1990).

Observations of the CS 2→1 line at 98 GHz, at 50" resolution, were made in frequency switching mode during 3 runs of 30 hours each in October 1989 and May 1990 with the SEST Telescope at the European Southern Observatory, in La Silla. Spectra were corrected for atmospheric attenuation using standard calibration methods; no correction for beam efficiency was applied. Up to third order baselines were subtracted from the spectra; single gaussian fits were used to compute the mean velocity, full-width at half-maximum, and integrated intensity of the lines. Single velocity components, corresponding to one of the CO molecular clouds in the line of sight, were observed in practically every case. The CS line is normally excited at gas densities above $10^4 cm^{-3}$, a condition that appears to be fulfilled near the Galactic center and in the dense star-forming regions in the Galactic plane, but seldom elsewhere. Thus, the observed CS line can be associated with fair certainty with the dense gas surrounding compact HII regions detected by IRAS. Some profiles depart from a normal distribution, but a detailed study of profile characteristics is posponed to further consideration and hopefully more observations.

3. DISTRIBUTION AND FIR LUMINOSITY OF EMBEDDED MASSIVE STARS

Because the CO survey data were analized so as to enhance the contrast for molecular clouds with CO masses above $5 \times 10^5 M_\odot$, the striking correspondance between CS detections and CO contour maps (Fig. 1) strongly supports the generally accepted view that massive stars form in large molecular clouds, like the ones identified in our CO surveys. Such association is used below to help determine the distances for the

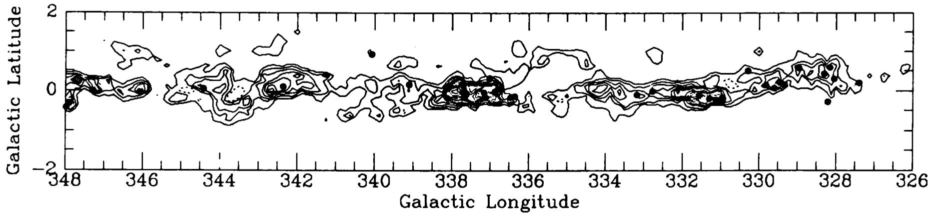

FIGURE 1. Contour-plot of CO emission integrated in velocity over a region corresponding to the Norma Spiral Arm. Contour interval is 8K km/s. Filled circles are CS detections in the same velocity range.

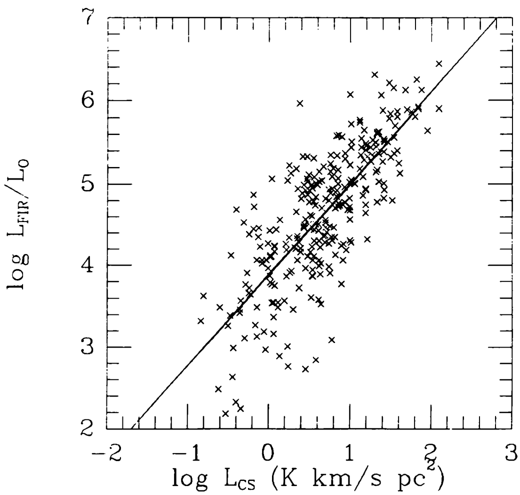

FIGURE 2. Radial distribution of embedded massive stars in the third and fourth Galactic quadrants. Galactocentric radii were derived from CS line velocities using a CO rotation curve within the solar circle and a constant velocity V(R)=220 km/s outside.

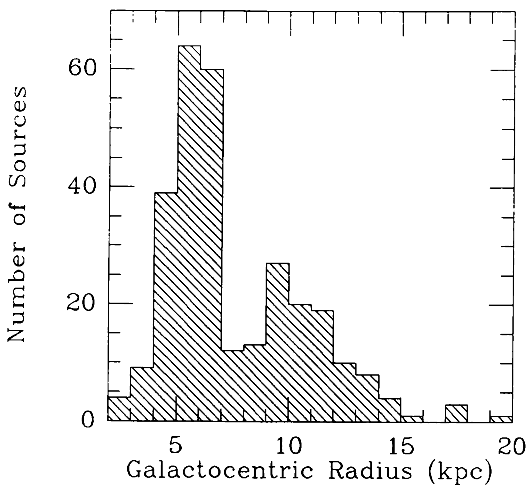

FIGURE 3. FIR luminosity from IRAS against CS luminosity measured with SEST for dust and dense molecular gas heated by embedded massive stars. The best linear fit is log L_{FIR}=(1.109±0.051) log L_{CS}+(3.884±0.045).

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embedded stars within the solar circle.

Assuming purely circular motion about the Galactic center and through the use of a standard rotation curve, the CS line velocities were used to derive Galactocentric radii for the embedded stars. In the inner Galaxy massive stars concentrate in a ring about 3 kpc wide (FWHM) at a mean Galactocentric radius of 5 kpc (Fig. 2), coincident with but somewhat narrower than the independently derived distribution of molecular clouds (Bronfman et al. 1988a). For sources within the solar circle a two-fold distance ambiguity must be solved; we have used here the distance ambiguity resolution for their parent molecular clouds, obtained through standard techniques like OH and H_2CO absorption, distance to the Galactic plane, and size to linewidth ratio. The secondary peak in Fig. 2, outside the solar circle, corresponds to the Carina and outer spiral arms. The distribution there is slightly shifted toward negative latitudes following closely the warp of the Galactic plane.

Having determined the distances of the embedded stars, it is possible to compute the FIR luminosities of their dust coccoons; the luminosity from an IRAS pixel of 2'x2' is computed here as $L=4\pi D^2 \Sigma \nu F_\nu$ (Boulanger and Perault 1988), where D is the kinematic distance, F_ν is the flux at frequency ν, and the sum goes over all IRAS bands. For the same FIR colors CS is detected more often in point sources within the solar circle than outside, where molecular clouds seem to be underluminous also in CO (Digel et al. 1990). There is a fair correlation between CS and FIR luminosities (Fig. 3) possibly meaning that sources undetected in CS correspond to stars of relatively low luminosity, unimportant for our sampling of massive stars embedded in large molecular clouds in the Galactic plane.

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