COLD MOLECULAR MATERIAL IN THE GALAXY

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The kinetic temperatures in molecular clouds are usually considered to range upward from about 10 K (e.g., Dickman 1975). These temperatures are generally measured by observing the CO $J = 1 \rightarrow 0$ transition and assuming that this line is optically thick and thermalized. This assumption also underlies estimates of the total mass and distribution of molecular material in our galaxy based on CO surveys. Because a significant amount of molecular material could in principle be missed by galactic CO surveys, a search was undertaken for "ultra-cold" molecular gas, by which is meant an excitation temperature, $T_{ex} < 5$ K. No evidence was found for a large amount of such material (Evans, Rubin, and Zuckerman 1980), but many clouds with T_{ex} between 5 and 10 K were found. To determine if this low T_{ex} is due to low kinetic temperature, low density, or low CO abundance, we have undertaken observations of a large number of clouds in the $J = 2 \rightarrow 1$ CO line and the $J = 1 \rightarrow 0$ ^{13}CO and CO lines. These observations will be analyzed to determine the properties of these clouds.

The clouds for our analysis were obtained from two sources. First, the survey of Downes et al. (1980) was used to select clouds with a small equivalent width for the 6-cm line of formaldehyde, W (6-cm) $\lesssim$ 0.150 km s^{-1} . A preliminary version of the formaldehyde survey was used by Evans et al.; here, we observed all directions between $\ell = 15°$ and $49°$ with W (6-cm) $\lesssim$ 0.150 km s^{-1} . A total of 33 directions with 100 velocity components were observed in the $J = 1 \rightarrow 0$ and $J = 2 \rightarrow 1$ lines of ^{12}CO. Second, the study of carbon monoxide toward extragalactic radio sources showing 21-cm absorption (Combes et al. 1980) was used. Using the $J = 1 \rightarrow 0$ and $J = 2 \rightarrow 1$ lines of ^{12}CO and the $J = 1 \rightarrow 0$ line of ^{13}CO, the clouds in the directions of 3C27, 3C111, 3C154, and 3C353 were studied in detail. The ^{12}CO data were obtained on the 4.9m telescope at the Millimeter Wave Observatory at Fort Davis, Texas; the ^{13}CO data were obtained on the 2.5m telescope at the Observatoire de Bordeaux in Bordeaux, France.

For some of the components, the excitation temperatures of the $J = 1 \rightarrow 0$ and $J = 2 \rightarrow 1$ CO lines agree, suggesting that the

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transitions are thermalized. In addition ^{13}CO has been detected towards 29 of the 44 velocity components in which it has been searched for, indicating that the CO lines are often optically thick. We find that ∿ 80% of the excitation temperatures are less than 10 K, with a peak at 6 K. Thus there seems to be a substantial population of cold clouds.

The most interesting result of our analysis to date is the extremely low ratio, $R = \frac{T_A^* (2 \rightarrow 1)}{T_A^* (1 \rightarrow 0)}$, seen toward several clouds. At least 10 percent of the clouds from the H_2CO survey have R sufficiently low that no fit to an LVG model for the line transfer is possible. The uncertainty in the number of clouds arises from the uncertainty in the beam efficiency caused by uncertainties in source size. Of the clouds toward extragalactic radio sources, maps were used to assess this effect and we conclude that all of these sources show low values for R, with the possible exception of 3C353.

We are completing maps in all the CO transitions toward the extragalactic radio sources. The bulk of the material toward 3C111 and 3C123 lies ∿ 1/2° from the direction of the radio source. These two clouds appear to be similar to the dark, molecular clouds studied by Snell (1981). Although the ^{12}CO lines toward 3C111, 3C123, and 3C353 are similar, the ^{13}CO line is ∿ 3-5 times weaker in 3C353 relative to the lines in 3C111 and 3C123. Understanding the cause of the weaker ^{13}CO will help in unraveling the physical conditions in the three clouds.

References

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