PROBING GIANT MOLECULAR CLOUD CORES WITH MILLIMETER AND SUBMILLIMETER OBSERVATIONS OF $C^{18}O$ AND DUST

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1. Introduction

Giant molecular cloud cores are extremely complex regions. Despite extensive observations starting with the first detection of carbon monoxide in interstellar space, we really do not understand their density structure, nor the velocity distribution of material within them. These parameters are obviously critical to our understanding of the process of massive star formation that occurs in GMC cores, and the mass spectrum of stars that results. The dramatic improvement in observational capability at millimeter and submillimeter wavelengths during the past years now allows the observation of optically thin tracers of material to be carried out over large parts of GMC cores. It is thus increasingly important to understand the capabilities of different tracers, and in this presentation we describe work carried out using both gas and dust as tracers of material in these regions. Each has its advantages and disadvantages; the dust emission is largely free of excitation issues and is certainly optically thin at these wavelengths, but the emissivity of dust is not well known. Molecular tracers suffer from uncertainties due to excitation, and the interstellar chemistry may produce variations in abundance. However, spectral lines do offer important kinematic information.

In this project, we have observed three GMC cores: Orion A, M17, and Cepheus A. Using the FCRAO antenna, we have observed the $J = 1$–0

transition, and with the CSO the $J = 2$–1 and $J = 3$–2 transitions of $C^{18}O$. From the three lowest transitions, the total column density can be determined with high accuracy. Using the CSO we have observed these same sources in the continuum at 1300 and 800 μm, and for Orion at 450 μm as well, giving us valuable information about the dust distribution. This summary highlights some conclusions from $C^{18}O$ observations; a more complete analysis of the gas and dust emission is in preparation.

2. Observations and Analysis of $C^{18}O$ Emission

$C^{18}O$ emission is a useful tracer of GMC cores because its lines are optically thin, while being strong enough to be readily mapped across large parts of these regions. In addition, the fractional abundance of carbon monoxide in well-shielded regions appears to be relatively constant. The major uncertainty that remains is the degree of molecular excitation and thus obtaining the total column density from the transition(s) observed.

For relatively well-excited ($T_{ex} > h\nu/k$) lines, the integrated intensity of a given line observed directly yields the column density in the upper level of the transition. We define the **correction factor**, **CF**, to be the ratio of the total molecular column density to the column density derived from the set of transitions observed, as determined from a statistical equilibrium calculation. The correction factor when the three lowest transitions of $C^{18}O$ have been observed is shown in the figure. As long as the density is greater than $\sim 10^3$ cm^{-3}, CF is essentially independent of both temperature and density - showing a total variation of less than a factor of 1.5:1. This set of the three lowest $C^{18}O$ transitions therefore enables us to accurately determine the column density in GMC cores without having to assume LTE or adopting any particular excitation model.

We have assumed a constant value of CF equal to 1.75, based on the range of gas temperatures previously determined for these GMC cores (Bergin et al. 1994). The peak $C^{18}O$ column densities found are 1.5, 3.2, and 1.9×10^{18} cm^{-2} for Orion A, M17, and Cepheus A, respectively. The total masses of the cloud cores are 580, 11500, and 500 $M_\odot$, assuming a $C^{18}O$ fractional abundance of 1.7×10^{-7}. The radii of the cores are 1.2, 4.9, and 1.3×10^{18} cm. Together with the observed FWHM linewidths averaged over the cloud cores, we obtain virial masses (assuming an r^{-1} density distribution) of 350, 3000, and 400 $M_\odot$, respectively. The relatively good agreement between molecular and virial masses suggests that the $C^{18}O$ fractional abundance is not very far from the value that we assumed.

From the cloud masses and dimensions we derive mean volume densities equal to 3.7, 1.9, and 4.3×10^4 cm^{-3} for Orion A, M17, and Cepheus A. These densities are less by about 2 orders of magnitude than those de-

rived from multitransition studies of high dipole moment molecules such as HC_3N (Bergin, Snell, & Goldsmith 1996). The linewidths and line center velocities of the $C^{18}O$ and HC_3N are quite similar, despite their very different excitation requirements. This is a significant constraint on models for what appear to be very inhomogeneous GMC cores.

3. Observations of the Dust and Comparison With the Gas

The observations of the dust were carried out with the CSO facility bolometer. Based on other studies, the contribution from spectral lines may be appreciable at the positions of embedded sources but in the general cloud volumes this should not be a significant effect. The free-free emission represents only a minor correction. The dust opacity is obtained by assuming that the dust temperature is equal to the kinetic temperature of the dense gas as determined from observations of CH_3C_2H (Bergin et al. 1994). A preliminary reduction of the Orion data suggests that the spectral index of the dust optical depth between 1300 μm and 450 μm ($\tau(\nu) \sim \nu^{\beta}$) is β = 1.2. In M17 and Ceph A, the dust opacity per unit column density of $C^{18}O$ is essentially independent of molecular column density (or equivalently, of position within the cloud) and is equal for the two GMC cores. In distinction, the positions in Orion exhibit a large scatter, and a mean value approximately an order of magnitude less than that for the other two clouds studied.

References

Bergin, E.A., Goldsmith, P.F., Snell, R.L., & Ungerechts, H. 1994, *ApJ*, **431**, 674.
Bergin, E.A., Snell, R.L., & Goldsmith, P.F. 1996, *ApJ*, 460, 343.