CO ISOTOPE LINE SHAPES IN DARK CLOUDS

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The ratio of ground-state densities $R_o \equiv N(^{13}CO)/N(C^{18}O)$ has been used to infer physical and chemical conditions in giant molecular clouds (Wannier et al. 1976) and dark clouds (Mahoney et al. 1976; Langer et al. 1979). In dark clouds R_o is found to vary from values near the terrestrial ratio $[^{13}C][^{16}O]/[^{12}C][^{18}O] \sim 5$ at positions of high extinction to values ~ 20 at positions of low extinction. In this paper we present high-resolution $J = 1 \rightarrow 0$ spectra of CO, ^{13}CO, and $C^{18}O$ at positions of high extinction in TMC-2, L134, and L134N. The $C^{18}O$ lines have non-Gaussian wings and are $\sim$ half as wide as the ^{13}CO lines. We find that R_o must vary across the line, from a minimum of $R_o \sim 4$ at the peak of the $C^{18}O$ line to a maximum of $R_o \sim 10$ in the wings, unless the ^{13}CO line has peak opacity $\gtrsim 5$. The variation of R_o with position and with velocity is consistent with models of clouds which have a dense core with low velocity-dispersion and low fractionation, and a rarefied envelope with high velocity-dispersion and high fractionation.

The observations were made with the NRAO 36-foot telescope† on Kitt Peak, Arizona. Five minute total-power on-off switching was used. The angular and spectral resolutions were 1.1' and 30 kHz (0.08 km s^{-1}). The antenna temperatures T_A^* were corrected for atmospheric absorption by chopper-wheel calibration. The observed positions [α(1950); δ(1950)] were TMC-2, [$04^h29^m43^s$; 24°18'54"]; L134, [$15^h50^m59^s$; -04°26'58"]; L134N, [$15^h51^m28^s$; -02°45'00"].

The $C^{18}O$ lines are extremely similar, being strong ($T_A^* \sim 2$ K) and narrow (Δv(FWHM)$\sim$0.6 km s^{-1}) with distinct "wings". The ^{13}CO lines have FWHM wider than the $C^{18}O$ lines by a factor $\sim$2. Figure 1 shows CO spectra in TMC-2.

We assume plane-parallel radiative transfer, and that the CO line is optically thick and thermalized. We find that R_o is unlikely to be independent of velocity. Only channels in the $C^{18}O$ line core are consistent with $R_o = 5$, while R_o, if $\gtrsim 10$, can be constant with respect to line velocity only if the ^{13}CO line has a peak opacity $\sim$5 and $T_{ex} \sim 8$ K, which condition requires densities $n \lesssim 10^3 cm^{-3}$ (Kwok 1978). For TMC-2, CS observations indicate $n \sim 6 \times 10^4 cm^{-3}$ (Linke and Goldsmith 1979). Thus (1) R_o cannot be constant with velocity if terrestrial; and (2) R_o can be constant if $\gtrsim$10, but only for a highly saturated, subthermal ^{13}CO line at a relatively low density.

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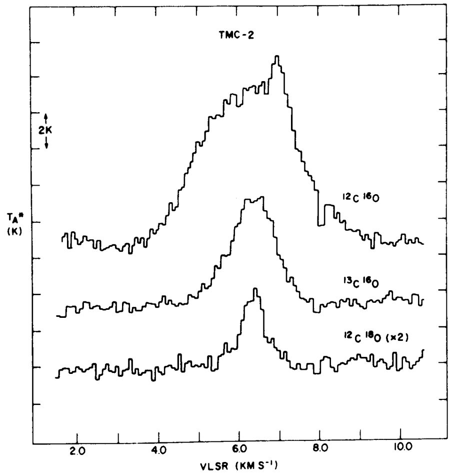

Figure 1

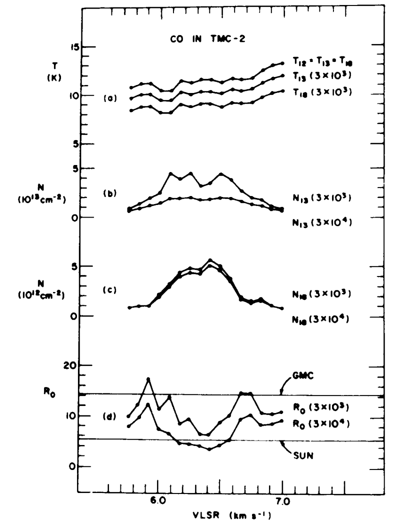

Figure 2

For higher densities 3×10^3 cm^{-3} $\lesssim$ n $\lesssim$ 3×10^4 cm^{-3} we use the model of Kwok (1978) to predict T_{ex} for each line. We then compute $N(^{13}CO)$ and $N(C^{18}O)$ for each channel where the $C^{18}O$ line has signal-to-noise ratio $\gtrsim$ 4, and calculate the corresponding R_o. The results are shown in Figure 2.

The variation of R_o from ~4 to ~10 is seen in all three clouds. Random errors are too small to obscure the trend. Systematic errors of 15% in each spectrum would change the absolute values of R_o, but the relative variation of R_o would be unchanged. The variation of R_o with velocity may be consistent with the decrease of R_o with extinction found by Langer et al. (1979), if the line core is formed in a dense interior region with low fractionation and if the line wings are formed in a rarefied envelope with high fractionation. If so, then cloud cores have low Δv while cloud envelopes have high Δv, as suggested by the correlation between Δv and spatial extent in the ρ Oph cloud (Myers et al. 1978).

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