MILLIMETER-WAVE ABSORPTION STUDIES OF THE ONSET OF DARK-CLOUD CHEMISTRY

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We have recently observed mm-wave absorption lines of ^{13}CO, HCO^+, HCN, C_2H, HNC, CN in front of distant, compact radio sources (Lucas and Liszt 1993, 1994). Molecules are easily detected, while the extinction is moderate (typically 1 mag.); HCO^+ spectra are richer, broader, and more complex than ^{12}CO emission observed with single dishes in the same directions (BL Lac, NRAO 150, B0212+735). Molecular abundances are similar in magnitude to those in dark clouds, while the UV radiation field should be dominant. These results suggest that a chemically rich component of the interstellar medium could be present, but not well represented in CO emission surveys. The clouds we have detected appear to be very similar to diffuse clouds such as ζ Oph, where Liszt and Lucas (1994) have detected, in emission, a comparable column density of HCO^+. We briefly summarize here further recent progresses.

To obtain a better characterization of those clouds, we used the Plateau de Bure array to systematically survey HCO^+ absorption in front of 30 mm-wave continuum sources (Lucas and Liszt 1996). Observed spectra are shown in Fig. 1.

Nearly every source below $b = 15°$ was detected. The search for HCO^+ emission in the same directions, with the NRAO 12m antenna, occasionally yielded some weak lines (0.05 K), even for $\tau > 1$, implying that $T_{\rm EX}$ must be very close to 2.73 K; thus accurate column densities may be deduced from the 3 mm optical depth alone. Detection statistics show that absorption occurs $\sim 30\%$ as often as for 21 cm HI. The optical depth distribution of individual absorption components have very similar slopes for HCO^+

and 21 cm HI.

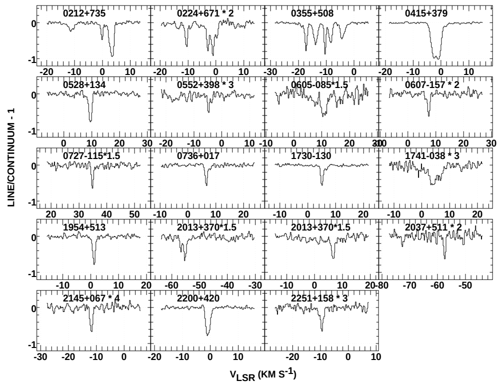

Figure 1: HCO^+ survey detections. Our sample contained all known sources with $S_{3\mathrm{mm}} > 2.5$ Jy for $b > 15°$, and $S_{3\mathrm{mm}} > 2.0$ Jy for $b < 15°$; we added all sources with CO emission in the survey of Liszt and Wilson (1993). A bandwith of 100 MHz was searched, with a resolution of 140 kHz (336 km $s^{-1}$and 0.47 km s^{-1}).

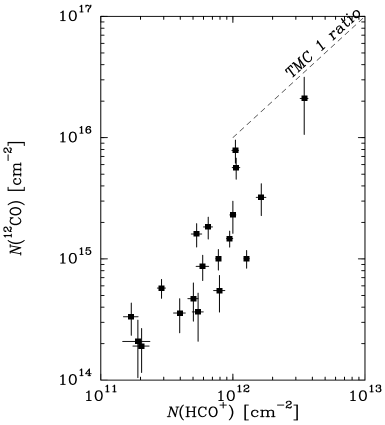

Figure 2: ^{12}CO versus HCO^+ column densities: there is clearly an underabundance of ^{12}CO for $N(HCO^+)$ lower than $\sim 10^{12}$ cm^{-2}; similarly, the strength of the ^{12}CO emission increases abruptly in that range. The same phenomenon is observed in UV absorption studies at $N(H_2) \sim 4\,10^{20}$ cm^{-2}. We are seeing the onset of dust- and self-shielding at extinctions below 1 mag, in diffuse clouds and/or outer regions of dark clouds.

We have recently obtained ^{12}CO emission and absorption data in some of the surveyed directions (B0212+735, B0224+671, NRAO150, B0528+134, NRAO530, and 3C454.3 (Liszt and Lucas, work in preparation); we use available data for B2013+370 (Lequeux et al. 1993). By direct comparison of emission and absorption, we deduce T_{EX} for each cloud; the results are in the range 3–8 K, indicative of excitation conditions where $n(H_2)T_{\mathrm{K}} \sim 3000 - 10000$ cm^{-3} K. Further constraints from HCO^+ emission, which is excited by electrons, imply $T_{\mathrm{K}} > 20 - 40$ K for most sources. At these excitation temperatures, about half of the CO molecules are in the lowest rotational state; the CO column densities can be accurately deduced from the $J = 1 - 0$ optical depth after correcting for the excitation. Fig. 2 shows a plot of ^{12}CO versus HCO^+ column densities.

The absorption optical depths of ^{12}CO are surprisingly low: one would expect larger optical depths on the basis of the observed *emission* intensity ratio between ^{12}CO and ^{13}CO. Since this occurs in nearly every source, one may exclude accidentally low column densities in the direction of the sources. Furthermore, the ^{13}CO emission is quite strong while the C^{18}O is very weak wherever we searched for it: the ^{13}CO to C^{18}O ratio is much larger than terrestrial. In front of 3C111, this ratio, both in absorption and in emission, is larger than 25. Direct comparison of ^{12}CO to ^{13}CO *absorption* gives ratios of about 20 in most sources where this ratio may be computed.

Chemical fractionation from exchange with $^{13}C^{+}$ would increase the ^{13}CO abundance for T_K lower than 35 K, while selective photodissociation with ^{12}CO being self-shielded has the effect of increasing the C^{18}O abundance, with respect to ^{12}CO, by $\sim 5-8$. The same effect should also apply to ^{13}CO. Thus, the high ^{13}CO abundances probably result from the chemical fractionation overcoming the selective photodissociation, and *the kinetic temperatures should be low.*

We have measured 18 cm OH absorption with the VLA on some of the sources from the HCO^+ survey. Column densities were computed assuming $T_{EX} = (2.73 + 1)$ K, since absorption/emission observations of some of our sources, and similar ones, (surprisingly) lead to very low T_{EX} for 18 cm OH (Dickey et al. 1981). *OH and HCO^+ are well correlated*: with an OH/HCO^+ ratio of 0.03 to 0.05, which is about the same ratio as in dark clouds. However, simple mechanisms linking OH to HCO^+, initiated, e.g., by $C^+ + OH \rightarrow CO^+ + H$, should result in higher values for the same ratio. New chemical models of diffuse clouds involving supersonic turbulence, and its dissipation, succeed to produce CH^+ (and HCO^+) with endothermic reactions; but they produce also too much OH (Falgarone et al. 1994, Spaans et al. 1994).

Liszt and Lucas (1995) have shown, using 2 mm and 6 cm H_2CO absorption, that H_2CO, like CO, turns on at $N(HCO^+) \sim 10^{12}$ cm^{-2}. Work in progress shows a similar effect is also seen in HCN, CN, and HNC.

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