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C_3H_2 OBSERVATIONS AS A DIAGNOSTIC PROBE FOR MOLECULAR CLOUDS

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Recently the three-membered ring molecule, cyclopropenylidene, C_3H_2, has been identified in the laboratory and detected in molecular clouds by Thaddeus, Vrtilek and Gottlieb (1985). This molecule is wide-spread throughout the Galaxy and has been detected by Matthews and Irvine (1985) in 25 separate sources including cold dust clouds, circumstellar envelopes, HII regions, and the spiral arms observed against the Cas A supernova remnant. In addition, Seaquist and Bell (1986) have detected C_3H_2 in the galaxy NGC5128.

A number of factors suggest that C_3H_2 may be an astrophysically important molecule. Its large dipole moment ($\approx$ 3.3D) and widespread occurrence give rise to relatively strong lines in many sources. In addition, its relatively small moments of inertia and asymmetric top structure result in numerous spectral lines distributed throughout the cm and mm wavelength range.

In order to evaluate the potential of C_3H_2 as a diagnostic probe for molecular clouds, and to attempt to identify the most useful transitions, I have carried out statistical equilibrium calculations for the lowest 24 levels of the ortho species and the lowest 10 levels of the para species. Because collisional excitation rates for C_3H_2 are not yet available, the rates computed by Green (1980) for H_2O were used. Both H_2O and C_3H_2 have C_{2v} symmetry, with b-type transitions, so their quantum level structure is qualitatively similar, though the energy level separation in H_2O is larger because of its large moments of inertia. To compensate for this I have used Green's H_2O excitation rates for T_K=200K to represent C_3H_2 at T_K=10K. (At 200K, the ratio of the average kinetic energy of H_2 molecules to typical H_2O energy level separations is comparable to the same ratio for H_2 and C_3H_2 at 10K). Also, the H_2O rates were scaled upward by an order of magnitude to reflect the significantly larger dipole moment and size of C_3H_2.

Many of the sources observed by Matthews and Irvine (1985) show evidence of being optically thick in the 1_{10}-1_{01} line. Consequently, the effects of radiative trapping should be incorporated into the equilibrium calculations. This was done using the Large Velocity Gradient approximation for a spherical cloud of uniform density as discussed by Goldreich and Kwan (1974).

Some results of the calculations for T_K=10K are given in Figures 1-3. Each figure shows contours of the logarithm of the ratio of peak line brightness temperatures for ortho-para pairs of lines at similar frequencies. The background temperature was taken to be 2.8K. Such line-strength ratios should be relatively free of systematic errors due to effects such as differential beam dilution, telescope efficiencies, atmospheric transmission etc. In each figure n_{H_2} is the neutral hydrogen density, X the C_3H_2 abundance relative to H_2, and dV/dR the velocity gradient in the molecular cloud.

The 1_{10}-1_{01} and 2_{20}-2_{11} line pair of Figure 1 showd a marked density dependence. Over the central range of H_2 densities which are appropriate for molecular clouds the 1_{10}-1_{01} line is predicted to be in emission and the 2_{20}-2_{11} line in absorption against the microwave background. This has been observed in a number of dark clouds by Matthews et al. (1986). In addition, the predicted line strength ratio of this pair exhibits a strong dependence upon n_{H_2} which implies that it may be especially useful as a density probe of molecular clouds.

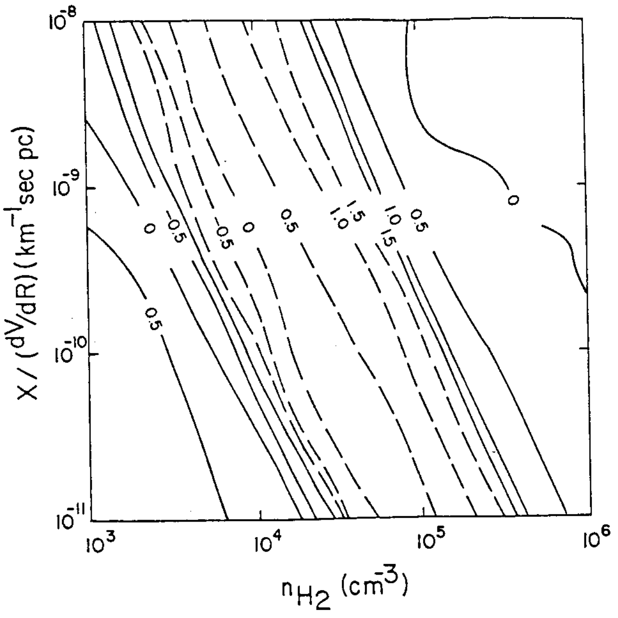

Figure 1. Logarithm of $T_b(1_{10}-1_{01})/T_b(2_{20}-2_{11})$.

The line frequencies are 18343 and 21587 MHz. Solid lines on the left represent both lines in absorption; on the right both lines in emission. In the area covered by dashed lines, the $1_{10}-1_{01}$ line is predicted to be in emission and the $2_{20}-2_{11}$ line in absorption.

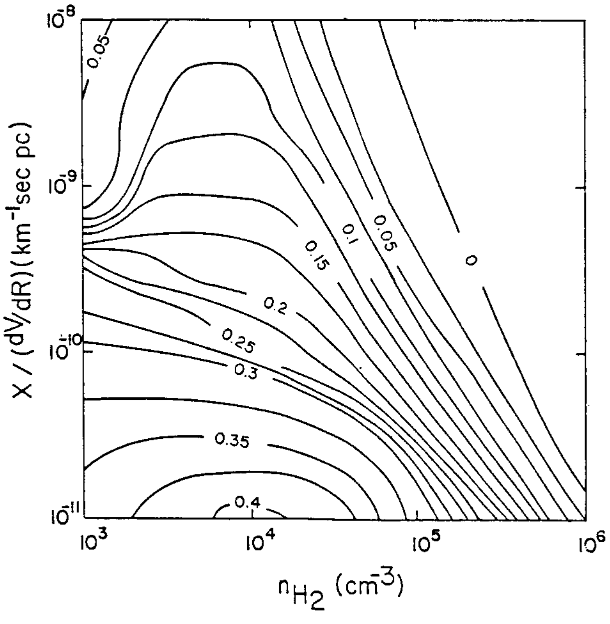

Figure 3. Logarithm $T_b(2_{12}-1_{01})/T_b(2_{02}-1_{11})$.

Both lines are in emission at frequencies of 85339 MHz and 82094 MHz.

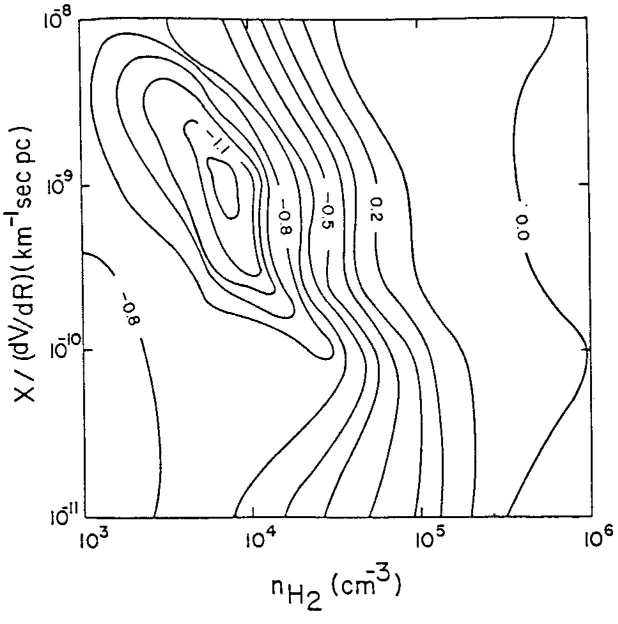

Figure 2. Logarithm $T_b(3_{21}-3_{12})/T_b(2_{11}-2_{02})$.

Both lines are in emission at frequencies of 44104 MHz and 46756 MHz.

Figure 2 suggests that the $3_{21}-3_{12}$ ortho line is likely to be quite weak relative to the $2_{11}-2_{02}$ para line at low-to-moderate H_2 densities. However, over certain parts of parameter space, information about both molecular abundance and n_{H_2} would be obtained from this pair.

The $2_{12}-1_{01}$, $2_{02}-1_{11}$ ratio in Figure 3 is relatively flat over density. (Note that different contour intervals are used in the three figures.) These lines appear to complement the K-band pair of Figure 1 very nicely in that their relative insensitivity to n_{H_2} yields information about $X/(dV/dR)$, which is necessary for a density determination from Figure 1.

In summary, it appears that the widespread nature of C_3H_2, the relatively large strength of its spectral lines, and their sensitivity to density and molecular abundance combine to make this a useful molecule for probing physical conditions in molecular clouds. The $1_{10}-1_{01}$ and $2_{20}-2_{11}$ K-band lines may be especially useful in this regard because of the ease with which they are observed and their unusual density-dependent emission/absorption properties. These conclusions, however, are preliminary, and will need to be confirmed when better collisional rate coefficients are available.

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