THE VARIATION OF THE X-FACTOR IN TWO TRANSLUCENT CLOUDS

LORIS MAGNANI
University of Georgia
Dept. of Physics and Astronomy, Athens, GA 30602
JOSEPH S. ONELLO
State University of New York
Dept. of Physics, Cortland, NY 13045
AND
DAP HARTMANN AND PATRICK THADDEUS
Harvard-Smithsonian Center for Astrophysics
60 Garden St., Cambridge, MA 02138

1. Introduction

One of the most fundamental physical properties of molecular clouds is the cloud mass which consists primarily of H_2 molecules. In the last two decades the CO(J=1-0) rotational transition has served as the primary tracer of $N(H_2)$. Thus, the determination of cloud mass and other related physical properties depends on how the CO data are converted into $N(H_2)$. The ratio of $N(H_2)$ to W(CO), the velocity-integrated CO(J=1-0) antenna temperature, is known as the X-factor or X_{CO} and is a critical quantity in radio astronomy. Previous methods for determining X_{CO} are reviewed by Magnani & Onello (1995). Values of X_{CO} for giant molecular clouds generally range from 1 to 4×10^{20} H_2 molecules cm^{-2} [K km $s^{-1}]^{-1}$ (we will drop the units hereafter for the sake of brevity). However, significantly different values of X_{CO} have been obtained for the class of interstellar clouds known as the high-latitude molecular clouds.

The majority of high-latitude molecular clouds can be categorized as translucent clouds; *i.e.*, molecular clouds whose visual extinction ranges from 1 - 5 magnitudes (van Dishoeck & Black 1988). The physical conditions of these objects span the regime where the chemistry changes from being dominated by photoprocesses to collisions between the reactants. Moreover, the CO abundance rises markedly at these extinctions and using a single value for X_{CO} may be inappropriate. Magnani, Blitz, & Wouterloot (1988) determined X_{CO} for a sample for high-latitude translucent clouds using traditional methods and found values ranging from 1 - 6 $\times$ 10^{20}.

The most common method for finding the value of X_{CO} uses the IRAS 100 μm emission as a surrogate for N(H_2). When combined with HI and CO observations, the IR data can lead directly to X_{CO} [*e.g.*, de Vries, et al. (1987); Meyerdierks et al. (1990); Herbstmeier et al. (1993)]. However, there are several difficulties with this method. For one, the gas-to-dust ratio must be constant from cloud to cloud. Secondly, the infrared emissivities per unit hydrogen nucleon must be known *a priori* for both the atomic and molecular components of the clouds. In light of these restrictions, Magnani & Onello (1993; 1995) have devised a new method for determining X_{CO} in translucent clouds. Their technique uses observations of the hyperfine, ground state, main line transition of CH at 3335 MHz as a tracer for N(H_2).

2. Discussion of the New CH Method

The CH hyperfine ground-state transitions are easily detected in translucent clouds (Magnani et al. 1989). Because of the efficient excitation properties of the lower rotational levels [Sandell & Johansson (1982); Federman & Willson (1982); Sandell, Stevens, & Heiles (1987); Sandell, Magnani, & Lada (1988)], the main line at 3335 MHz effectively traces low-density gas. N(CH) is determined readily from the velocity integrated 3.3 GHz line [see Magnani & Onello (1995) for details] and, with this determination, a conversion to N(H_2) can be made.

The relationship between N(H_2) and N(CH) is expected to be linear from astrochemical arguments (*e.g.*, Federman 1982), and is confirmed empirically to be linear by many independent studies: Federman (1982); Danks, Federman, & Lambert (1984); Cardelli & Wallerstein (1986); Mattila (1986); Federman & Lambert (1988). The linear relationship holds for diffuse and translucent molecular clouds but becomes less certain for clouds with extinctions greater than 4 visual magnitudes.

Based on both theoretical and empirical considerations, the relationships between N(CH) and N(H_2) is linear for values of N(H_2) typical of translucent molecular clouds. Consequently, observations of CH at 3.3 GHz immediately yield values for N(H_2). Uncertainties associated with the actual determination of N(H_2) using the CH method are discussed in Magnani & Onello (1995). In general, values for N(H_2) valid to within a factor of 2 can be achieved with the new method.

3. The Variation of X_{CO} in Translucent Clouds

Magnani & Onello (1995) discuss the variation of X_{CO} in a sample of 28 lines of sight in 18 different translucent clouds. Values of X_{CO} vary from 0.3 - 6.8 $\times$ 10^{20}, although the average value of 2 $\times$ 10^{20} is consistent with values used for giant and dark molecular clouds. Although this study suggests a variation in X_{CO} from cloud-to-cloud, only a few positions were observed *within* a given cloud. Consequently, the point-to-point variation in X_{CO} over an entire cloud was not determined in the study.

In this paper, we report the results of such a study in two high-latitude molecular clouds, MBM16 and MBM40. These objects are translucent clouds with visual extinctions in the 1 - 2 magnitude range.

4. The Variation of X_{CO} in MBM16 and MBM40

We determined X_{CO} for 8 lines of sight in MBM40 and found values ranging from 0.8 - 4.8 $\times$ 10^{20}, with an average of 1.8 $\times$ 10^{20}. However, the 4.8 $\times$ 10^{20} value is uncertain because the CH spectrum from which N(H_2) is derived is noisy. Discarding this measurement, the range of X_{CO} in MBM40 is rather constrained: 0.8 -2.0 $\times$ 10^{20}.

The case of MBM16 is quite different. X_{CO} was determined for 20 lines of sight and varies more markedly, from 1.2 to 14.9 $\times$ 10^{20}, with an average value of 5.0 $\times$ 10^{20}. For MBM16, determining X_{CO} on the basis of an observation along a single line of sight could lead to a highly misleading result.

Future work will determine whether translucent clouds taken as an ensemble display a variation of X_{CO} similar to MBM40 ro MBM16. Moreover, additional study could reveal the cause for the variation in MBM16. Preliminary results indicate an inverse relationship between X_{CO} and W(CO). Since $X_{CO} \equiv N(H_2)/W(CO)$, a possible explanation may be that N(H_2) remains relatively constant over a cloud like MBM16 while the CO abundance and, thus, W(CO) varies by an order of magnitude. The variation in the CO abundance could reflect slight changes in the self-shielding effects of N(H_2) which, in the regime of the translucent clouds, leads to large variation in the CO abundance (van Dishoeck & Black 1988). Alternatively, changes in the velocity structure of the cloud could also significantly affect W(CO). Future papers will investigate these possibilities.

References

Cardelli, J.A. & Wallerstein, G. 1986, ApJ, 302, 492
Danks, A.C., Federman, S.R., Lambert, D.L. 1984, A&A, 130, 62
de Vries, H.W., Heithausen, A., & Thaddeus, P. 1987, ApJ, 319, 723
Federman, S.R. 1982, ApJ, 257, 125

Federman, S.R. & Willson, R.F. 1982, ApJ, 260, 124
Federman, S.R. & Lambert, D.L. 1988, ApJ, 328, 777
Herbstmeier, U., Heithausen, A., & Mebold, U. 1993, A&A, 272, 514
Magnani, L., Blitz, L., & Wouterloot, J.G.A. 1988, ApJ, 326, 909
Magnani, L., Lada, E.A., Sandell, G., & Blitz, L. 1989, ApJ, 339, 244
Magnani, L. & Onello, J.S. 1993, ApJ, 408, 559
Magnani, L. & Onello, J.S. 1995, ApJ, 443, 169
Mattila, K. 1986, A&A, 160, 157
Meyerdierks, H., Brouillet, N., & Mebold, U. 1990, A&A, 230, 172
Sandell, G. & Johansson, L.E.B. 1982, in *Regions of Recent Star Formation*, ed. R.S. Roger & P.E. Dewdney (Dordrecht: Reidel), 479
Sandell, G., Stevens, M., & Heiles, C. 1987, A&A, 179, 25
Sandell, G., Magnani, L., & Lada, E.A. 1988, ApJ, 329, 920
van Dishoeck, E.F. & Black, J.H. 1988, ApJ, 334, 771