METHANOL ABUNDANCE IN LOW MASS PROTOSTARS

Sébastien Maret
Department of Astronomy, University of Michigan, 833 Dennison Building, 501 East University Avenue, Ann Arbor MI 48109-1090, USA

ABSTRACT

Methanol lines observations of a sample of low mass Class 0 protostars are presented. Using a 1D radiative transfer model, I show that several protostars have large abundance jumps in the inner hot and dense region of envelopes, probably because of thermal grain mantle evaporation. These abundances are compared with a grain surface chemistry model.

Key words: ISM: abundances - ISM: molecules - Stars: formation.

1. INTRODUCTION

During the formation of a star, the gas undergoes important changes, both on a physical and chemical point of view. In the prestellar phase, the gas is heavily depleted on grain mantles. When the gravitational collapse starts, the protostar gradually warm up the gas, and the trapped molecules are released in the gas phase. These molecules can then rapidly trigger the formation of more complex molecules, by gas phase chemistry. Methanol is a well suited molecule to study these changes, because it is abundant in grain mantles, and is expected to evaporate from grain mantles in the inner hot and dense regions of the protostars. Methanol observations can therefore be used to determine the physical and chemical conditions in these regions. In this contribution, I present methanol lines observations a sample of low mass protostars. Using a detailed radiative transfer model, I derive the methanol abundances in the envelopes, and discuss the implications on the formation of this molecule.

2. OBSERVATIONS AND RESULTS

Six Class 0 protostars [André et al. 2000] were observed. The methanol $5_{K}-4_{K}$ lines were observed with the IRAM-30m telescope, while the $7_{K}-6_{K}$ were observed with the JCMT. Fig. 1 show an example of methanol $5_{K}-4_{K}$ map obtained with the IRAM-30m on NGC1333-IRAS2. Lines have gaussian profile with high velocity wings. Narrow high energy lines (> 100 K) are detected on the central position. These lines likely originate from the inner and dense part of the envelope, while broader, low energy lines clearly originate from the two outflows detected in CO 3-2 and 2-1 [Knee & Sandell 2000], SiO 2-1 [Blake 1996; Jørgensen et al. 2004] and CS 3-2 [Langer et al. 1996].

3. MODEL

In order to determine the methanol abundances in the envelopes, a detailed 1D radiative transfer model has been developed. The model uses the escape probability formalism, and is presented into details in Maret et al. (2004, hereinafter Paper I). CH$_3$OH collisional rates with para-H$_2$ from Pottage et al. (2004) are used. The envelopes are assumed to be spherically symmetric, and the density profile is supposed to follow a power law. Index of the power law and

![Figure 1. Methanol 5K-4K maps of NGC1333-IRAS2.](#)
dust temperature profile from Jørgensen et al. (2002) and Paper I are used. The methanol abundance profile is supposed to follow a step function. The abundance is set to constant value $X_{\text{out}}$, in the outer cold part of the envelope. This abundance jumps to a $X_{\text{in}}$ value in the inner and hotter part of the envelope, because of the evaporation of the grains mantles. This evaporation is assumed to occurs at a temperature of 100 K. The best fit values $X_{\text{in}}$ and $X_{\text{out}}$ are determined by minimizing the $\chi^2$ between the model and the observations. Fig. 2 show the $\chi^2$ maps obtained for NGC1333-IRAS2 and IRAS16293-2422.

Figure 2. $\chi^2$ as a function of the inner and outer methanol abundances for NGC1333-IRAS2 and IRAS16293-2422. The contours indicates the 1, 2, and 3$\sigma$ confidence levels respectively. The number of observed lines, $N$, are also shown, as well as the reduced $\chi^2$ for the best fit model.

4. RESULTS AND DISCUSSION

The methanol abundances in the outer part of the envelope range from $3 \times 10^{-10}$ to $2 \times 10^{-9}$, and are quite similar from one source to the other. On the contrary, the inner abundance varies much from one source to the other. In two sources of our sample, NGC1333-IRAS2 and IRAS16293-2422, the observations can only be reproduced by our model if there are jumps in the abundances. The inner abundances are $2 \times 10^{-7}$ and $1 \times 10^{-7}$ respectively, i.e. a factor 100 and 200 larger in the outer envelope. In NGC1333-IRAS4B and L1448-MM, there are weak evidences of abundances jumps (1$\sigma$). In these sources, the inner abundance jump to $7 \times 10^{-7}$ and $5 \times 10^{-7}$ respectively, i.e. a factor about 300 larger than in the outer cold part of the envelope. These values should however taken with caution, because of the small confidence levels. In NGC1333-IRAS4A, L1448-N and L1157-MM, the observations are well reproduced with a constant CH$_3$OH abundance throughout the envelope, even if the presence of a jump can not be ruled out by the present observations.

Gas phase chemistry reactions can not reproduce the high abundances of methanol observed in ices (Herbst, private communication). Methanol is therefore likely to be be formed on grain surfaces by successive hydrogenation of CO (Tielens & Hagen 1982). Because methanol is evaporated from grain mantles in the inner part of the envelopes of our sample, these abundances are likely to reflect the composition of ices, and can be use to determine the efficiency of the formation of this molecule on grains mantles. I have compared the abundances obtained in the four protostars of our sample where abundance jumps were detected with a grain chemistry model (Keane & Tielens 2004). Both CO (Jørgensen et al. 2002), H$_2$CO (Paper I) and CH$_3$OH (this study) were found to be well reproduced by the model. The model indicates that density at the time of the formation of the molecule is $10^{-5}$ cm$^{-3}$. It also indicates that the probability of H to react with CO and H$_2$CO are equal, in agreement with recent laboratory experiment (Hidaka et al. 2004).

5. CONCLUSION

The present observations and model show that methanol abundance is greatly enhanced in the inner regions of protostellar envelope, probably because thermal evaporation of grain mantles. The observed abundances are well explained by a grain surface chemistry model, and indicates that methanol was formed at a density of $\sim 10^{-5}$ cm$^{-3}$, probably during the prestellar phase.

ACKNOWLEDGMENTS

I wish to thank Eric Herbst for a useful discussion about the methanol formation.

REFERENCES

André, P., Ward-Thompson, D., & Barsony, M. 2000, Protostars and Planets IV, 59+
Blake, G. A. 1996, in IAU Symp. 178: Molecules in Astrophysics: Probes & Processes, 31+
Hidaka, H., Watanabe, N., Shiraki, T., Nagaoka, A., & Kouchi, A. 2004, ApJ, 614, 1124
Jørgensen, J. K., Hogerheijde, M. R., Blake, G. A., et al. 2004, A&A, 415, 1021
Jørgensen, J. K., Schöier, F. L., & van Dishoeck, E. F. 2002, A&A, 389, 908
Keane, J. V. & Tielens, A. G. G. M. 2004, A&A, in press
Knee, L. B. G. & Sandell, G. 2000, A&A, 361, 671
Langer, W. D., Castets, A., & Lefloch, B. 1996, ApJ, 471, L111
Maret, S., Ceccarelli, C., Caux, E., et al. 2004, A&A, 416, 577
Pottage, J. T., Flower, D. R., & Davis, S. L. 2004, MNRAS, 352, 39
Tielens, A. G. G. M. & Hagen, W. 1982, A&A, 114, 245