Mem. S.A.It. Vol. 88, 724

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Deuterated methanol map towards L1544

A. Chacón-Tanarro, P. Caselli, L. Bizzocchi, J. E. Pineda, S. Spezzano, B. M. Giuliano, V. Lattanzi, and A. Punanova

Max-Planck-Institute für extraterrestrische Physik, Giessenbachstrasse 1, 85748 Garching, Germany, e-mail: achacon@mpe.mpg.de

Abstract. Pre-stellar cores are self-gravitating starless dense cores with clear signs of contraction and chemical evolution (Crapsi et al. 2005), considered to represent the initial conditions in the process of star formation (Caselli & Ceccarelli 2012). Theoretical studies predict that CO is one of the precursors of complex organic molecules (COMs) during this cold and dense phase (Tielens et al. 1982; Watanabe et al. 2002). Moreover, when CO starts to deplete onto dust grains (at densities of a few 10^4 cm^{-3}), the formation of deuterated species is enhanced, as CO accelerates the destruction of important precursors of deuterated molecules (Dalgarno & Lepp 1984). Here, we present the CH_2DOH/CH_3OH column density map toward the pre-stellar core L1544 (Chacón-Tanarro et al., in prep.), taken with the IRAM 30 m antenna. The results are compared with the $C^{17}O$ (1-0) distribution across L1544. As methanol is formed on dust grains via hydrogenation of frozen-out CO, this work allows us to measure the deuteration on surfaces and compared it with gas phase deuteration, as well as CO freeze-out and dust properties. This is important to shed light on the basic chemical processes just before the formation of a stellar system.

1. Introduction

Bizzocchi et al. (2014) found that methanol towards L1544 presents an asymmetric ring-like structure around the center of the core. This was explained by Vasyunin et al. (2017), who showed that complex organic molecules can peak at distances of 2000-4000 au from the center, if reactive desorption takes place. Thus, at densities around a few times 10^4 cm^{-3}, CO is heavily depleted onto dust grains, so the formation of methanol and other COM precursors is enhanced and they can partially be released into the gas phase via reactive desorption. However, at densities larger than 10^5 cm^{-3}, the freeze-out rate becomes larger than the reactive desorption rate, implying depletion of methanol and other COMs toward the core center. Nevertheless, deuterated methanol is expected to form on the surface more efficiently toward the center of the core, where the CO freeze-out is higher, and consequently the deuterium fraction and the D/H ratio on dust grains are also higher. Indeed, D/H needs to be orders of magnitude higher than its cosmic value to allow efficient deuteration of CO on the grain surface (e.g. Ceccarelli et al. 2014).

2. Observations

The emission of the CH_2DOH (2-1) and (3-2) lines, as well as the $C^{17}O$ (1-0) line, were observed using the 30 m IRAM antenna, placed at Pico Veleta, Granada, Spain. The angular resolution of the data is 30”, with a noise level of 16 mK for CH_2DOH and 20 mK for $C^{17}O$. Also, new observations of CH_3OH were done

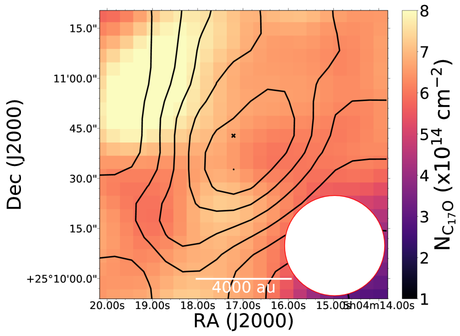

Fig. 1. Map of the $C^{17}O$ column density, superposed with the CH_2DOH/CH_3OH column density ratio in black contours. The contours represent increasing 10% intervals with respect to the peak value of the deuterium fractionation (~0.09). The HPBW is shown in the bottom right corner. The black cross marks the dust emission peak at 1.3 mm.

simultaneously in order to obtain a better spectral resolution than the previously presented by Bizzocchi et al. (2014), reaching a noise level of 64 mK.

The column density of deuterated methanol was derived averaging the values found for the two observed lines, assuming three different temperatures ranging from 5 to 8 K, optically thin emission and constant excitation temperature, as done in Bizzocchi et al. (2014). For consistency, the same was done for methanol using the two brightest lines of the transition observed. For the column density of $C^{17}O$ also optically thin emission was assumed, as well as a constant excitation temperature of 10 K towards the core.

3. Results

The maximum value found for the column density of deuterated methanol is 3.6×10^{12} cm^{-2}, and the one of methanol is 5.9×10^{13} cm^{-2}. These values are consistent with the ones found by Bizzocchi et al. (2014).

CH_2DOH shows a more compact and closer to the center distribution than CH_3OH. The deuteration distribution shows a maximum deuteration value of ~0.09, and it is placed at a distance of about 1400 au from the dust millimeter continuum peak towards the south-west (see Fig. 1), opposing the CH_3OH distribution, whose column density peaks in the north-east part of the core. This distribution differs from the deuteration map of N_2H^+, which peaks at the millimeter dust continuum peak (Caselli et al., 2002). Methanol deuteration also shows a decreasing deuteration level towards the outer parts of the core, which is expected due to the decrease in density and consequent lower amount of CO freeze-out. This is confirmed by the comparison of CO distribution with the deuteration level of methanol, which shows a clear anti-correlation between the abundances of CO and deuterated methanol (see Fig. 1).

CO presents a ring-like structure around the core center, depleting towards the center, and more abundant towards the north-east. The peak value is 8.8×10^{14} cm^{-2}, and it is found in the same region as the methanol peak, at a distance of ~3500 au from it.

Acknowledgements. The authors thank the help and support from the IRAM staff. ACT, PC, and JEP acknowledge the financial support of the European Research Council (ERC; project PALs 320620).

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