Cold methanol formation: testing model predictions

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Methanol is the simplest alcohol, one of the most important precursors of complex organic and prebiotic molecules. In star-forming regions, methanol is formed quite early, it is already visible in the gas of cold pre-stellar cores. In such environment, at a temperature of ~10 K, methanol is formed in the icy mantles of interstellar dust by sequential addition of hydrogen atoms to a CO molecule, which actively physisorbs on the dust. At the last hydrogenation step, the energy released during the reaction can be spent on desorption of the newly formed methanol molecule from the mantle surface. Chemical models predict that in cold cores gas-phase methanol is expected to be abundant at the outer edge of the CO depletion zone, where CO is actively adsorbed. CO adsorption correlates with volume density in cold cores, and, in nearby molecular clouds, the catastrophic CO freeze-out happens at volume densities above 10^4 cm^{-3}. The methanol production rate is maximized there and its freeze-out rate does not overcome its production rate, while the molecules are shielded from UV destruction by gas and dust. Thus, in cold cores, methanol abundance should generally correlate with visual extinction that depends both on volume and column density.

In this work, we test the most basic model prediction that maximum methanol abundance is associated with a local A_V~4 mag in dense cores and constrain the model parameters with the observational data. With the IRAM 30 m antenna, we mapped the CH_3OH (2–1) and (3–2) transitions toward seven dense cores in the L1495 filament in Taurus to measure the methanol abundance. We use the Herschel/SPIRE maps to estimate visual extinction, and the $C^{18}O$(2–1) maps from Tafalla & Hacar (2015) to estimate CO depletion.

This is the first study of methanol, performed simultaneously in several sources of the same star-forming region, with an angular resolution high enough to resolve dense cores. Comparison of the model results with the results of observations made it possible to limit the important free parameters of the model. To reproduce the observed methanol abundance in cold cores, hydrogen surface diffusion via tunneling is required, and the efficiency of reactive desorption of methanol should be 0.64%, which corresponds to calculations using the empirical formula obtained in laboratory studies using generally accepted values of methanol desorption energy and effective mass surface element (Minissale et al. 2016). We also find the constant photodesorption yield for CO equal to 10^{-2} molecules per incident photon, following Fayolle et al. (2011), is sufficient to rich the observed towards the cores CO depletion during reasonable timescales (~10^5 yr). The work is presented in Punanova et al. (2021).

References

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