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Solid CH_4 toward low-mass protostars: How much is there to build complex organics?

Karin I. Öberg[1], A. C. Adwin Boogert[2], Klaus M. Pontoppidan[3], Geoffrey A. Blake[3], Neal J. Evans[4], Fred Lahuis[5], and Ewine F. van Dishoeck[1]

[1]Leiden Observatory, Leiden University, P.O. Box 9513, NL–2300 RA Leiden, the Netherlands
email: oberg@strw.leidenuniv.nl
[2]IPAC, NASA Herschel Science Center,Mail Code100-22, California Institute of Technology, Pasadena, CA 91125, USA
email: aboogert@ipac.caltech.edu
[3]Division of Geological and Planetary Sciences, California Institute of Technology Pasadena, CA 91125, USA
email: pontoppi@gps.caltech.edu
[4]Department of Astronomy, University of Texas at Austin, Austin, TX 78712-0259, USA
email: nje@bubba.as.utexas.edu
[5]SRON, PO Box 800, NL–9700 AV Groningen, The Netherlands
email: F.Lahuis@sron.nl

Abstract. We use Spitzer IRS spectra to determine the solid CH_4 abundance toward a large sample (52 sources) of low mass protostars. 50% of the sources have an absorption feature at 7.7 μm, attributed to solid CH_4. The solid CH_4/H_2O abundances are 2–13%, but toward sources with H_2O column densities above 2×10^{18} cm^{-2}, the CH_4 abundances (20 out of 25) are nearly constant at $4.7 \pm 1.6\%$. Correlations with CO_2 and H_2O together with the inferred abundances are consistent with CH_4 formation through sequential hydrogenation of C on grain surfaces, but not with formation from CH_3OH and formation in gas phase with subsequent freeze-out.

Keywords. Astrochemistry, molecular processes, circumstellar matter, ISM: abundances, infrared: ISM

1. Introduction

CH_4 is believed to play a key role in the formation process of complex and prebiotic molecules (see, e.g., Markwick *et al.* 2000). In star forming regions most molecules are frozen out as ices and solid CH_4 has previously been detected towards mainly high mass protostars by, e.g., Boogert *et al.* (1996). Models predict solid CH_4 to form rapidly on cool grains through successive hydrogenation of atomic C, similarly to H_2O from O. Two other suggested formation pathways are photo-processing of CH_3OH and gas phase formation with subsequent freeze-out. Because formation pathway efficiency depends on environment, potential formation routes may be tested through exploring the distribution of CH_4 toward a large sample of objects of different ages, luminosities and ice column densities. In addition, correlations, or lack thereof, with other ice constituents may provide important clues to how the molecule is formed.

In this study we determine the CH_4 abundances and distribution pattern toward a sample of 52 low mass young stellar objects, in 11 different clouds and with a large spread in total ice column density. This is based on spectra acquired with the Spitzer Infrared Spectrometer (IRS) as part of our legacy program 'From molecular cores to protoplanetary disks' (*c2d*).

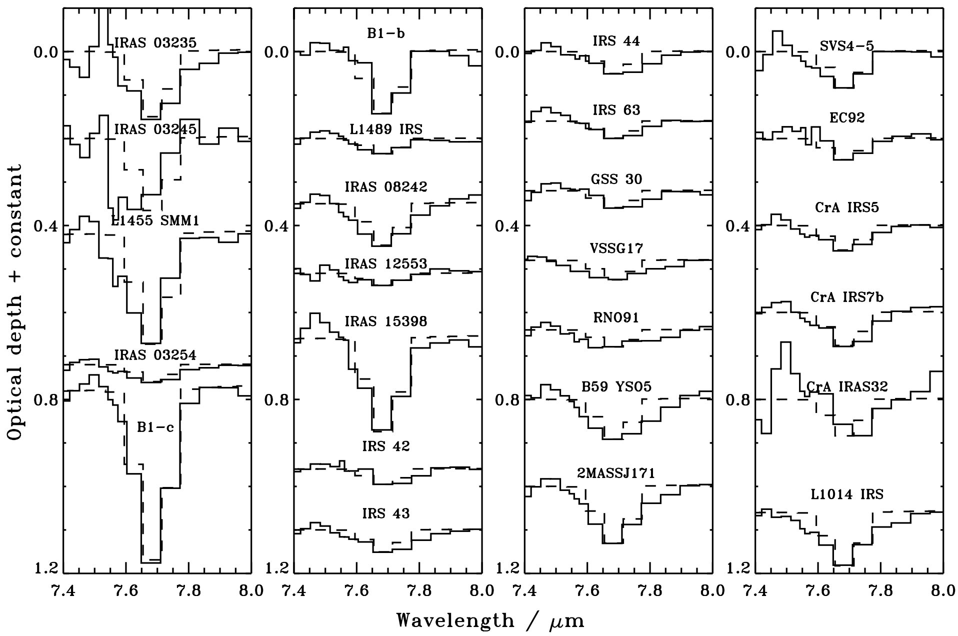

Figure 1. Continuum subtracted infrared spectra (solid line) of the CH_4 feature at 7.7 μm toward 25 low mass protostars, and laboratory spectra of CH_4 ice (dashed line).

2. Results and Discussion

Detailed results of this study are published in (Öberg *et al.*, ApJ in press). We detect solid CH_4 at 7.7 μm in 25 of our sources (Figure 1) and derive column densities by comparing the observed 7.7 μm features with a laboratory H_2O:CH_4 ice mixture. The calculated CH_4 abundances with respect to solid H_2O vary between 2 and 13%. Toward sources (20/25) with H_2O column densities above $3{\times}10^{18}$ cm^{-2} all CH_4 abundances fall between 2 and 8%, however and the average is 4.7±1.6%. In the sources with no CH_4 detection, the average 3σ upper limit is 15%. These CH_4 abundances are comparable to what has been found towards high mass stars previously.

The nearly constant CH_4 abundance we found here can be contrasted with the large variations of the CH_3OH abundances in Boogert *et al.* (ApJ in press) for the same sources. CH_4 seems hence unrelated to CH_3OH. In general our results agree with model predictions where CH_4 is formed on the grain surface. Aikawa *et al.* (2005) predicts CH_4 ice abundances with respect to H_2O between ≈1–10%. In contrast gas phase models predict steady state CH_4/H_2 abundances of only $\sim 10^{-7}$ (e.g., Woodall *et al.* 2007), compared with our inferred CH_4/H_2 abundances of $\sim 2-13\times10^{-6}$ (assuming a standard H_2O/H_2 ratio of 10^{-4}). The grain surface formation pathway is also supported by correlation studies between CH_4 and other observed ice molecules i.e. CH_4 correlates better with molecules formed on surfaces than those formed in the gas and subsequently frozen out.

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