

Formation of NH₂CHO and CH₃CHO upon UV processing of interstellar ice analogs

Rafael Martín-Doménech[✉], Karin I. Öberg and Mahesh Rajappan

Center for Astrophysics | Harvard & Smithsonian
60 Garden St, Cambridge, MA, 02138, USA
email: rafael.martin_domenech@cfa.harvard.edu

Abstract. Complex organic molecules (COMs) may have played a role in the formation of life in the early Earth (Herbst & van Dishoeck (2009)). Here we present the formation of NH₂CHO and CH₃CHO upon vacuum-ultraviolet (VUV) irradiation of CO:NH₃ and CO:CH₄ ice mixtures, simulating the UV processing of interstellar ices in the interior of dense clouds. We have found that the conversion from NH₂ radicals to NH₂CHO is 4–15 times higher than that from CH₃ to CH₃CHO, probably due to the competing formation of larger hydrocarbons in the latter case.

Keywords. ISM: clouds, ISM: kinematics and dynamics, ISM: molecules

1. Introduction

Formamide (NH₂CHO) is the simplest molecule containing the peptide bond, and acetaldehyde (CH₃CHO), with a similar structure, is also thought to play an important role in astrobiology. Pure gas-phase chemical models fail to reproduce the observed abundances of formamide and acetaldehyde across the different regions of the interstellar medium (ISM) in which they are detected. These molecules are thus thought to be produced by energetic processing of interstellar ice mantles (Jones *et al.* (2011), Bennett *et al.* (2005)). This process can be experimentally simulated in the laboratory under astrophysically relevant conditions using ultra-high vacuum chambers.

2. Experimental setup

The experimental simulations were performed using the SPACE CAT (Surface Processing Apparatus for Chemical Experimentation to Constrain Astrophysical Theories) setup located at the Center for Astrophysics (Lauck *et al.* (2015)), which consists of an ultra-high vacuum chamber with a base pressure on the order of 10⁻¹⁰ Torr at room temperature. The CO:NH₃ and CO:CH₄ binary ice mixtures with different compositions were co-deposited onto a CsI substrate at a temperature of 11 K. After deposition, the ice samples were VUV irradiated with a Hamamatsu L11798 H₂D₂ lamp with a typical flux of $\sim 5 \times 10^{13}$ photons cm⁻² s⁻¹, which features a strong emission band at ~ 160 nm that would correspond to the emission of molecular hydrogen, and weaker emission ($\sim 30\%$ of the flux at 160 nm) around Ly- α wavelengths. During irradiation, the samples were monitored using a Bruker Vertex 70v Fourier transform infrared (FTIR) spectrometer with a liquid-nitrogen-cooled MCT detector in transmittance.

3. Results

Fig. 1 shows the IR spectrum in the 2400–975 cm⁻¹ range of the CO:NH₃ ice mixture before and after irradiation. The formation of NH₂CHO is evidenced by the growth of IR bands at ~ 1698 cm⁻¹, ~ 1390 cm⁻¹, and ~ 1325 cm⁻¹. Likewise, new IR features

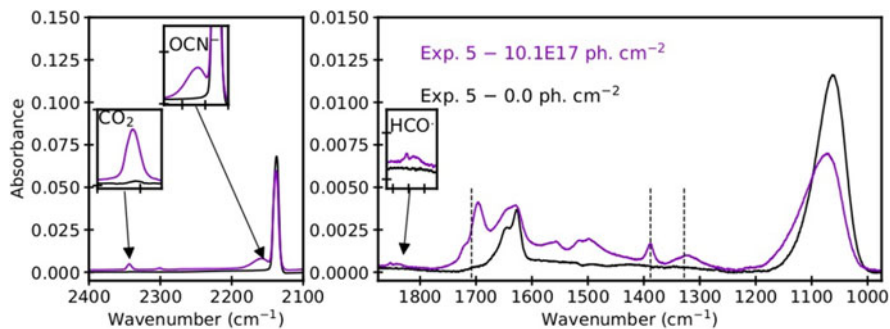


Figure 1. IR spectrum of a CO:NH₃ ice sample before (black) and after (purple) irradiation. Dashed lines indicate the position of the photoproducted formamide ice IR features.

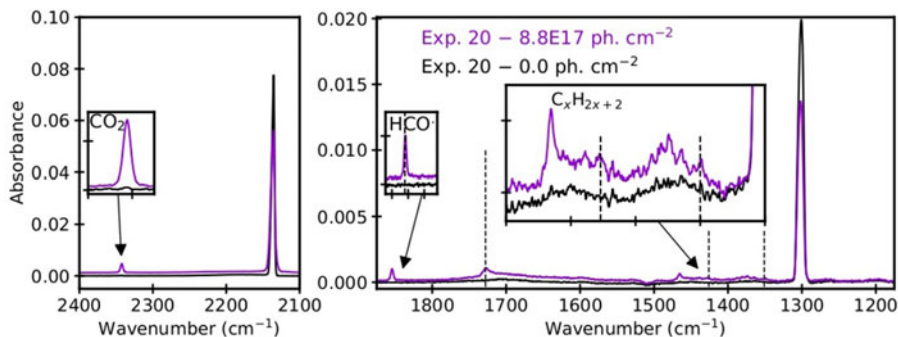


Figure 2. IR spectrum of a CO:CH₄ ice sample before (black) and after (purple) irradiation. Dashed lines indicate the position of the photoproducted acetaldehyde ice IR features.

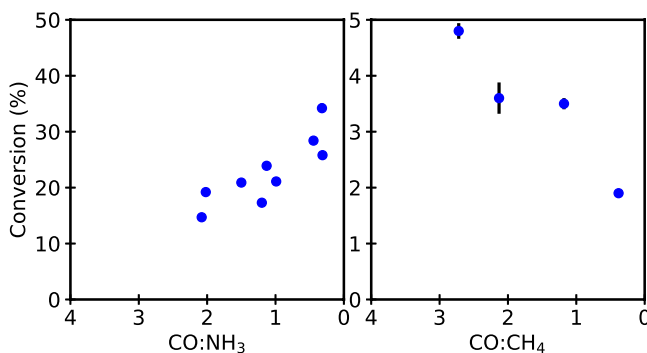


Figure 3. Conversion from NH₂ and CH₃ radicals into NH₂CHO or CH₃CHO after irradiation of different CO:NH₃ or CO:CH₄ ice mixtures (*left* and *right* panels, respectively) with 6.5×10^{17} photons cm⁻².

due to the formation of CH₃CHO appear at 1728 cm⁻¹, 1427 cm⁻¹, and 1350 cm⁻¹ in Fig. 2 showing the IR spectrum in the 2400–1175 cm⁻¹ range of the CO:CH₄ ice mixture before and after irradiation.

Fig. 3 shows the conversion from NH₂ and CH₃ radicals into NH₂CHO and CH₃CHO molecules, respectively. This conversion is lower for acetaldehyde formation, probably because it is competing with the formation of larger hydrocarbons (C_xH_{2x+2} in Fig. 2).

References

- Bennett, C. J., Jamieson, C. S., Osamura, Y., & Kaiser, R. I. 2005, *ApJ*, 624, 1097
Herbst, E. & van Dishoeck, E. F. 2009, *ARA&A*, 47, 427
Jones, B. M., Bennett, C. J., & Kaiser, R. 2011, *ApJ*, 734, 78
Lauck, T., Karssemeijer, L., Shulenberger, K., *et al.* 2015, *ApJ*, 801, 118