

## Formation of complex organic molecules on cold surfaces

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Interstellar Complex Organic Molecules (iCOMs) are considered as the building blocks of more complex pre-biotic compounds. In particular, formamide (NH<sub>2</sub>CHO), widely observed in different astrophysical media, is thought to be the starting point of some emblematic metabolic and genetic species [1]. Formamide formation through gas phase route exists [2, 3], even if it is still debated, but solid-state chemistry should also be a vector of the molecular complexity observed in later phases of the matter evolution, such as in comets and meteorites.

Our group aims at understanding how the molecular complexity may increase on cold surfaces, from atoms or molecules, without the help of others external energetic agents (photons, electrons, ions...). During the last few years we have developed a new experimental facility (named VENUS) to study the different non-energetic pathways of solid-state astrochemistry.

During my presentation I will show how we can constrain the penetration depth of H and O through molecular ices (e. g. H<sub>2</sub>O, NO, H<sub>2</sub>CO). Penetration actually occurs at a negligible rate in comparison with other surface processes (diffusion and self reaction) (Minissale et al, submitted). Thus, I will present evidence that formamide can also be formed very efficiently following solid-state chemical pathways (Dulieu et al, in prep.).

Finally, I will give few examples of how we can nowadays determine the chemical networks (including the evaluation of barriers, and type of reaction) of specific chemical solid state systems, such like the hydrogenation of NO (Nguyen et al, in prep.), combining complete sets of experiments with state-of-the-art calculations of quantum chemistry.

[1] Saladino, R. et al., 2012. Formamide and the origin of life. *Physics of life reviews*, 9(1), pp.84–104.

[2] Barone, V. et al., 2015. Gas-phase formation of the prebiotic molecule formamide: insights from new quantum computations. *Monthly Notices of the Royal Astronomical Society: Letters*, 453(1).

[3] Codella, C. et al., 2017. Seeds of Life in Space (SOLIS) - II. Formamide in protostellar shocks: Evidence for gas-phase formation. *Astronomy & Astrophysics*, 605, p.L3.