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Laboratory experiments for understanding the chemical evolution of organic matter in astrophysical ices

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Abstract

The challenges of our projects consist in simulating through laboratory experiments, the chemical evolution of astrophysical ices for understanding what could be the different stages of the organic matter during the life cycle of interstellar grains to their incorporation in planetary systems such as in comets or in asteroids inside the Solar System. Our experiments consist in recreating primitive or cometary ices evolution, which allow obtaining data on the chemical reactivity that occur during the evolution process (RING project), the characterization of species sublimating during the ice warming (VAHIIA project), as well as on refractory residue (RAHIIA project). All these results can then serve for space missions.

1. Introduction

The interstellar dust grains are composed of a silicate core or of carbonaceous materials. During their life cycle in the interstellar medium, these grains can be found in some regions called dense molecular clouds, where the main elements contained in these clouds (atoms, H_2, CO, HCN, N_2…) can accrete, and then combine to form a mantle of "primitive" interstellar ices. In some areas, the dense molecular cloud collapses under the effect of its own gravity, which leads to the formation of a protostar surrounded by an envelope of gas and dust. The formation of the protostar induces a warming of these grains and their irradiation by X-rays or ultra-violet photons. The "primitive" molecules within the ice mantle will react leading to the formation of complex organic molecules and refractory compounds. With time, a few million years, the envelope surrounding the future star is dissipating, forming a protoplanetary disk where dust grains are distributed along the midplane. Under the effect of gravity, in a process that can last a few tens of millions years, these grains coagulate to form various objects of planetary systems, such as planets, comets, asteroids and meteorites for the Solar Systems.

Through experimental investigations, we try to understand the chemical evolution of organic matter from dense molecular clouds to planetary systems, as well as the chemical evolution that can occur inside these planetary systems (Figure 1). Among the various objects of planetary systems, comets are believed to form in cold region of the solar nebula. They are composed of a mixed of processed and non processed icy or crude grains, and for these raisons still bring a large amount of water and organic compounds already carried by interstellar grains. This contribution is focused on laboratory experiments relevant for understanding the chemical reactivity that could occur in cometary environments.

2. Experimental approach

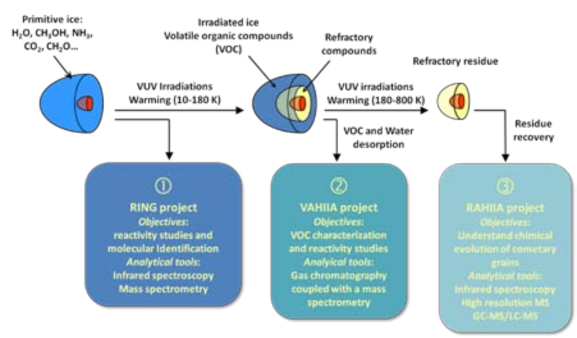

Figure 1: Presentation of experimental approaches used in the astrochemistry group of the PIIM laboratory for investigation the chemical evolution of cometary grains.

Using infrared spectroscopy and mass spectrometry, as well as isotope labeling, we are investigating the chemical reactivity (RING project, reactivity In Grains) that can occur within analogs of primary or cometary ices, by working on small size systems (one to three reactants). These systems are based on molecules that have been detected in the corresponding astrophysical environments. The objective is to investigate specific chemical reactions (e.g. formic acid reactivity with water or ammonia [1], Figure 2) and highlight pathways for the formation of specific molecules that might explain their detection (e.g. formation of glycine [2] or aminoacetonitrile [3]). An example of this approach is displayed on Figure 2. Furthermore, the investigation of the chemical reactivity provide a screening of new molecules that can be searched for [4].

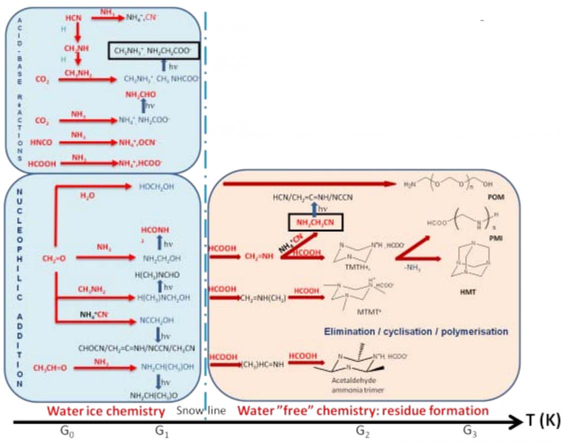

Figure 2: Chemical reactivity in astrophysical ices .

We are developing two others approaches, which consist in characterizing the evolution of primitive and cometary ice analogs (H_2O, NH_3, CH_3OH, CO, CO_2…). These cometary ice analogues are submitted to various physical processes such as VUV irradiation, and then warmed under thermal processes. During the ice warming, volatile organic compounds (VOC) desorb. To get a better understanding of how chemical reactions can lead to the formation of these VOC, we are developing the VAHIIA project (Volatile Analyses coming from the Heating of Interstellar Ice Analogs). The VAHIIA project will provide preliminary information on VOC that would sublimate during the warming of cometary nucleus. The VOC characterization is performed using an analytical gas chromatography coupled to a mass spectrometry (GC-MS) system. The last approach concerns the characterization of refractory residues that are formed after the sublimation of water and of the most volatile organic compounds. This is the RAHIIA (Residue Analysis from the Heating of Interstellar Ice Analogues) project. The residue analogues are considered as the first stage of the complex organic matter in astrophysical environments. Once formed, these residue analogues can be submitted to further physical or chemical processes and evolve through a complex organic matter such as the one observed in meteorites. The residue analogues are recovered and characterized using various analytical methods (HRMS, HPLC-MS, Raman spectroscopy…) to determine their composition and investigate formation pathways of organic molecules detected within them [5].

3. Conclusions

In this contribution, we present three complementary projects that allow obtaining information on the chemical reactivity that occur during the formation of planetary objects such as comets, as well as on the chemical reactivity that occur inside planetary objects. These investigations provide chemical pathways for the formation of molecules already detected, as well as propositions on molecules that could be detected, such as in cometary environments. Furthermore, our experimental results can give clues and help for the treatment of data coming from space missions such as the Rosetta mission.

Acknowledgements

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