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The AHIIA experimental set-up for understanding cometary chemistry

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Abstract

In this contribution, we present the AHIIA experimental system dedicated to the study of chemical reactivity and evolution occurring in comets and asteroids. This experimental set-up is built of three complementary units. The first one based on infrared spectroscopy and mass spectrometry, allows the investigation of reactivity that occur inside cometary ices, while the second unit consists in a gas chromatography - mass spectrometry (GC-MS) directly connected to the ultra vacuum chamber where cometary ice analogs are formed. This unit provides information on volatile organic compounds (VOC) that sublime during the heating of these analogs. The third unit allows the recovery of refractory organic residues formed after the sublimation of all VOC for their ex situ analyses. The AHIIA experimental system provides a complete simulation that could occur in cometary environments.

1. Introduction

Studying the formation and the chemical evolution of the organic matter starting from the molecular clouds to the early solar system and earth is of crucial importance for understanding the origin and evolution of the solar nebula as well as at the end, the emergence of life on Earth (Ehrenfreund & Charnley 2000,Irvine, 1998). Comets are among interplanetary objects that have undergone less alterations during this evolution and have thus preserved a part of the organic matter that have been present in the solar nebula. Remote sensing along with in-situ investigations of comets throughout more than 20 missions during the last decades, allowed the identification of numerous organic species such as methanol, formaldehyde, symmetric hydrocarbons, sulfur and nitrogen bearing molecules (Bockelée-Morvan et al., 1998; Feaga et al., 2007; Lis et al., 1997, bockelee Morvan et al 2004, A Hearn et al 2012; Ootsubo et al. 2012). However, probing such objects is a difficult task. Therefore, for enhancing data interpretations obtained from cometary missions and understanding the chemical reactivity that occurs in such environment, laboratory experiments have been developed. They consist in recreating in laboratory the evolution that can undergo a cometary material when a comet evolve around the Sun. Analogs of cometary ice are formed inside ultra-vacuum chamber (generally 10^{-9} mbar) by depositing a gas mixture relevant of a cometary ice composition (H_2O, NH_3, CH_3OH, CO_2...). These analogs are then subjected to physical processes that could undergo a cometary ice in interplanetary environment, such as UV irradiations and/or cosmic rays. These processes activate the initial molecules leading for example to radical recombination forming new and particularly more reactive molecules. Once analogs are irradiated, the ice is warmed simulating a comet approaching the Sun. This warming allows an increase in the complexity of the chemical reactivity leading after the desorption of volatile organic compounds (VOC) to organic residues.

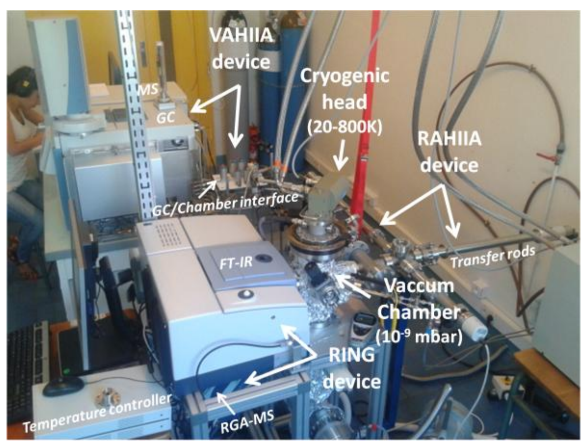

Figure 1: The AHIIA experimental set-up developed in our astrochemistry group for the investigation of the chemical evolution in astrophysical environments.

This contribution is focused on the development of the AHIIA experimental set-up (Figure 1) which is relevant for understanding the chemical reactivity and chemical evolution that could occur in astrophysical environments.

2. Experimental approach

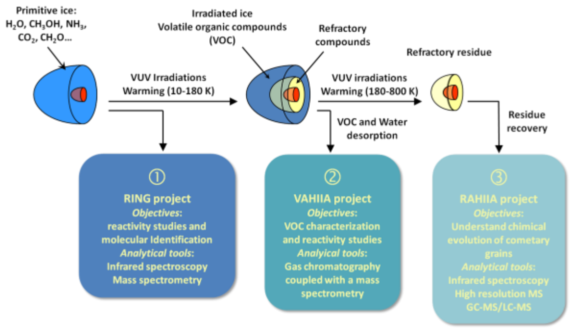

Figure 2: Presentation of experimental approaches used in our astrochemistry group for the investigation of the chemical evolution in astrophysical environments.

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 and highlight pathways for the formation of specific molecules that might explain their detection [1].

We are also 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 developed the VAHIIA experiment (Volatile Analyses coming from the Heating of Interstellar Ice Analogs). The VAHIIA experiment 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) experiment. 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 [2].

3. Conclusions

In this contribution, we present three complementary experiments forming the AHIIA experimental set-up 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.

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