Thesis topic: Laboratory experiments to understand the origins of organic matter in interplanetary objects.

Thesis supervisor: Pr. Grégoire Danger (HDR, Laboratoire PIIM, gregoire.danger@univ-amu.fr)

Thesis co-supervisor : Dr. Alicja Domaracka (HDR, CIMAP, GANIL, domaracka@ganil.fr)

Host laboratory: ASTRO team, Physique des Interactions Ioniques et Moléculaires, Aix-Marseille Université, UMR CNRS 7345

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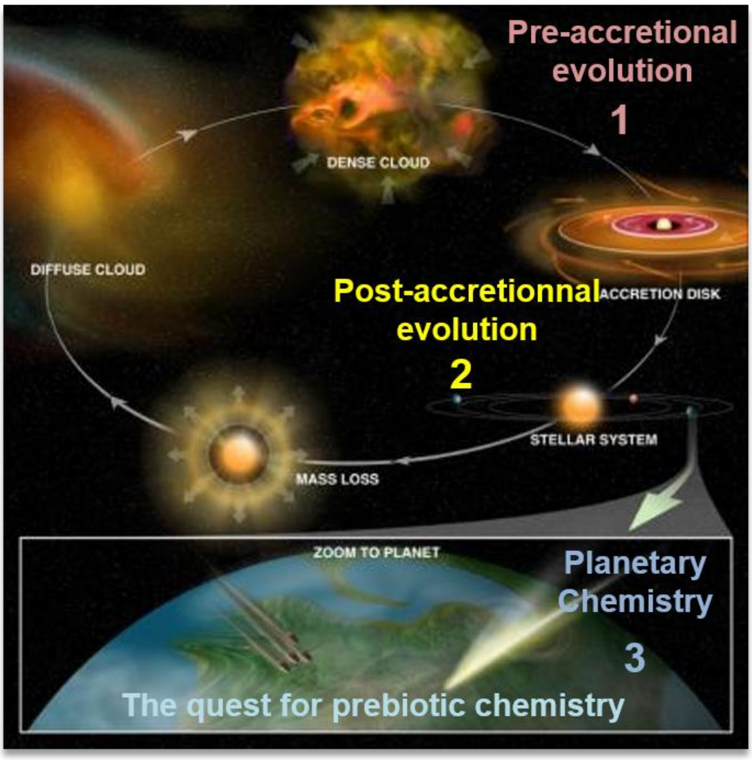
Scientific context: Through our research program, we are developing laboratory experiments to understand possible origins of organic matter within the solar system, as observed in certain meteorites and their parent bodies such as asteroids and comets. By extension, this program aims to determine if the processes of organic matter formation within the solar system could lead to similar matter in other planetary systems. We experimentally simulate the different phases of solar system evolution in the laboratory, focusing on the solid phase as a source of organic matter.



The first step involves the evolution of icy grains from the dense molecular cloud during its collapse, to the evolution of the solar nebula and the formation of the protoplanetary disk. This pre-accretionary evolution is simulated within low-pressure (10^{-9} mbar) and low-temperature (12K-77K) systems by creating an analog of icy grains resembling those found in the dense molecular cloud. This analog is then subjected to various sources of irradiation (UV photons, electron or ion bombardment) that it may encounter during the formation of the protoplanetary disk. Once altered, the analog of icy grain is heated to simulate its evolution towards warmer regions within the disk. Some of the molecules formed during the initial alteration phase sublime, enriching the gaseous phase. The most refractory molecules at 300K form an organic residue analogous to what could have been present on the surface of certain grains in the protoplanetary disk. This residue is referred to as pre-accretionary organic matter analog.

The second step focuses on the evolution of this pre-accretionary organic matter analog once it is incorporated into objects that will give rise to the interplanetary bodies in our solar system. Analysis of carbonaceous chondritic meteorites shows that their parent bodies have undergone aqueous or thermal alterations. We subject these pre-accretionary analogs to these post-accretionary alteration processes to understand how this matter is transformed within the parent bodies of these meteorites.

The final phase involves the evolution of the organic matter formed during the first two phases once it is delivered to the surface of terrestrial planets, particularly in the environment of primitive Earth. We are particularly interested in the role that this exogenous organic matter could play in the emergence of specific chemical systems, and how environmental conditions can influence the evolution of this matter.

All of these experiments rely on the development of analytical methodologies for the characterization of organic compounds in the generated gas or solid phases. Thus, we have developed an innovative system for analyzing volatile organic compounds (VOCs) released during the heating of icy grain analogs. In parallel with VOC analysis, an innovative analytical strategy has been developed for analyzing solid phases, based on high-resolution mass spectrometry coupled with liquid or gas chromatographic techniques.

The synergy we have established enables us to achieve a comprehensive characterization of our analogs, providing valuable insights into their chemical evolution. These insights are essential for understanding the chemical evolution of interplanetary objects in our solar system.

Thesis objectives: The thesis will be an experimental thesis that aims to understand the various physicochemical processes responsible for the observed organic matter within interplanetary objects, and to determine its composition based on the considered objects. The first objective is to develop a set of experiments to understand the type of organic matter that can form during pre-accretionary processes. In the MICMOC setup (10^{-8} mbar, 77K) at the PIIM laboratory, commonly studied ices (H_2O, CH_3OH, NH_3) altered by UV photons at 121 nm will be modified by adding CO, CO_2, H_2S, SO_2, and/or PH_3 to better mimic observed ices. The volatile organic compounds in the gas phase (analyzed by GC-Orbitrap) as well as the refractory organic compounds (HRMS, LC-HRMS, GC-HRMS) will be analyzed to determine their composition and the chemical reactivity induced by these modifications. By combining these analyses, the aim is to establish the chemical connections that may exist between the gas and solid phases. The second objective is to reproduce these ices at the CIMAP facility at GANIL, where they will be altered by ion bombardment (Ar, S, Mg at ~100 keV). The same analytical techniques will be used to characterize the gas and solid phases of these experiments and the results will be compared to the experiments performed in MICMOC to determine the influence of the irradiation source on the formation of molecular species. The third objective is to simulate post-accretionary conditions and study the evolution of the formed samples. All the obtained results will be compared to analyses of extraterrestrial objects (sample returns or carbonaceous chondritic meteorites). By the end of this thesis, a better understanding of the physicochemical processes that led to the formation of the observed organic matter within interplanetary objects will be achieved.

Available devices in the host laboratory: Experimental set-ups for analog formation, analytical devices GC-HRMS et UPLC-MS.

Collaborations: FT-ICR technology (LDI, équipe COBRA, Rouen, France, or ESI Analytical BioGeoChemistry, Munich, Germany), UPLC-orbitrap ou –qQq (IC2MP, Poitiers, France), ou encore la RMN (800 MHz équipe Analytical BioGeoChemistry, Munich, Germany), ion bombardments at CIMAP, GANIL.

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