

Photo- and thermo-chemistry of ices as a source for organic matter: from astrochemistry to astrobiology

Louis L.S. d'Hendecourt (1), Cornelia Meinert (2), Uwe J. Meierhenrich (2) and Grégoire Danger (1)
(1) Equipe ASTRO, PIIM, UMR 7345, CNRS, AMU, Marseille, France (2) ICN, UMR 7272, CNRS, Université de La Côte d'Azur, France

ldh@ias.u-psud.fr

Abstract

Extraterrestrial ices are abundant in astrophysical environments linked to star forming regions as well as environments where protoplanetary disks, planets and various debris such as comets and asteroids do form. These ices can be easily simulated in the laboratory, leading to the formation of organic residues that can be analysed by classical gas analytical chemistry methods. Among detected species, many amino-acids are observed. Interestingly aldehydes and sugars were also detected. Over-irradiation of the residues under vacuum likely produces an insoluble organic material that resembles the one observed in primitive meteorites. Astrobiological implications from astrochemistry may thus be seriously considered.

1. Introduction

The abundance and importance of ices in astronomical settings cannot be understated. Ices are observed in the infrared spectra of protostars at the end phase of molecular clouds lifetime prior to the formation of protoplanetary disks. In these disks, many objects do contain dirty ices such as comets, asteroids and icy moons of giant planets in our Solar System. Simulating these ices in the laboratory is a not so difficult task with the use of matrix isolation techniques [1] in which gas phase simple molecules are deposited onto a cold infrared transparent window. Various methods to impart energy within these ices do exist, pertaining to different environments in space. In our case, following the model given by [2], we use essentially Lyman α photons provided by a plasma discharge microwave lamp.

2. Organic matter from ices

2.1 The formation of organic residues

The sample, a gas mixture of abundant interstellar molecules (H_2O , CH_3OH , NH_3 in our case) is deposited under vacuum on a MgF_2 window, cooled to 77 K and simultaneously photolyzed with the UV discharge lamp to ensure for a complete penetration of the sample with UV photons. In most of our experiments we use around 1 to 10 Ly α photons per deposited molecules. At the end of this phase, the sample is warmed-up to room temperature where the presence of a semi-refractory organic residue is always observed in the infrared spectrum of the window as well as visually (see Figure 1). Many examples of these residues can be found in [3]. We assume that such a residue does represent an analogue of the Soluble Organic Matter (SOM) present in primitive meteorites.

1.1 Targeted molecules in the residue

About 100 μg (up to 300 μg) is obtained at each run which renders the analytical procedure quite elaborate. In the group of Uwe Meierhenrich in Nice, the use of a performing double dimensional gas chromatographic apparatus (GCxGC-TOFMS) has proven its efficiency for such a task. This targeted technique is very sensitive and we ensure that any contamination from the analytical procedure is avoided by using ^{13}C isotopic labelling in the CH_3OH from the initial gas mixture. Targeted searches for amino acids have been performed and have shown many amino acids, including proteigeneous ones to be present in the sample as well as some diamino acids. A complete list of those can be found in [5]. Second, the search for sugars have been also performed in similar samples with a different

extraction protocol. They have revealed the presence of 8 aldehydes including glycolaldehyde and, most importantly, glyceraldehyde, the first sugar of the ose family [6]. Later on, using the same techniques with a more elaborated protocol to make sure that all the sugars could be detected, a suite of sugars was found, including ribose, a most important component of the RNA molecule since it is part of the backbone of this RNA [7]. A key figure of these results is the quite large abundance of sugars such as ribose with the presence of various aldopentoses (5 carbon atoms) which is tentatively explained as due to a reaction within the evaporation of the ice that polymerizes H_2CO and produces all these sugars via a reaction in part similar to the well-known formose reaction.

2.2 Insoluble organic materials

We decided to post irradiate the residue at room temperature (300 K) in vacuum. Actually this experiment was serendipitously performed while testing the irradiation of residues with UV-Circularly Polarized Light in order to obtain a symmetry breaking in the amino acids detected (L vs D amino acids). This experiment is described in [8] with its astrophysical explanation for the origin of amino acid enantiomeric excesses in meteorites. Unexpectedly to us, after extracting the SOM part of the sample, some insoluble part was indeed remaining. This was confirmed by a following experiment where high UV irradiation doses were delivered to the sample (10 keV per bond). Indeed the sample starts to “aromatize” and passes through a stage where it resembles the well-known IOM from primitive carbonaceous chondritic meteorites. This is briefly depicted in Figure 2 taken from [9].

3. Conclusions

UV irradiation of ices does provide organic materials that we assume to be analogues of the soluble organic materials in primitive meteorites. Their importance to possibly feed prebiotic chemistry on telluric planets must be seriously considered. This approach must follow a holistic astrophysical scenario which depicts the global astrochemical evolution of our Galaxy [10]. However further experiments in preparation will consider the evolution of this material under specific environmental conditions, adapted to early Earth, in order to test far from equilibrium processes that are necessary to establish the inert to living transition in an organic molecular network in interaction with a specific environment, a minimal definition for “life”.



Figure 1: an image of the residue under visible light obtained with a microscope (X60)

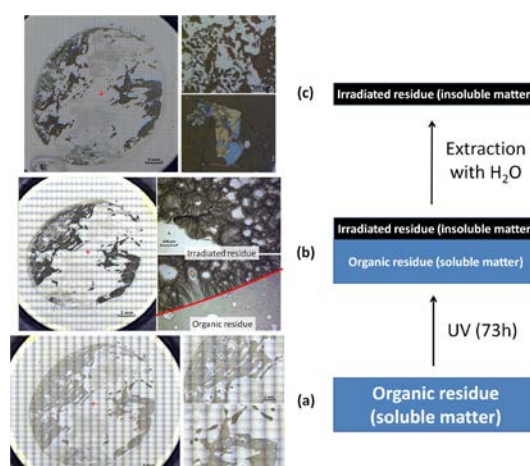


Figure 2: Transformation of laboratory SOM to laboratory IOM upon over irradiation [9].

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