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VUV irradiation of interstellar ice analogues: an abiotic source for organic matter in planetary systems

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Abstract

Laboratory organic residues from energetic and thermal evolution of astrophysical ices are sometimes considered as analogues of meteoritic and/or pre-cometary matter, because of similarities in physical structure and chemical composition. In particular, various organic molecules of potential prebiotic interest, such as amino acids, have been detected. Moreover, enantiomeric excesses have been induced in amino acids by the irradiation of the ice samples with asymmetric light (UV-CPL), a scenario that may explain their origin in primitive chondrites.

1. Introduction

Interstellar ices (H_2O, CO, CO_2, CH_3OH, NH_3, CH_4, etc.) are widely observed in the mid-infrared range around protostellar objects [1], from which planets, comets and asteroids may eventually form. In the laboratory, experiments simulating the energetic (UV photons, cosmic rays) and thermal evolution of ice analogues lead, after warming the sample up to room temperature, to the formation of a water-soluble semi-refractory organic residue. Theses residues have been studied thanks to numerous analytical techniques over the last 40 years, allowing their partial physical and chemical characterisation [2]. They are then sometimes considered as analogues of pre-cometary and/or meteoritic (soluble part) matter.

The origin of enantiomeric excesses (ees) in meteoritic amino acids is still unknown but an asymmetric process leading to this enantioselective enrichment may have been at work in astrophysical environments. Among the usually proposed mechanisms, UV-Circularly Polarized Light (UV-CPL) irradiation is the one we tested, in a global and coherent astrophysical scenario.

2. Experiments

Our experimental setup MICMOC consists in a high vacuum chamber (10^{-7} mbar) in which an infrared (IR) transparent MgF_2 window is cooled down to 10 or 78 K. A gas mixture, previously prepared in an independent gas line, is then injected in the cryostat where it condenses to form a thin film of ice analogues onto the window. These analogues are, simultaneously to their deposition, irradiated by UV photons thanks to a H_2 discharge lamp, for 24 to 96 hours.

MICMOC has been designed to be mounted on the DESIRS beamline at the SOLEIL synchrotron facility, which provides a very high quality UV-CPL beam, allowing the asymmetric irradiation (right- or left- CPL) of the samples (ice analogues and/or organic residues).

At the end of the experiments, organic residues are recovered and stored under argon atmosphere in special sample holders until their analysis, more often by multi-dimensional gas chromatography (GCxGC-TOFMS), allowing the detection of dimly abundant molecules as well as the precise determination of potential enantiomeric excesses in chiral ones.

3. Results

Several organic molecules of potential prebiotic interest (hydantoin, amino and di-amino acids) have been recently detected by our group [3,4], molecules that are also present in some carbonaceous chondrites.

The irradiations with UV-CPL of initially achiral ice analogues (H_2O, CH_3OH, NH_3) and/or organic residues have shown to induce some small but significant enantiomeric excesses (< 2%) in the amino acids recovered [5,6]. The sign of the ees are directly dependent on the helicity (right of left polarization) as well as on the energy (6.6 and 10.2 eV) of the photons, suggesting a Circular Dichroism (CD) effect. On the other side, the sign is not dependent on the amino acid (measurement for 5 amino acids), neither on the stage at which the samples are irradiated (ice phase only or residue phase only), showing that chiral molecules are already made in the ice phase.

4. Summary and Conclusions

The study of laboratory organic residues made from energetic and thermal evolution of astrophysical ices has led to the detection of numerous organic molecules, including some of potential prebiotic interest such as amino acids. Whereas a direct comparison between these organic residues and extraterrestrial matter is not straightforward, several similarities in structure and molecular composition can be found.

Enantiomeric excesses have been successfully induced in amino acids by irradiation with UV-CPL of initially achiral ice analogues. The results of this astrophysical scenario have potential implications on the origin of ees in meteorites and support the idea that the protosolar nebula has indeed been formed in a region of massive star formation, regions where UV-CPL of the same helicity is actually observed over large spatial areas.

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