Photochemistry of interstellar/circumstellar ices as a contributor to the complex organics in meteorites

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Abstract. The UV irradiation of interstellar/circumstellar ice analogs is known to lead to the formation of organic compounds such as amino acids and maybe nucleobases. In this work, the mechanisms of formation and distribution of amino acids, chosen as tracers for the organic compounds formed in such experiments, are studied and compared with meteoritic data.

Keywords. Astrochemistry, methods: laboratory, ISM: molecules, ultraviolet: ISM, meteorites

1. Introduction

Organic molecules have been shown to be formed in interstellar/circumstellar environments consisting of gas and dust particles covered with a thin ice layer containing mainly H_2O, and then CO, CO_2, CH_3OH, NH_3, and CH_4 (Gibb *et al.* 2004), and subjected to UV-photon and cosmic-ray radiations (Mathis *et al.* 1983). Those organics are then incorporated into protostellar nebulae, such as the one in which our Solar System formed, as well as into comets and interplanetary dust particles, that can be collected in Earth's atmosphere (Matrajt *et al.* 2005) and onboard spacecraft (Sandford *et al.* 2006). Their recent analysis shows the presence of a non-negligible organic fraction. Some compounds, such as amino acids and nucleobases, are of particular interest for prebiotic chemistry. Amino acids have been identified in organic residues formed from the UV irradiation of interstellar ice analog mixtures (Bernstein *et al.* 2002, Muñoz Caro *et al.* 2002, Nuevo *et al.* 2008), and have been detected in carbonaceous chondrites such as Murchison (Cronin & Pizzarello 1997). However, their detection in the interstellar medium (ISM) is still debated (Kuan *et al.* 2003). Nucleobases have also been found in meteorites (van der Velden & Schwartz 1977, Stoks & Schwartz 1979), but have so far never been observed in the ISM (Charnley *et al.* 2005).

2. Experimental setup and protocol

In a vacuum chamber (a few 10^{-8} torr), gases are deposited on a substrate cooled down to 15–20 K. These gases are chosen to mimic the composition of the ISM. Under such physical conditions, the gases condense on the substrate in a thin ice layer, which is simultaneously irradiated by a UV H_2 lamp, emitting UV photons at 121.6 nm (Lyman α) and around 160 nm. After irradiation, the system is warmed to room temperature, where an organic residue remains on the substrate and can be analyzed. Such residues contain a large variety of compounds, including amino acids (Bernstein *et al.* 2002, Muñoz Caro *et al.* 2002, Nuevo *et al.* 2008). Liquid (LC) and gas (GC) chromatographies are the main techniques used to analyze residues. Such techniques separate residues into their individual compounds by differences of diffusion rates through a chemically-active column.

3. Results

Formation and distribution of amino acids. Analyses of these organic residues show that amino acids *always* form as long as the starting ice mixture contains the 4 elements C, H, N, and O (Nuevo *et al.* 2008). The irradiation time and the temperature (10–80 K) have no significant effect on their final distribution. In most of cases, glycine is found to be the most abundant amino acid formed, the abundance of the other compounds decreasing exponentially with their molecular mass, indicating that such compounds were formed via non-biological processes. However, the formation mechanisms of amino acids are not clearly understood. Laboratory studies show that there are in fact several competing mechanisms leading to their formation, and that their distribution in the laboratory is different from what is observed in meteorites (Elsila *et al.* 2007, Nuevo *et al.* 2008).

Comparison with meteoritic amino acids. The abundances of the 3 most abundant amino acids formed in laboratory organic residues, namely glycine, alanine, and serine, have been compared with their abundances in 1 g of the Murchison meteorite (Nuevo *et al.* 2008 and references therein). In the residues, alanine was found to be produced with abundances half that of glycine, whereas in Murchison these two amino acids have similar abundances. Serine is formed with lower relative abundances in Murchison than in residues. These discrepancies indicate that the formation mechanisms of amino acids are different in the laboratory and in meteorites, or that Murchison had subsequent alteration, such as the (photo-) chemical process or decomposition of high molecular mass amino acids into smaller compounds such as glycine and alanine. However, this comparison is biased since mainly only proteinaceous amino acids have been searched for in organic residues (Nuevo *et al.* 2008). The search for non-proteinaceous amino acids such as α-aminobutyric acid or isovaline in residues, which have been detected in Murchison, may allow a better understanding of the formation mechanisms of such compounds.

Nucleobases. Nucleobases are complex molecules consisting of one (pyrimidine-based) or two (purine-based) rings containing nitrogen atoms. They are probably key compounds for prebiotic chemistry. The formation and photo-stability of pyrimidine- and purine-based compounds are currently being studied at NASA Ames, where pyrimidine mixed with H_2O ice is UV irradiated at low temperature. The early results show that such mixtures lead to the formation of nucleobase-like compounds.

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