Amino acid interaction on interstellar ice analogues

Modelling chemical alteration of amino acids in interstellar ice analogues under UV irradiation and thermal processing

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In Short

- Astronomical observations have revealed a large inventory of organic molecules in the Solar System.
- The formation of organic molecules on interstellar ice is caused by the interaction with radiation and thermal processing.
- Both laboratory and space experiments are performed in order to understand the chemical processes at play.
- Performing computational studies provides deeper insights to chemical reaction pathways and helps identifying resulting product.

The enhanced capabilities of space-based observational instruments have unveiled a surprisingly large inventory of organic molecules in our solar system [1]. Through astronomical observations of trans-Neptunian, Kuiper belt objects and comet nuclei, precursors of organic molecules such as formaldehyde (H_2CO), ammonia (NH_3), hydrogen (H), cyanide (HCN), hydrogen sulfide (H_2S), methanol (CH_3OH), acetylene (C_2H_2) and CO were successfully detected. These molecules are thought to be precursors of basic building blocks of life. Furthermore, the detailed analysis of meteorites (e.g.Orgueil, Murchinson, Allende and Tagish Lake) revealed a possible extraterrestrial origin of prebiotic matter on Earth [2]. This is illustrated for example by the large number of amino acids identified in the Murchinson meteorite. Here α-aminoisobutyric acid (AIB) and isovaline were found, which are rare or nonexistent on earth, respectively [3]. It is still an open question whether or not the extraterrestrial delivery of complex molecules is a necessity for the emergence of life on Earth. Consequently, to understand the emergence of life on Earth, it is essential to disclose the formation processes, the stability and the pathways of organic molecules in our Solar System.

The formation process of organic molecules starts in molecular clouds, where volatile molecules, such as water (H_2O), carbon monoxide (CO), carbon dioxide (CO_2) and ammonia (NH_3) freeze onto remnant dust particles from the presolar cloud. These dust grains typically contain a silicate or carbonaceous core, surrounded by a mantle of ice (see fig: [1], forming the parent bodies of comets and meteorites [4]. Over their lifespan, frozen small bodies in the outer Solar System are exposed to a harsh radiation environment including cosmic radiation, solar wind and solar energetic particles. Laboratory experiments showed that the irradiation with UV photons or energetic particles alters their chemical composition drastically. Within the ice, molecular bonds are broken, leading to the formation of radicals and molecular fragments. If comets move closer to the sun they are thermally processed. The rise in temperature initiates the sublimation of volatile compounds such as e.g. CO and H_2O that form the atmosphere of a comet. On the other hand, the heating leads to a higher reactivity of the remaining molecules, catalyzing the growth of complex organic compounds that remain on the comet nuclei.

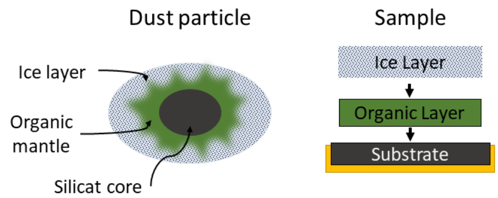

***Figure 1:** Sketch of a dust particle made of a silicate core, a organic mantle and a ice layer of frozen volatiles compared to the sample structure of experiments at FUB.*

In recent years, a number of laboratory experiments looking at the interaction of interstellar ice analogues with UV photons and energetic particles were performed. A detailed analysis of the HLRNrefractory organic compounds revealed many different organic molecules, including amino acids [5,6], sugars, sugar derivatives [7,8], and nucleobases [9,10]. Nevertheless, it has shown that their formation depends on many factors such as the initial ice composition, temperature and the dose of irradiation [1]. Due to the difficult nature of such experiments it is crucial to perform computational studies in parallel. Not only will this provide deeper insights into chemical reaction pathways but also allow to identify resulting reaction products.

To expose samples to an extended spectrum of solar and cosmic radiation, the experiments OREOcube and Exocube (PI: A.Elsaesser) [11,12] are currently being devolved by the European Space Agency and will be installed on the outside of the International

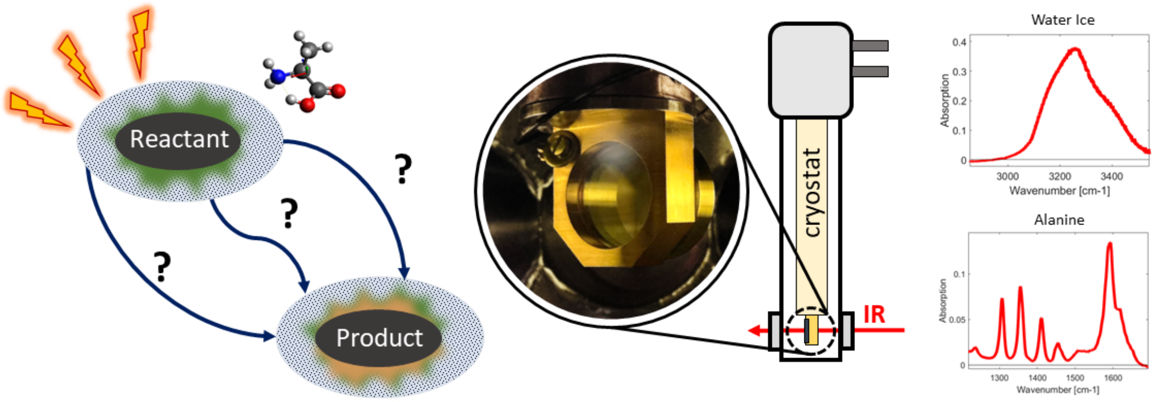

Figure 2: *Performing computational studies in parallel to experimental ones are crucial to understand chemical reaction pathways and help identifying resulting products.*

Space Station. While irradiating samples consisting of amino acids and other organic molecules, in-situ spectroscopy will deliver time-resolved data about their degradation and photochemical pathways. In the frame of these projects, ground control experiments performed at Freie Universitaet Berlin are designed to examine the stability and interaction of amino acids within interstellar ice analogs at the organic ice interface under UV radiation (see fig: [2]). A thin layer of organic molecules on a substrate is cooled to cryogenic temperatures in ultra-high vacuum (10^{-8} mbar). On top of the organic layer, a layer of ice is formed via background deposition. To trigger various chemical processes, the sample is exposed to a simulated solar spectrum including photons in the ultraviolet range. In order to monitor the changes in detail on a molecular level, the sample is under continuous observation using real-time Fourier Transform infra-red spectroscopy during the ice deposition, irradiation-, and warm up process.

Given their their fundamental importance as the building blocks of life, it is of special interest to understand the stability of amino acids (e.g. alanine) on interstellar ice analogues and their role in the growth of organic molecules towards higher complexity in space.

WWW

https://www.physik.fu-berlin.de/en/einrichtungen/ag/ag-elsaesser/index.html

More Information

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