Interstellar ices in the lab: probing resonant structural changes due to free electron laser irradiation of interstellar ice analogues

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Interstellar ices are postulated to play an important role in interstellar chemistry, such as the formation of the most abundant molecule H_2 [1]. Only 6 molecular species have so far been detected in the solid state - H_2O, CO, CO_2, CH_3OH, NH_3 and CH_4 [2]. However, it is suggested that there are many more species present in these icy mantles, such as complex organic molecules (COMs) and prebiotic species. The recent launch of the James Webb Space Telescope (JWST) targets the detection and further exploration of these species and will inspire a new "ice age" in astrochemical research.

The Laboratory Ice Surface Astrophysics (LISA) end station at the free electron laser (FEL) facility FELIX in Nijmegen, the Netherlands, has been designed to study the effect of the release of vibrational energy in the bonding network of ices of interstellar relevance [3,4]. By employing the wide tunability and high intensity of the FELs at FELIX, ices grown in the ultra-high vacuum chamber of LISA are selectively irradiated on- and off-resonance in the mid-infrared (MIR) range at temperatures below 20 K. Infrared radiation is ubiquitous in space, but the release of vibrational energy in the ice layers can also result from exothermic chemical reactions in these layers. Then, understanding how this kind of energy can be taken up and dissipated in structure of an interstellar ice is key in investigating grain-surface reactions.

Our previous studies of porous amorphous solid water (pASW) showed local crystallisation of the ice upon resonant irradiation with FEL-2 of FELIX [3]. Restructuring after resonant IR excitation was also observed in other astrochemically relevant ices, such as pure CO_2 [4] and mixtures of H_2O and NH_3. Our latest experiments systematically covered mixed ices of CO_2 and H_2O in different ratios between 1:5 and 20:1 (H_2O:CO_2). We observed the strongest irreversible structural changes in amorphous ices that contained more water than carbon dioxide. Crystalline ices appeared to be unaffected by the FEL irradiation. The irradiation experiments also revealed a strong connection between the components of the mixtures, since irradiation of the H_2O-band in CO_2-rich ices results in restructuring of the CO_2-band and irradiation of the CO_2-band results in restructuring of the H_2O-band in H_2O-rich ices. To explain these results on a microscopic level, we will employ theoretical simulations [5,6]. In future experiments we aim to expand our studies to layered ices, as well as mixtures of other molecular species of astrochemical relevance.

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