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EPSC Abstracts
Vol. 16, EPSC2022-877, 2022
https://doi.org/10.5194/epsc2022-877
Europlanet Science Congress 2022

Laboratory studies of irradiated Enceladus ice analogues

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The phenomenal revelation by the Cassini spacecraft of exospheric plumes spewing from the surface of Enceladus into space [1] overturned our common perception that icy moons are geologically inactive and cold planetary bodies in our solar system. Instead, the on-board magnetometer detected a disturbance in Saturn's magnetosphere due to plumes outgassing, hereby hinting at the existence of a subsurface ocean [2] which motivated closer flybys of the icy moon. The observation of the plumes' composition further revealed the presence of complex organics [3] and raised the question of their origin. The icy grains in the plumes that exceed the escape velocity travel outward to Saturn's E-ring from 4 to 8 Saturn radii. A study by Nölle et al. evidenced how during this journey the organic portion within the ice is strongly altered by impinging photons, while the degradation of salt rich particles is dominated by plasma sputtering [4].

Past studies have extensively probed the vacuum-UV (VUV) irradiation of icy grains in the interstellar medium [5,6], whereas little is known about photon irradiation of ices under environmental conditions characteristic for those present on icy moons such as Enceladus. New insights from space-based instruments onboard ESA's JUICE or NASA's Europa Clipper spacecraft are expected to arrive at similar ocean-bearing worlds in the 2030s. Therefore, preparatory laboratory studies are essential in order to advance our understanding of surface processes which are relevant for the chemical complexity of icy grains found on icy moon exteriors, plumes and within interplanetary space.

A cryogenic ultra-high vacuum (UHV) setup at Leiden University's Laboratory for Astrophysics is used to explore the formation of complex organic molecules by energetic processing of Enceladus ice analogues. The latter is realised by using special lamps, a microwave discharge H_2-flow lamp to generate VUV light (120-180 nm) and a Xe-arc lamp with an SED peaking approx. at λ_{max} of the Sun. The UHV system can spectroscopically probe thin ices of varying composition and temperatures to constrain physical and chemical processes occurring within the ice. Fourier-transform infrared spectroscopy (FTIR) monitors changes in the solid state by means of vibrational spectroscopy, while a mass spectrometer complementarily confirms the detection of gas-phase species which desorb from the ice during linear warming of the underlying substrate.

Ices observed on Enceladus are mimicked in the laboratory at a temperature of 70 Kelvin and comprise mostly water (H_2O) mixed with lesser amounts of carbon dioxide (CO_2) and ammonia (NH_3) [7]. Experimental irradiation studies of these mixed ices are presented which include, but are not limited to, the formation of complex organic molecules. In addition, UV-photolysis of CO_2 rich ice is explored to study its lifetime on the surface of Enceladus, following the discovery of concentrated

CO_2 patches at the moon's south pole [8]. These experimental results allow to investigate possible theories for the presence of volatiles on the surface of Enceladus such as plume deposition or gas seeping through fractures in the icy crust [9].

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