Tracking the fate of ocean carbon within the ice shells of icy moons

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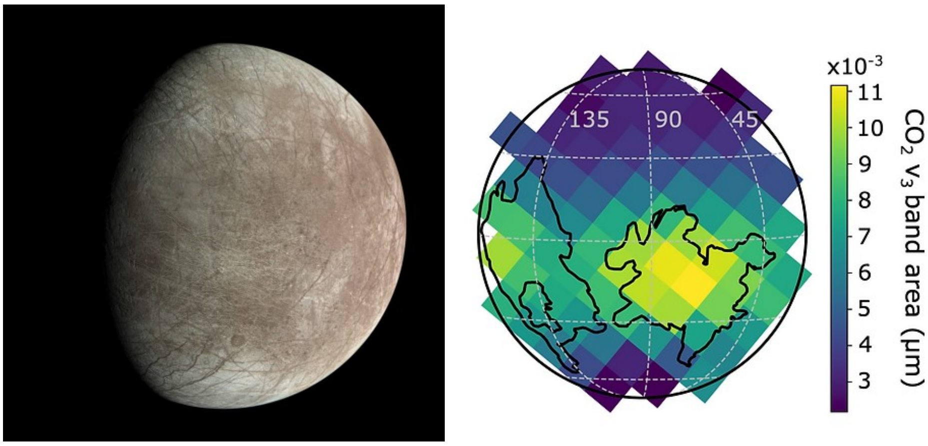

Figure 1: Left: An image of the surface of Jupiter's moon Europa, taken by the Juno spacecraft. Image credit: NASA. Right: Distribution of CO_2 on Europa's surface, imaged in the infrared by the James Webb Space Telescope. Blue colours indicate areas with lower abundance of CO_2, yellow indicate higher. The black outlines indicate the location of geologically young regions of Europa's surface. Image credit: Reference [4].

Project highlights:

- Conduct pioneering experiments investigating the fate of oceanic carbon within the ice shells and at the surface of Europa, Enceladus and other icy ocean worlds
- Develop an interdisciplinary skillset involving ultra-low-temperature experimental geochemistry, cryo-spectroscopy and thermodynamic modelling
- Join a large interdisciplinary group (AstrobiologyOU) with involvement in many aspects of the search for life beyond Earth

Project description:

This project will investigate the geochemical history, and possible origins, of various carbon compounds detected at the surfaces of icy worlds such as Jupiter's moon Europa and Saturn's moon Enceladus. The successful candidate will combine ultra-low-temperature simulation experiments, cryo-spectroscopy and geochemical modelling to establish how carbon from deep interior oceans is incorporated into, transformed within, and ultimately expressed at the surface of the ice shells of icy worlds.

Several icy worlds, including moons of Jupiter and Saturn, harbour vast subsurface oceans that may contain favourable conditions for life [1]. Carbon, an essential element for all known life, has been detected in myriad different forms at the surfaces of icy worlds [*e.g.*, 2, 3], offering a tantalising glimpse into a potentially rich carbon chemistry occurring below the ice. In a recent exciting development, CO_2 was detected on the surface of Europa by the James Webb Space Telescope [4], where it is localised in geologically young terrain that suggests it has been delivered there from below (Figure 1).

Understanding the budgets of organic and inorganic carbon in the oceans is a driving priority for icy worlds science. Ocean carbon could offer a potential energy source for life, may drive prebiotic chemistry, or could even be the product of life itself. Yet what spacecraft observe at the surfaces of these worlds is the result of a complex range of processes within their ice shells that act to transport ocean material to the surface. Recent experimental work, including by the AstrobiologyOU team, has begun to show that both organic and inorganic carbon compounds may be significantly modified when subjected to the extreme changes in temperature and pressure expected in icy world ice shells [5,6]. This has important implications for how they are ultimately expressed at the surface, and how future missions may search for signs of habitable conditions or even life itself.

This project will use laboratory experiments to investigate the evolution of the carbon system within icy world ice shells. The project will involve (i) tracking how carbon compounds, including potential biosignatures, transform during freezing of simulated 'ocean' fluids that contain carbon in multiple forms, (ii) establishing in what forms carbon is locked into ice after freezing, and (iii) investigating the spectroscopic signatures of ice-bound ocean carbon that could be used to identify it in spacecraft data. There is scope for aspects of the project to be adapted to the interests of the successful candidate. Other possibilities include: conducting thermodynamic modelling to predict the evolution of the carbon system under conditions relevant to icy world ice shells; analysing samples of natural ices from icy world field analogue locations; and/or applying for and conducting beamline experiments at national facilities (e.g., Diamond Light Source).

Results from this project will support recently launched missions such as ESA's JUICE and NASA's Europa Clipper, as well as existing observations from JWST and Cassini, and could underpin the design of future missions that aim to directly search for evidence of life at the icy worlds.

The project will involve some combination of the following tasks:

1. Experimentally simulate geological processes within icy world ice shells using laboratory facilities enabled for cryogenic temperatures and low pressures, and analyse the resulting materials using analytical techniques such as Raman spectroscopy, electron microscopy and X-ray diffraction (including possibly at national beamline facilities, subject to external funding).
2. Employ isotope substitution experiments to track the fate of carbon compounds during freezing.
3. Collect near-infrared spectra of carbon-bearing ices under icy moon surface conditions for comparison with spacecraft/telescope data.
4. Compare experimental results with analyses of natural carbon-bearing ices from icy world analogue locations on Earth.
5. Conduct thermodynamic modelling of ultra-low-temperature transformations in the carbon system to help extrapolate from experimental data.

Qualifications required: The ideal candidates will have a minimum 2:1 in a relevant science degree, such as geosciences or chemistry, or equivalent qualifications. Specialism in planetary geochemistry or cryosphere geochemistry is advantageous, as is laboratory experience.

References:

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