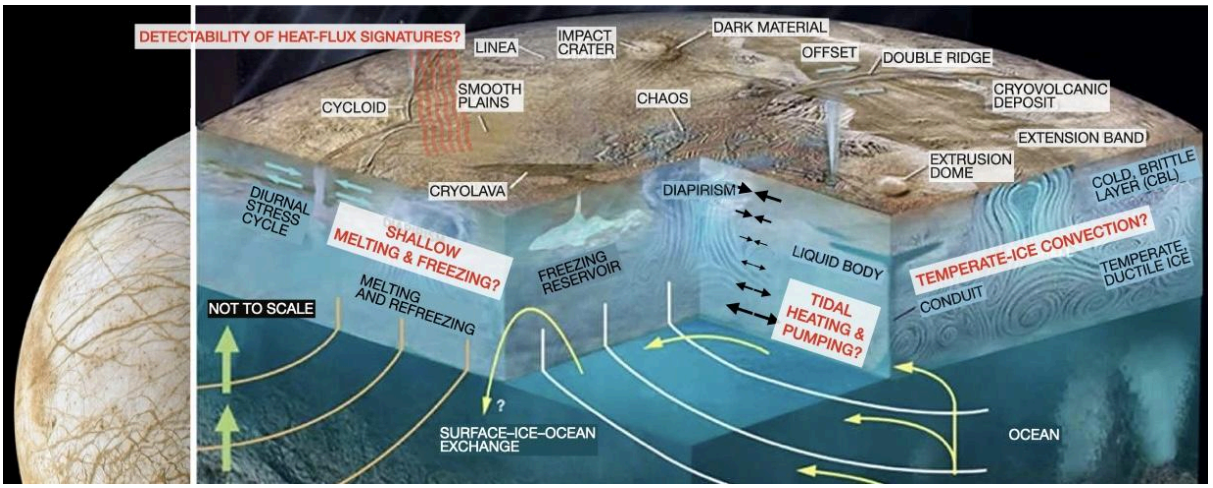
EARTHSCIENCES

# Earth as an icy world

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|---|---|
| **Primary supervisor:** | Richard Katz<br>https://www.earth.ox.ac.uk/people/richard-katz |
| **Co supervisor(s):** | Andrew Wells<br>https://www.physics.ox.ac.uk/our-people/wellsa |
| **Key words:** | Snowball Earth, icy worlds, phase change, convection |
| **Research theme(s):** | • Geophysics and Geodynamics<br>• Planetary Evolution and Materials |
| **Eligible courses for this project:** | • MSc by Research in Earth Sciences (2–3 years)<br>• DPhil in Earth Sciences (3–4 years)<br>• Interdisciplinary Life and Environmental Science Landscape Award (ILESLA) |

## Overview




Jupiter's moon Europa. (Left) Image using Galileo data (NASA/JPL/Ted Stryk). (Right) Cutaway of Europa's ice shell and internal ocean from Roberts+ 2023. Space Sci. Rev.10.1007/s11214-023-00990-y . Pictured are hypothesised physical processes in relation to surface morphology.

Earth froze over to become an icy world several times in the past. Two snowball episodes in the Cryogenian period (625–725 Ma) and one in the Huronian (~2 Ga) left Earth covered in a thick layer of ice, with a warmer ocean beneath. Some of this ice must have formed by freezing at the base of the ice shell, rejecting the salts from the growing ice crystals. The same physics applies to other icy words today: Europa and Enceladus, as examples, have global salty oceans beneath thick ice shells. This project asks what are the physics of such systems — from the planetary scale to the ice-crystal scale — and how they interconnect to govern the long-term evolution of the ice and ocean. Of particular importance is the fidelity of the barrier between ocean and atmosphere (or space). Can water or gas transit the icy shell? This raises a variety of questions regarding melting and freezing, interphase density difference, thermal contraction, tidal flexure, fracture, porous flow, and even convection of partially molten ice. The project student will work in this space, selecting a specific research

pathway based on interests and a careful assessment of the literature and the state of the field.

## Methodology

The project will be conducted using theoretical and computational tools to quantify physical hypotheses, assess their plausibility and potentially observable consequences, and make testable predictions. The use of advanced-model AI will be welcome, but the student will develop a detailed understanding of all the physics, mathematics and numerical methods involved. This methodology makes the project suitable for candidates with a background in applied mathematics, theoretical physics, or engineering mathematics.

## Timeline

**Year 1:** Skills courses, literature review, mini-projects and planning. Attendance at a summer school or workshop.

**Years 2 and 3:** Research progress through intensive development of theory, computation, and analysis of results. Attendance at one international and one national conference. Development of manuscripts.

**Year 4:** Final project, travel as required, and intensive writing.

## Training & Skills

- Theoretical tools for planetary geophysics
- Computational methods for solving and analysing problems numerically
- Responsible and ethical use of AI
- Making and presenting a scientific talk/poster
- Writing a scientific paper
- Teaching/mentoring undergraduates and Masters students

## References & Further Reading


- Snowball Earth climate dynamics and Cryogenian geology-geobiology, *Science* paper.
- Science Case for Studying Icy Worlds, UK whitepaper.
- A Potential Mushy Source for the Geysers of Enceladus and Other Icy Satellites, *GRL paper*.


## Further Information


Contact: Profs. Richard Katz (richard.katz@earth.ox.ac.uk) and Andrew Wells (andrew.wells@physics.ox.ac.uk).