# EARTHSCIENCES

# Tidal dissipation, magmatism and mantle convection on lo

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Key words:	Planetary science, fluid mechanics, convection
Research theme(s):	Geophysics and Geodynamics
	<ul> <li>Planetary Evolution and Materials</li> </ul>
Eligible courses for this	DPhil in Earth Sciences
project:	

This project is suitable for applicants with a training in physics, planetary or geophysics, applied mathematics, theoretical and applied mechanics, engineering and geophysical fluid dynamics. The student could become part of either the Earth Science or Mathematics departments.

#### Overview

Intense magmatism and volcanism in Jupiter's moon lo is driven by tidal heating. Magmatic segregation from the mantle and heat-piping across the crust exports the tidal heat to space, maintaining a thermal equilibrium. This magmatic transport will tend to stratify lo's mantle, with refractory, Mg-rich olivine in a deep layer and fertile, Fe-rich minerals in a shallow layer. The compositional and thermal density structure of this stratification are both unstable and so convection is expected. The character and consequences of this convection are unknown. Unlike most convective systems, this one is partially molten, and its mass and energy transport may be dominated by magmatic segregation.



Figure: schematic figure showing lo's surface, tidal deformation, melt segregation, heat-piping to volcanoes, eruption and planetary resurfacing (see ref. 1, below).

This project aims to develop general theory and models of mantle convection in internally heated, partially molten planets. It aims to understand how heat transport mechanisms

control the evolution of such planets. The main application will be to Io, but there is broad potential for application to the early Earth and tidally heated (exo)planets.

## Methodology

The theory will be based on two-phase flow of partially molten rock, where the solid (rock) and liquid (magma) phases are modelled as viscous fluids.

The project will use a variety of modelling techniques, giving the student an opportunity to expand their skills in key mathematical areas. Numerical simulations will provide time-dependent solutions to the nonlinear partial differential equations. These simulations will be developed by considering a series of related problems of increasing physical/mathematical complexity. At some point in this series, the models will require high-performance computing.

The results of the numerical modelling will give insight into the key governing physics, which will enable the student to design and solve simplified problems, such as by linearised stability analysis. These may be analytical or semi-analytical. They will provide a more robust and transparent demonstration of the key controls. This will be complemented by scaling analysis.

All parts of the modelling will aim to generate testable predictions. These will be compared with existing observations if available, or help motivate and shape future observations through collaborations with scientists on planetary missions.

#### Timeline

**Year 1**: Intensive training in discretisation of PDEs and numerical model development using PETSc. Literature survey and synthesis. Project refinement and planning.

**Years 2 and 3**: Analysis of numerical simulations. Training in mathematical tools for simplified analysis as appropriate to background. Research and writing about model results.

Year 4: Focus on predictions and data comparisons. Thesis writing.

#### **Training & Skills**

The student will take a graduate-level course in scientific computing, and may follow other courses in mathematics, planetary physics or Earth science as appropriate. Attendance at a fluid dynamics summer school is expected, depending on availability.

The student will also learn through weekly project meetings with the supervisors. A key focus will be on scientific writing and illustration for publication.

Other courses on professional skills are available through the University. Attendance is encouraged.

# **References & Further Reading**

Spencer, D. C., Katz, R. F., & Hewitt, I. J. (2020). Magmatic intrusions control lo's crustal thickness. Journal of Geophysical Research: Planets, e2020JE006443.



Spencer, D. C., Katz, R. F., Hewitt, I. J., May, D. A., & Keszthelyi, L. P. (2020). Compositional layering in Io driven by magmatic segregation and volcanism. Journal of Geophysical Research: Planets, e2020JE006604.

Hernlund, J. W., Tackley, P. J., & Stevenson, D. J. (2008). Buoyant melting instabilities beneath extending lithosphere: 1. Numerical models. Journal of Geophysical Research: Solid Earth, 113(B4).

## **Further Information**

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