Iron snow in planetary cores

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Research theme(s):	• Geophysics and Geodynamics • Planetary Evolution and Materials
Eligible courses for this project:	• MSc by Research in Earth Sciences (2-3 years) • DPhil in Earth Sciences (3-4 years) • Interdisciplinary Life and Environmental Science Landscape Award (ILESLA) • Intelligent Earth (UKRI CDT)

Overview

The separation of silicate rocks from liquid iron alloys to form the mantles and cores of planets and planetesimals was a key phase in the early evolution of the solar system. Since then the liquid metallic cores left at the centre of planetary bodies including the Earth have cooled and, in at least some cases, begun to solidify. This process of solidification could include the formation of “iron snow” where solid iron particles form within the liquid core and sink towards the centre of the planet. On Earth, this is believed to result in the formation of the “F-layer” just above the inner core boundary, while on Mars and Ganymede the iron snow is believed to form at the top of the core and remelt as the solid falls deeper into the interior. In all cases the existence and behaviour of a snow layer will have dramatic consequences for the evolution of the planet. We have recently developed the first model of iron snow that captures the physics of the processes of formation, growth and falling of solid particles

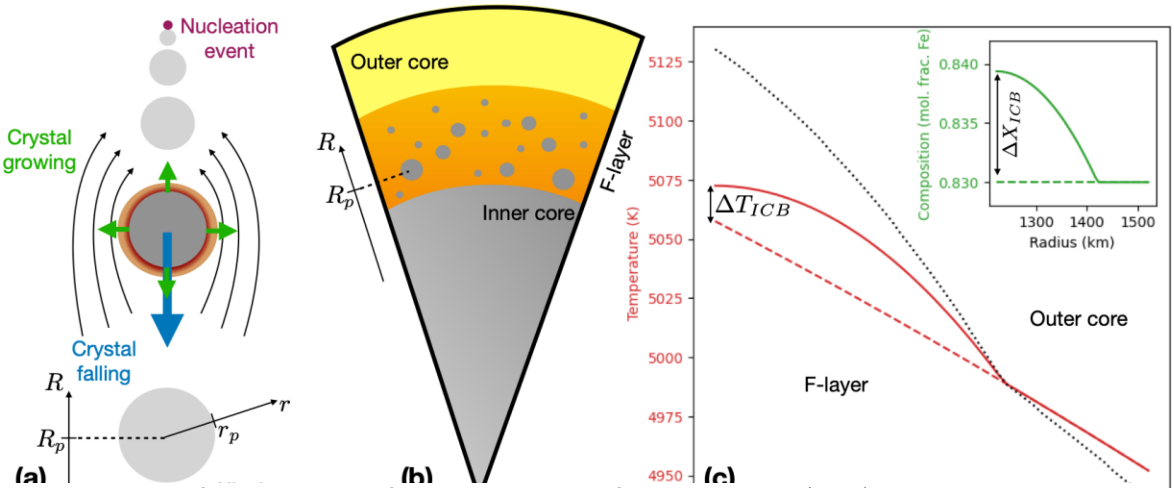

Figure 1 outline of the model setup for the Earth’s F-layer from Walker et al. (2025). The model is built to represent the micro-physics of single iron particles (a) which are combined to give a model of a snow layer (b). Key summary properties of the model are shown in (c).

(Walker et al. 2025; Figure 1). However, the application of this model has been limited and there are many avenues for further research. It is the further application and development of our model that will form the starting point for research in this project.

Methodology

Our existing approach is to combine a thermodynamic model for an Fe-O alloy under core conditions with models of the nucleation, growth and falling of individual isolated iron particles (Figure 1a). Many models of these isolated particles are then combined to create a statistical view of the snow layer (Figure 1b). The approach is currently designed to focus on the F-layer in Earth's inner core, assumes an iron-oxygen composition, and takes composition and temperature as input parameters (Figure 1c). This leaves a number of areas ripe for methodological development and deciding which of these to take forward will form an integral part of your doctoral study. Potential approaches include:

- Application of the existing approach to smaller bodies where crystallisation is expected in the shallow part of the core and remelting occurs at depth. In this way the existing model of Earth's F-layer could be applied to bodies like Ganymede (e.g. Rückriemen, et al. 2015). The key technical challenge would be the inclusion of the melting process in a realistic manner.
- Extension of the underlying thermodynamic model to other relevant compositions including carbon (Komabayashi et al. 2024), silicon (Komabayashi 2020) or sulphur (Thompson et al. 2022). Another option would be to model the thermodynamics of a H_2O-NaCl mixture that would be directly relevant to comparison with experiments.
- Improvement of the description of the dynamics of boundary layers around falling iron crystals. Currently this is based on scaling laws from state of the art simulations of isolated particles (Inman et al. 2020). However, in these models the particle does not change size as it falls and numerical simulations of this process would be invaluable in testing and improving the current approach.
- Develop methods to balance the heat and light element production in the slurry layer with the heat and light element transport through and out of the layer. This is challenging because the falling crystals cause motion in the surrounding fluid and this contributes to the transport of heat and light elements. However, a 1D continuum model has recently been developed (Wilczyński et al. 2023) and it is anticipated that this could be used as the basis for this work. The key product from such a method would be knowledge of the slurry layer temperature and composition, something that can be compared with geophysical observation.

Timeline

Year 1: Review the literature around snow zones in planetary cores, identification of key research questions and development of a research plan. Completion of an initial shorter project (e.g. extend the thermodynamic model or implement crystal remelting). Bespoke training in chosen methods.

Years 2 and 3: Undertake a major strand of research (e.g. boundary layer dynamics or development of model capable of generating temperature and composition). Generation of the majority of the results.

Year 4: Data integration, thesis completion, papers for international journals/conference presentation.

Training & Skills

You are likely to develop skills in the development and use of numerical models of various types. These could include cutting edge methods in fluid mechanics, thermodynamics and/or machine learning. You will become expert in the development of scientific software representing physical models as well as developing a deep knowledge of planetary cores.

References & Further Reading

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Further Information

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