Quantum materials at the interface of mobile electrons and frustrated magnetism studied using high magnetic fields

Project supervisor: Dr Paul Goddard*

In magnetically frustrated materials it is not possible to satisfy all magnetic interactions simultaneously. They are the subject of a great deal of current research, because they may be home to a so-called quantum spin liquid. Here, the magnetic moments find themselves in a disordered, but still interacting liquid state and can display long-range quantum entanglement, exotic fractional excitations and a profound response to external stimuli. The majority of frustrated magnetic materials are insulators. However, it is well established that the interplay of localised magnetic moments and mobile electrons can give rise to unexpected and potentially useful behaviours. In this context, the rare-earth (RE) pyrochlore iridates $RE_2Ir_2O_7$ have emerged as an extremely promising family of materials, on account of their magnetic frustration and highly correlated conduction electrons. They also host electronic band structures with topologically interesting features; another area of active research, usually separate from frustrated magnetism. This family of quantum materials are therefore a treasure trove of fascinating new physics waiting to be investigated.

We have recently formed a collaboration with sample growth experts at the University of Oxford and theorists at the University of Cambridge, and as a result have access to some of the only single-crystal samples of the rare-earth pyrochlore iridates. This, combined with the powerful combination of systematic experimental measurements and theoretical simulations & analysis has allowed us to make some recent breakthrough regarding the interactions between the electrons, spins and excitations in these materials [1, 2]. We now plan to open up the study to more materials and to use very high fields and different theoretical techniques to deepen our understanding of these uniquely correlated systems. The potential for discovery of properties of fundamental and functional significance is high.

Applied magnetic field is an exceptionally useful tool for investigating quantum materials. The field is continuous, reversible and directional, and couples directly to charge carriers, superconducting pairs or spins, providing information on the nature, anisotropy and strength of the interactions present in the system. The stronger the interactions present, the higher the field required to understand them and in some cases successful experiments will require a visit to facilities that provide the highest available fields in the world (45 T for steady fields and 100 T for pulsed fields) such as the European Magnetic Field Laboratory, or the National High Magnetic Field Laboratory in the US.

By investigating this emerging class of quantum material, we hope to push our understanding of the interplay between frustrated magnetism and mobile electrons beyond the current limits and open a route for exploiting the untapped potential of these materials to underpin future technologies.

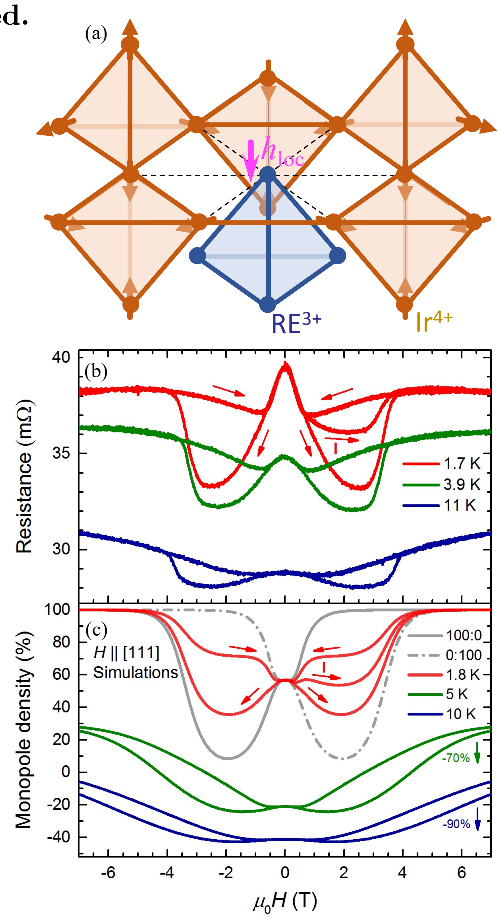

Figure 1: (a) Rare-earth pyrochlore iridates host two interlocking magnetic sublattices of corner-sharing tetrahedra and can harbour a unique combination of frustrated moments, exotic excitations and highly correlated electrons. Comparison of measured magnetoresistance (b) and theoretical simulations of the density of magnetic monopoles (c) highlights a hitherto unidentified scattering mechanism linking monopoles and mobile electrons [1].

[1] M. J. Pearce *et al.* Nature Communications 13, 444 (2022).
[2] M. J. Coak *et al.* arXiv:2210.05641 (2022).

*For further information please contact p.goddard@warwick.ac.uk.