### Controlling exotic magnetic order and frustration in 2D materials

*Joint programme between the Institut Laue Langevin (ILL) research nuclear reactor, Grenoble and the University of Birmingham. Experimental low-temperature physics focussed on lab-based crystal synthesis & characterisation followed by neutron scattering experiments to study the details of magnetic structures in exotic new 2D materials.*

2D materials are the future. Graphene was just the beginning, and the possibilities before us now are endless. Our group aims to identify new unstudied new 2D materials, synthesise them and understand the full range of their properties.

This project is a joint studentship with Dr Andrew Wildes at the ILL, head of the newly-upgraded D007 beamline and Dr Matthew Coak, University of Birmingham Condensed Matter Physics Group, as part of the ILL's competitive PhD studentships scheme. As a full resident employee of the ILL for half of the project duration you will receive a generous full staff salary, enjoy being part of a cohesive cohort of joint ILL students from across Europe with regular social and development events, and experience living in a cosmopolitan city at the foot of the French Alps. This scheme will allow you to build your research direction and establish a network of contacts and collaborators across Europe and is an excellent springboard into a career in neutron scattering or beyond.

The range of experience you will gain from this project will give you flexibility and independence in a future research career, whether within the academic system or outside. You will gain experience in laboratory skills, planning and running projects and experiments, hands-on design and manufacture of components, advanced data analysis and programming skills. You will work as part of a cohesive friendly team and as a part of the wider condensed matter group here at Birmingham and in Grenoble, with a close-knit structure and ongoing exposure to other groups and ideas.

This project aims to investigate the fundamentals of quantum magnetism in the (*Transition-Metal*)$PS_3$ family of 2D crystals. The programme will be to:

- Grow a series of compounds of carefully-controlled chemical composition in our 2-zone furnaces.
- Characterize each with in-house X-ray, magnetisation and electrical conductivity measurements at cryogenic temperatures, in Birmingham.
- Measure their magnetic structure at the ILL research nuclear reactor in the South of France.
- Work with the rest of the D007 team on testing, commissioning and optimising this cutting-edge new neutron instrument, including demonstrating new sample environments such as ultra-high-pressure cells.
- Analyse complex data to unpack the microscopic details of the magnetism, and model the resulting configurations and their dynamics.

One focus is on the series $V_{1-x}PS_3$ ($0 \le x \le 0.33$), which has valence state and vacancy mixing due to the V deficiency. These materials have barely been investigated despite their great promise in nanodevices, and their magnetism remains a mystery. Exotic magnetic states may exist, and are predicted for this S=3/2 state on a honeycomb lattice. As well as these intrinsic compounds, we will engineer magnetically frustrated lattices by mixing the metal atoms on the 2D honeycomb lattice – for instance a 50:50 mix of Fe and Co atoms in $Fe_{0.5}Co_{0.5}PS_3$ will have half its spins wanting to order along the axis pointing out of the crystal planes (Fe) and half within the plane (Co). We have shown in previous projects of this kind that this leads to fascinating new magnetic states such as spin glasses or spin liquids, or potentially magnetic textures like skyrmions, as there is no one simple ground state that the system can easily adopt. The full phase diagram of $Fe_{(x)}Co_{(1-x)}PS_3$ is sure to be rich with new fundamental physics.

Please email Dr Matt Coak at m.j.coak@bham.ac.uk or Dr Andrew Wildes at wildes@ill.fr with any enquiries or to arrange an informal discussion. This project is fully funded for UK or international students.

*The School of Physics and Astronomy at the University of Birmingham is an Institute of Physics Juno Champion since 2014 and holder of the Athena SWAN Silver Award. Both initiatives recognise the School's commitment to promote diversity and equality, and to encourage better practice for all members of the community, whilst also working towards developing an equitable working culture in which all students and staff can achieve their full potential. We welcome applications from all qualified applicants, and encourage applications from traditionally under-represented groups in physics and astronomy including, but not limited to, women and Black, Asian and Minority Ethnic.*