Contribution ID: **4** Type: **Poster**

Incommensurate and multi-q magnetic misfit structure in the frustrated quantum spin ladder material antlerite, Cu3SO4(OH)4

Tuesday, 21 March 2023 16:00 (2 hours)

In frustrated magnetic systems, the competition amongst interactions can introduce extremely high degeneracy and prevent the system from readily selecting a unique ground state. In such cases, the magnetic order is often exquisitely sensitive to the balance among the interactions, allowing tuning among novel magnetically ordered phases. We present antlerite, $Cu_3SO_4(OH)_4$, as a potential platform for tuning frustration. In this naturally occurring mineral, Cu^{2+} ($S = 1/2$) quantum spins populate three-leg zigzag ladders in a highly frustrated quasi-one-dimensional structural motif with coupled ferro- and antiferromagnetic spin chains. Contrary to previous reports, the low-temperature magnetic state of its three-leg zigzag ladders is a quasi-one-dimensional analog of the magnetic state recently proposed to exhibit spinon-magnon mixing in botallackite. Density functional theory calculations indicate that antlerite's magnetic ground state is exquisitely sensitive to fine details of the atomic positions, with each chain independently on the cusp of a phase transition, indicating an excellent potential for tunability [1]. In addition to its low-temperature commensurate phase with ferro- and antiferromagnetic order on the outer and inner legs of the ladders, this mineral also hosts an incommensurate helical+cycloidal state, an idle-spin state, and a multiple-**q** phase which is the magnetic analog of misfit crystal structures [2]. The antiferromagnetic order on the central leg is reentrant. The high tunability of the magnetism in antlerite makes it a particularly promising platform for pursuing exotic magnetic order and spin excitations.

[1] A. A. Kulbakov *et al.*, Phys. Rev. B **106**, L020405 (2022).
[2] A. A. Kulbakov *et al.*, arXiv:2207.05606 (submitted).

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Session Classification: Poster session TUESDAY

Track Classification: Magnetism, Superconductivity, Topological Systems, Magnetic Thin Films an other electronic phenomena