PAUL SCHERRER INSTITUT

SCD Colloquium

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Quantum Magnetic Materials In and Out of Equilibrium

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Quantum magnetic materials provide clean realisations of highly entangled quantum many-body systems on truly macroscopic lengthscales. The complex spin commutation relations and the richness of possible magnetic and multipolar order parameters make quantum magnets the most promising platforms for investigating the rich physics both of entanglement and of topology in different spaces. In the course of the past decade, major advances in numerical methods have begun to provide unparalleled new insight into quantum spin systems, while major advances in experimental capabilities, particularly using intense and pulsed light sources, offer to realise predictions and spring new surprises. This colloquium provides an overview of three areas of research in modern quantum magnetism.

First, the core business of quantum matter is finding new phases and excitations. The gapless, or algebraic, spin liquid has become a ubiquitous feature in theoretical models of quantum magnetism, but remains a major challenge to observe unambiguously. Measurements on the candidate Kitaev material α-$RuCl_3$ revealed both field-induced gapless modes and gapless spin excitations, indicating a new type of "proximate Kitaev" physics. Variational Monte Carlo studies in the spinon basis find a novel class of multinode algebraic quantum spin-liquid phase at zero field, with a hierarchy of new field-induced topological states, that provide an entirely new paradigm for a quantum magnetic ground state and excitation spectrum.

Second, the quantum phase transitions separating different quantum many-body states exhibit discrete classes of universal critical behaviour. Fully frustrated quantum antiferromagnetic models possess unusual bound-state excitations that lead to anomalous thermodynamic properties, including first-order quantum phase transitions that persist to finite temperatures before terminating at a thermal critical point. New capabilities in finite-temperature tensor-network methods provide a quantitative account of this physics in the phase diagram of the material $SrCu_2(BO_3)_2$ (SCBO), as revealed by specific-heat measurements under pressure and applied magnetic field. Further NMR experiments point to the possibility of observing a deconfined quantum critical point in SCBO.

Third, quantum magnets present a natural candidate for creating out-of-equilibrium many-body phenomena with intense, pulsed and coherent light. Magnetophononics, the modulation of magnetic interactions by driven infrared-active lattice excitations, is emerging as a key mechanism for such ultrafast dynamical control. The alternating $S = ½$ chain provides an example illustrating the use of linear magnetophononic driving to create nonequilibrium steady states (NESS) with driven excitations and designer spectra. However, strong spin-phonon coupling also causes a giant self-blocking, a counterintuitive feedback effect whereby the spin system damps the driven phonon, and this may complicate the search for these types of novel physics in $CuGeO_3$. Nonlinear magnetophononic driving solves the problem of coupling the spin and phonon energy scales, and has been used to excite the anomalously low-lying two-triplon bound state in SCBO.

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