Experimental report

08/04/2026

Proposal: **5-41-1193** **Council:** 10/2022

Title: Probing the quantum phase transitions in the triangular-lattice antiferromagnet Na2BaCo(PO4)2

Research area: Physics

This proposal is a new proposal

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Samples: NBCPO
EuAgAs

Instrument	Requested days	Allocated days	From	To
ORIENTEXPRESS	1	1	26/06/2023	27/06/2023
D23	8	8	26/06/2023	04/07/2023

Abstract:

S = 1/2 triangular-lattice antiferromagnet (TLAF) provides a fertile ground for unconventional quantum phases and phase transitions.Introducing an easy-axis spin exchange anisotropy to the TLAF results in the spin supersolid in zero magnetic field, while applying a magnetic field along the easy-axis drives the system through a sequence of quantum phase transitions by which the spin supersolidity disappears and then reemerges.Recently, the compound Na2BaCo(PO4)2 (NBCPO) with an ideal triangular lattice of Co2+ ions has caught much attention. It is theoretically found that the spin Hamiltonian of NBCPO can be well described by an easy-axis XXZ-type Heisenberg model. According to the established model, the NBCPO hosts a spin supersolid state. When the field is applied along the c axis, it will undergo successively the Y, Up-Up-Down, V, and the polarized phases with increasing field. The Y and V phase spontaneously break both the lattice translation symmetry and the spin rotational U(1) symmetry, thereby constituting the supersolid state. We propose to study the field-induced magnetic order and to check the spin supersolidity scenario in NBCPO by single-crystal neutron diffraction.

Probing the quantum phase transitions in the triangular-lattice antiferromagnet $Na_2BaCo(PO_4)_2$

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Abstract: Triangular lattice antiferromagnets (TLAFs) are highly frustrated quantum spin systems and promising hosts for exotic quantum spin states, including the quantum magnetic analogue of the long-sought supersoild state, namely, spin supersolid, in which both the lattice translational and spin rotational symmetries are broken simultaneously. We performed single-crystal neutron diffraction experiments on $Na_2BaCo(PO_4)_2$ (NBCP), a spin supersolid candidate, using the thermal-neutron two-axis diffractometer D23, to provide microscopic evidences for the coexistence of solid and superfluid spin orderings.

NBCP, a novel TLAF with T_N ~ 150 mK, is an ideal material realization of the spin-1/2 easy-axis XXZ model, for which two spin supersolid states are expected in a magnetic field applied along the *c* axis. Using high-quality single crystals of NBCP, we measured the temperature variation upon changing magnetic field in an adiabatic demagnetization process, which reveals a giant magnetocaloric effect with the lowest cooling temperature of 94 mK. Two low-temperature valley-like regimes with pronounced spin fluctuations are revealed (Figure 1), which agrees well with the theoretically calculated two spin supersolid phases for $B<B_{c1}$ and $B_{c2}<B<B_{c3}$.

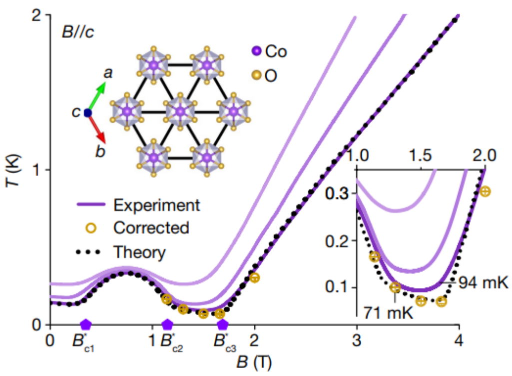

Fig. 1: Measured and calculated adiabatic cooling curves of NBCP from an initial temperature $T_0 = 2$ K and various initial fields $B_0 = 3$, 3.5 and 4 T.

To search for microscopic evidences for the spin supersolid states in NBCP, we further conducted single-crystal neutron diffraction measurements at D23. Reciprocal-space scans at 95 mK under applied fields along the *c* axis are presented in Fig. 2a, which shows a significant change in the ordering vector at the transition fields. In the regime $B<B_{c1}$ and $B_{c2}<B<B_{c3}$, the ordering vector locates at (1/3, 1/3, q_c) with an incommensurate out-of-plane q_c, whereas the system shows commensurate ordering for $B_{c1}<B<B_{c2}$. Fig. 2b shows the diffraction intensities at (1/3, 1/3, 0.836), (1/3, 1/3, 1)

and (1/3, 1/3, 0.664) as functions of the applied field, which show great similarities with the density matrix renormalization group (DMRG) calculations shown in Fig. 2d. In the supersolid phases, intertwined spin solid and superfluid orders coexist, while in the UUD phase, only a solid order is present. By comparing experiments with DMRG calculations, we identify that (1/3, 1/3, 0.836) and (1/3, 1/3, 0.664) correspond to the Y and V spin supersolid states (the observed incommensurate q_c can be attributed to the sensitivity of spin supersolid states to weak interlayer couplings), respectively, whereas the (1/3, 1/3, 1) reflection corresponds to the gapped UUD solid order. Fig. 2c shows the temperature dependences of the representative magnetic reflections. A maximal moment is estimated to be roughly 0.59 and 1.74 μ_B at 95 mK for B = 0 and 0.8 T, respectively. These findings support the coexistence of magnetic ordering and strong fluctuations in the spin supersolid phases.

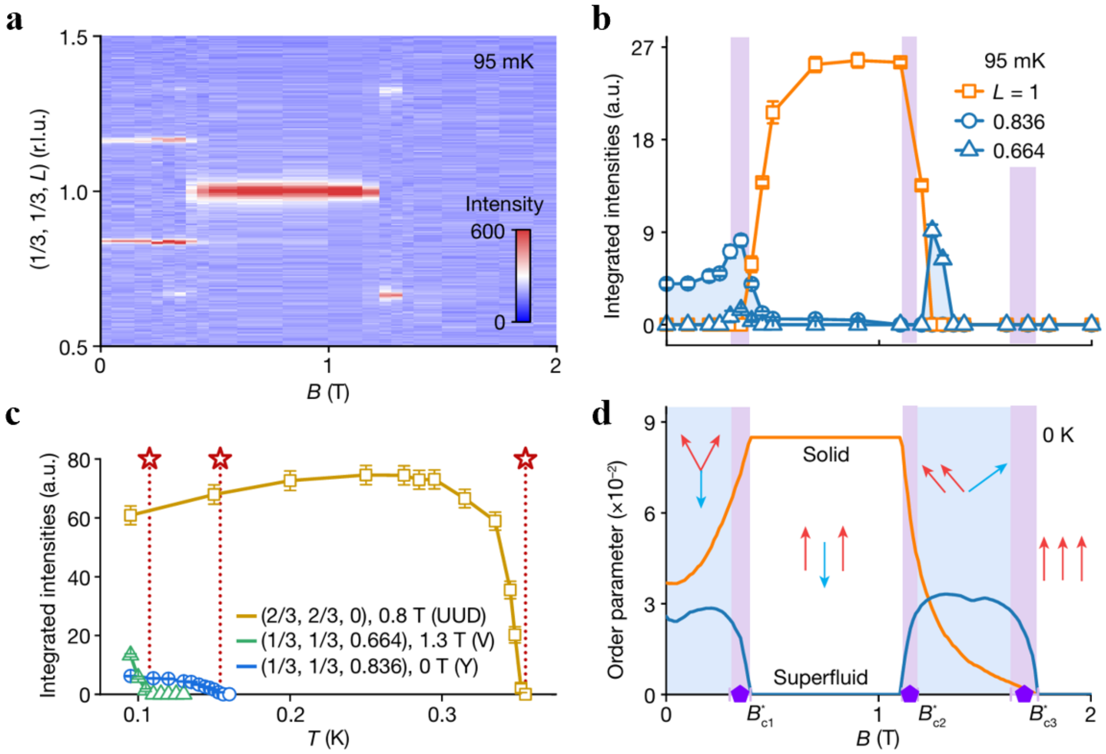

Fig. 2: Neutron diffraction data collected at D23 including the reciprocal-space scans at 95 mK under different fields applied along the *c* axis (a), field and temperature dependences of representative magnetic reflections (b, c), and the comparison with ground-state DMRG calculations (d).

These results indicate that a spin supersolid state has been identified in a real-world quantum magnet for the first time. In addition, the giant magnetocaloric effect of NBCP associated with the strong quantum spin fluctuations in the spin supersolid states makes it a very promising quantum material coolant for sub-Kelvin refrigeration.

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