Magnetic Excitation in the Hyperkagome Antiferromagnet Mn_3RhSi

Low- and high-energy inelastic neutron scattering measurements of a hyperkagome antiferromagnet revealed little magnetic specific heat capacity contribution in the enhanced electronic specific heat γ term.

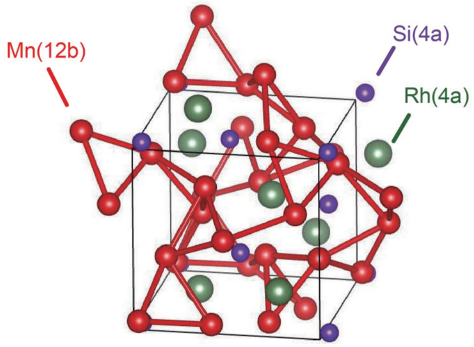

Fig. 1: Mn_3RhSi cubic crystal structure with a lattice parameter of a = 6.467 Å at 293 K. The red bond network is a hyperkagome lattice of the Mn site (12b), where the Mn–Mn bond distance ranges from 2.66 to 2.76 Å. [Reproduced from Ref. 3]

The hyperkagome antiferromagnetic semimetal Mn_3RhSi lacks spatial inversion symmetry in its β-Mn-type crystal structure (**Fig. 1**). The material exhibits intriguing magnetic behavior in which magnetic diffuse scattering due to magnetic short-range order is observed in the paramagnetic state up to 720 K, approximately 500 K higher than its Néel temperature of 190 K. The hyperkagome lattice is also found in well-studied β-Mn, which is a known spin liquid candidate and is a heavy Fermion 3*d* material with an electronic specific heat coefficient (γ) of about 70 mJ/MnK^2.[1] In ordered β-Mn-type alloys, a quantum critical behavior is observed in the enhanced γ term.[2] Here, the team of Shin-ichi Shamoto (Comprehensive Research Organization for Science and Society, Japan) studied the magnetic excitation of Mn_3RhSi by low- and high-energy inelastic neutron scattering measurements to elucidate the magnetic contribution to the enhanced γ term. Their research results provided the fluctuating magnetic moment size and the magnetic specific heat capacity at low temperatures for Mn_3RhSi.

In this study, the team measured a 1.65 g Mn_3RhSi single crystal and observed one magnon mode up to the maximum energy, as shown in **Fig. 2**. The observed intensity in **Fig. 3(a)** revealed that the magnitude of the magnetic moment of Mn $3d^5$ was approximately 5 μ_B and is almost localized. The magnetic moment of the long-range order state below the Néel point was only 2.6 μ_B at 4 K,[4] indicating that most of the magnetic moment fluctuates without being ordered. This fluctuation is thought to be due to the geometrical spin frustration of the hyperkagome lattice. Interestingly, by using a magnetic moment of 2.6 μ_B and the Néel temperature (190 K), the effective exchange interaction can be estimated, yielding a predicted transition temperature of 700 K from the magnetic moment of 5 μ_B based on classical mean field approximation theory. The predicted temperature is very close to the temperature of the magnetic short-range order temperature 720 K mentioned above. The ability to measure low- and high-energy spin fluctuations even with a small crystal has allowed us to better understand mysterious magnetic materials.

Figure 3(b) shows the magnon dispersion of the low-energy mode in Mn_3RhSi. The solid line is fit using the equation $E = E_{top} \sin^{\alpha}(\pi h)$, where the best fit was obtained with E_{top} = 39.5(3) meV and α = 0.53(3). The peculiar dispersion leads to the magnon specific heat capacity of $C_{mag} = dU/dT \propto (T/E_{top})^{3/\alpha}$. As for the electronic specific heat coefficient γ of Mn_3RhSi, the magnon heat capacity becomes small at low temperatures because of the large exponent of $\sim(T/E_{top})^6$, resulting in little magnon effect on the *T*-linear electronic specific heat. The team confirmed that the magnon dispersion continues to the low-energy region below 1 meV at **SIKA** without an appreciable spin gap. The combination of the low- and high-energy inelastic

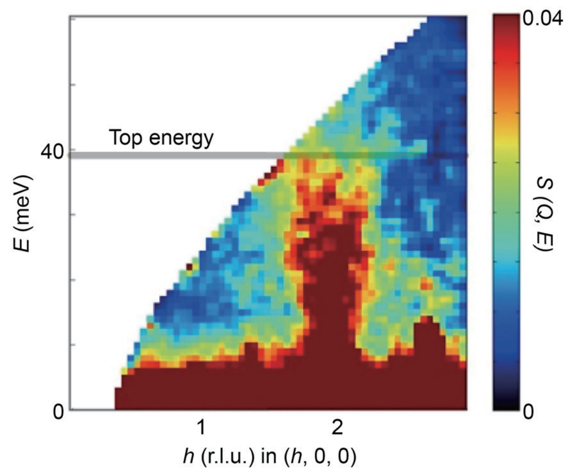

Fig. 2: Dynamical structure factor divided by the Bose factor $(Q, E)/\{n(E) + 1\}$ in the low-Q region measured with E_i = 95 meV. The single-crystal scattering intensity at T = 6 K is averaged vertically in the range of $-0.2 < k < 0.2$ and $-0.2 < l < 0.2$ (r.l.u.). The horizontal scattering plane is [h, 0, 0]-[0, k, k]. The top energy of the low-energy magnon mode is shown by a solid line. [Reproduced from Ref. 3]

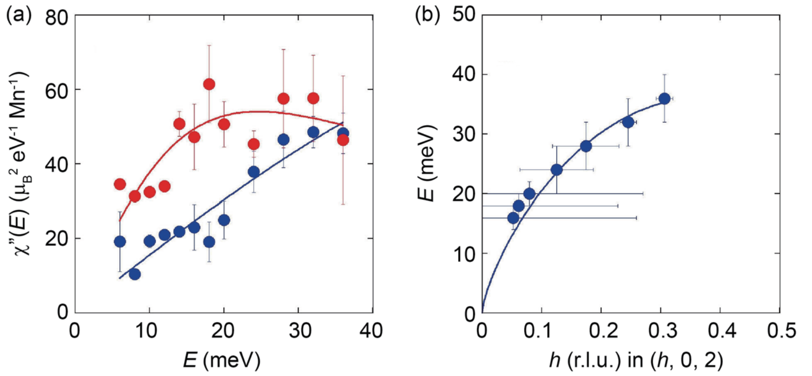

Fig. 3: (a) The dynamical spin susceptibilities are plotted as a function of energy at T = 6 K (blue open circles) and 200 K (red closed circles). (b) Magnon dispersion observed at T = 6 K. Solid lines are used to aid with visual inspection. [Reproduced from Ref. 3]

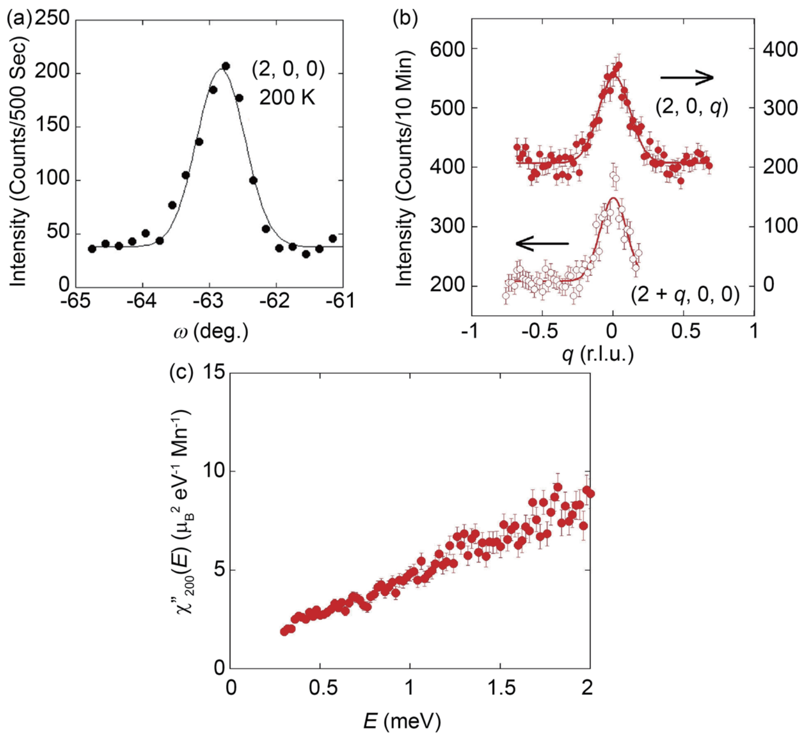

Fig. 4: (a) ω-scan at (2, 0, 0) of the Mn_3RhSi crystal. (b) The constant-energy q-scan in (2 + q, 0, 0) (open circles) and (2, 0, q) (closed circles) of E = 1 meV at T = 200 K. The horizontal scattering plane is [h, 0, 0]-[0, 0, l]. (c) Low-energy Q-integrated local dynamical spin susceptibility $\chi_{200}(E)$ at Q = (2, 0, 0) measured at T = 200 K. [Reproduced from Ref. 3]

neutron scattering measurements of a hyperkagome antiferromagnet revealed how magnetic excitation can contribute to the magnetic specific heat capacity in the enhanced electronic specific heat γ term. (Reported by Shin-ichi Shamoto, Comprehensive Research Organization for Science and Society, Japan)

This report features the work of Shin-ichi Shamoto and his collaborators published in Phys. Rev. Research ***6****, 033303 (2024).*

ANSTO SIKA – Cold Neutron Triple-axis Spectrometer

- Neutron Inelastic Scattering
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