Emergent Bound States and Impurity Pairs in Chemically Doped Shastry-Sutherland System

Shi, Z., Steinhardt, W. (Duke, Physics), Graf, D. (NHMFL, FSU), Corboz, P. (Univ. of Amsterdam), Weickert, F. (NHMFL, FSU), Harrison, N., Jaime, M. (NHMFL, LANL), Marjerrison, C. (Duke, Physics), Dabkowska, H. (McMaster Univ.), Mila, F. (EPFL), Haravifard, S. (Duke, Physics, MEMS)

Introduction

Geometrical frustration in low-dimensional quantum spin systems often leads to exotic states of matter, where new physics emerge. However, understanding of these systems is often hindered by the complex Hamiltonians. $SrCu_2(BO_3)_2$ (SCBO), a realization of the exactly-solvable Shastry-Sutherland (SSL) model, provides an important testing ground for our understanding of quantum magnetism and its relationship to superconductivity [1]. The system is expected to become superconducting upon chemical doping, though so far no clear evidence of superconductivity has been found in experiments. Therefore, understanding the effect of doping in the SSL system is urgently needed.

Experimental

We have studied high quality single crystals of $SrCu_{(2-x)}Mg_x(BO_3)_2$ (x = 0.02, 0.03, 0.05) using four complementary magnetometry techniques in high magnetic fields, revealing a surprisingly rich phenomenology of the impurity configurations in these systems [2]. The results are confirmed by our numerical simulations using infinite projected entangled pair states, which gives a detailed description of the various of the emergent impurity bound states [2].

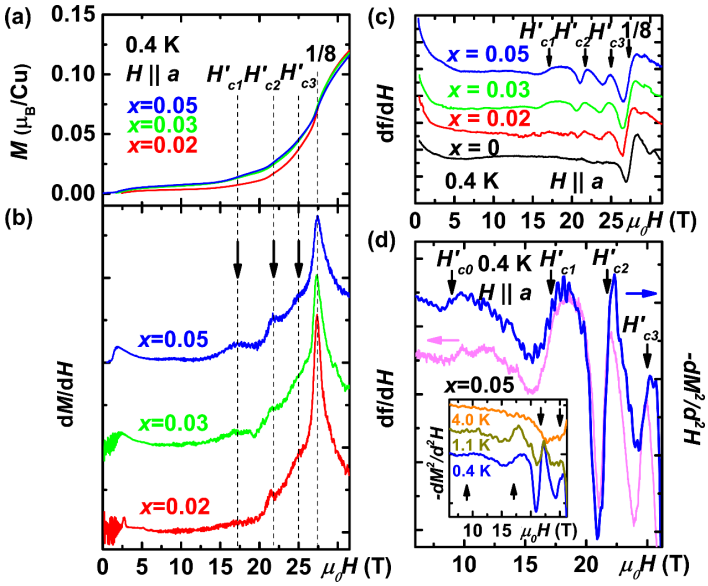

Figure 1: Emergence of magnetization anomalies below the 1/8 plateau with *H* || *a* axis, at *T* = 0.4 K [2]. Field dependence of **a**, *M* and **b**, *dM*/*dH*, for three doping levels *x* = 0.02,0.03, and 0.05. H'_{C1}, H'_{C2}, and H'_{C3} and the corresponding dashed lines indicate three of the additional anomalies below the 1/8 plateau. **c**, The first derivative of the TDO frequency shift, *df*/*dH*, as a function of applied field for *x* = 0,0.02,0.03, and 0.05. **d**, A zoomed-in plot of *df*/*dH* (left axis) and $-dM^2/d^2H$ (right axis) vs. $\mu_0 H$ for the x = 0.05 sample, shows an additional broad anomaly at a lower field H'_{C0}. Inset: $-dM^2/d^2H$ vs. $\mu_0 H$ for a few selective temperatures. Traces in (**b**), (**c**), and inset of (**d**) are shifted for clarity.

Results and Discussion

Figure 1 shows the magnetization curves as function of *x* for the low-field region. The results clearly show that three low-field anomalies, H'_{C1}, H'_{C2}, and H'_{C3} are enhanced with higher doping, while the 1/8 plateau is suppressed. The TDO measurements performed in a DC magnetic field confirms the emergence of the H'_{C1}, H'_{C2}, and H'_{C3} anomalies with doping, and their absence in the pure system. Another broad anomaly at $H'_{C0} \sim 9$ T, which is much weaker than its higher field counterparts, is only observed for the highest doping concentration *x* = 0.05 sample. Our iPEPS simulations have revealed that the H'_{C2}, and H'_{C3} anomalies are stabilized by the interaction between the doped impurities and triplets and bound states of triplets, while the H'_{C0}, and H'_{C1} anomalies are results of various configurations of impurity pairs.

Conclusions

Our results provide a clear description of the magnetization process for $SrCu_{(2-x)}Mg_x(BO_3)_2$, revealing a rich impurity-induced phenomenology, suggesting that even for samples with a Mg-doping as low as 1% ~ 2.5%, a single-impurity description is not, and interactions between the impurities and triplets must be considered.

Acknowledgements

A portion of this work was performed at the National High Magnetic Field Laboratory, which is supported by National Science Foundation Cooperative Agreement No. DMR1157490 and DMR-1644779, the State of Florida and the U.S. Department of Energy.

References

[1] Haravifard, S., *et al., Nat. Commun.* 7, 11956 (2016).
[2] Shi, Z., *et al.,* under review at *Nat. Commun.*