Gapless spin-liquid ground state in the $S=1/2$ kagome antiferromagnet

Subject Code: A04

Frustrated quantum magnets have developed into one of the hottest topics in condensed matter physics because of the wide range of novel physical phenomena they exhibit, which includes quantum spin-liquid states, fractionalized spin degrees of freedom, and exotic topological properties. This trend is reinforced strongly by the continuing discovery and refinement of quantum magnetic materials, which closely realize the most challenging models in the field. The "kagome conundrum," finding the ground state of the nearest-neighbor $S=1/2$ antiferromagnetic Heisenberg model on the kagome lattice (KHAF, represented in Fig. 2), has been pushed to the frontier of frustrated magnetism not only by the unresolved theoretical and numerical challenges it poses but also by continuing progress in analyzing the material herbertsmithite.

Now, with the support of the National Natural Science Foundation of China, a collaborative study led by Prof. Xiang Tao (向涛) from the Institute of Physics, Chinese Academy of Sciences, and Prof. Bruce Normand from Paul Scherrer Institute, Switzerland has demonstrated that the ground state of the KHAF is a gapless spin liquid. This result was published in *PRL* (2017, 118: 137202) and was selected to be a *PRL* Editors' Suggestion. It was accompanied on the "Physics" website of the American Physical Society (APS) by a "Viewpoint" article, "Closing in on the Kagome Magnet," by Prof. Bryan Clark from the University of Illinois, to introduce the context and importance of this work for the non-specialist reader. In May 2017, this research was cited as one of the 5 Editors' Choice papers in the APS News monthly newspaper that is mailed to all APS members.

Prof. Xiang and collaborators have been working for a decade on developing tensor renormalization group (TRG) techniques to solve quantum many-body problems, and have achieved significant progress. In 2014 they introduced the PESS tensor-network wave function for frustrated systems. The method works on an infinite system and the accuracy of such a state is improved by increasing the tensor bond dimension, D. The team's new breakthrough is a novel tensor contraction scheme that allowed them in essence to double the maximum accessible D from 13 to 25. As shown in Figure, this is important not only for its intrinsic precision but for enabling a far more accurate extrapolation towards infinite D, where the result is exact. One key indication of a gapless state is the way in which the ground-state energy, E_0 (Fig. (a)), converges as a function of D: exponential convergence corresponds to a gapped state, whereas the researchers' demonstration of algebraic convergence confirms a gapless quantum spin liquid (QSL). To establish that the gapless QSL is a robust state, the team added a further interaction to the model (J_2, shown in green in the insets of Fig. (b)), and showed that the QSL of the KHAF exists over a finite range of this parameter before being driven into a magnetically ordered state. Thus after many years of doubt and difficulty interpreting finite-system results, the TRG-PESS technique has delivered the most accurate and convincing result yet for the KHAF, and it establishes a new gapless paradigm for the nature of the QSL.

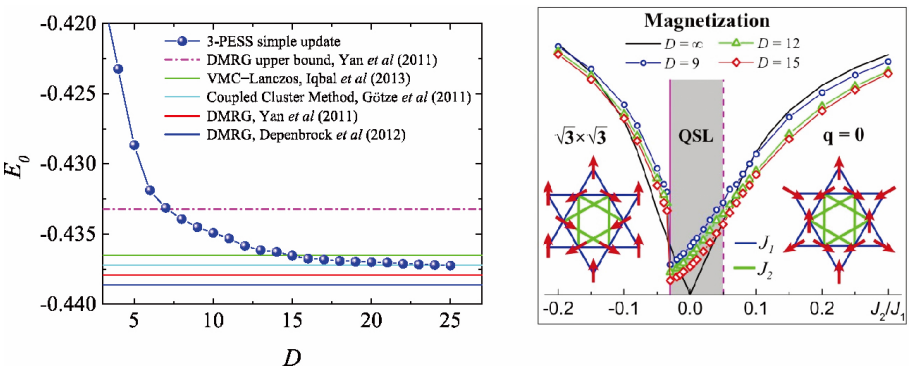

Figure (a) The ground state E_0 as a function of D; (b) the phase diagram of J_1-J_2 KHAF.

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