TT 15: Focus Session: Spectroscopy of Quantum Spin Liquids

The search for quantum spin liquids is a central endeavor in condensed matter and materials physics. It is motivated by their unusual nature, as they represent new phases of matter exhibiting topological forms of order not captured in the standard Landau-Ginzburg-Wilson picture, which includes fractionalized excitations and topologically protected edge modes. This session covers the central advances in the study of spin liquids over the last couple of years.

Organizers: Roderich Moessner and Frank Pollmann (MPI-PKS Dresden)

Time: Monday 15:00–17:45 Location: H20

Invited Talk TT 15.1 Mon 15:00 H20
Thermodynamics of Fractional Quantum Spin Liquids — •Yukitoshi Motome — University of Tokyo, Tokyo, Japan

After the proposal by P. W. Anderson in 1973, the quantum spin liquid (QSL) has attracted continuous interest as a new quantum state of matter. Although several candidate materials have been synthesized, it remains elusive to prove that their low-temperature state is a QSL, mainly because of the lack of order parameters that are experimentally accessible. On the other hand, one of the salient features of QSLs is the fractionalization of quantum spins. In this contribution, we theoretically show that the fractionalized spins manifest themselves in the finite-temperature properties, in particular, in the paramagnetic state as a precursor of QSL. We address this issue in the Kitaev model and its extensions, in which the quantum spin fractionalizes into two types of Majorana fermions in the QSL ground state. By using the newly-developed quantum Monte Carlo technique in the Majorana fermion representation, we find that many experimentally-accessible quantities experience the fractionalization in their temperature dependences. We also show that, in some cases, the fractionalization causes exotic phase transitions between the three states of matter in magnets: solid (long-range ordered state), gas (paramagnet), and liquid (QSL). Our findings will be helpful as "smoking gun" experiments for QSLs.

This work has been done in collaboration with J. Nasu, M. Udagawa, Y. Kamiya, and Y. Kato.

References at www.motome-lab.t.u-tokyo.ac.jp/publication-e.html.

Invited Talk TT 15.2 Mon 15:30 H20
Proximate Kitaev quantum spin liquid behavior in α-$RuCl_3$ — •Stephen Nagler — Quantum Condensed Matter Division, Oak Ridge National Laboratory

The magnetic semiconductor α-$RuCl_3$ is composed of very weakly coupled honeycomb layers of edge-sharing $RuCl_6$ octahedra. The Ru^{3+} ion has 5d electrons in a low spin state, and the system is expected to have an effective $J = 1/2$ single ion ground state with an interacting spin Hamiltonian containing Kitaev-like terms. Inelastic neutron scattering on powders and single crystals has been used to determine the energy scale of the magnetic interactions and the overall form of the magnetic fluctuations. The results indicate that the Kitaev term is significant. Moreover, detailed measurements of the response show evidence for the fractionalized excitations that are characteristic of the Kitaev Quantum Spin-liquid.

Research using ORNL neutron scattering facilities is supported by the US Department of Energy, Division of Scientific User Facilities.

Invited Talk TT 15.3 Mon 16:00 H20
Kagome chiral spin liquid and symmetry protected topological phases — •Yin-Chen He — Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Straße 38, 01187, Dresden, Germany

In my talk I will introduce the chiral spin liquid phase that occurs in kagome antiferromagnets and discuss its physical origin as a gauged U(1) SPT phase. I will first present our numerical (DMRG) study on the kagome XXZ spin model that exhibits two distinct spin liquid phases, namely the chiral spin liquid and the kagome spin liquid (the groundstate of the nearest neighbor kagome Heisenberg model). Both phases extend from the extreme easy-axis limit, through SU(2) symmetric point, to the pure easy-plane limit. The two phases are separated by a continuous phase transition. Motivated by these numerical results, I will then focus on the easy-axis kagome spin system, and reformulate it as a lattice gauge model. Such formulation enables us to achieve a controlled theoretical description for the spin liquid phase. We then show that the chiral spin liquid is indeed a gauged U(1) symmetry protected topological (SPT) phase.

[1] Yin-Chen He, S. Bhattacharjee, F. Pollmann, and R. Moessner, arXiv:1509.03070
[2] Yin-Chen He, S. Bhattacharjee, R. Moessner, and Frank Pollmann, PRL **115**, 116803 (2015)
[3] Yin-Chen He and Yan Chen, PRL **114**, 037201 (2015).
[4] Yin-Chen He, D. N. Sheng and Y. Chen, PRL **112**, 137202 (2014).

15 min. break

Invited Talk TT 15.4 Mon 16:45 H20
Three-dimensional Kitaev spin liquids — •Maria Hermanns, Kevin O'Brien, Achim Rosch, and Simon Trebst — Institute for Theoretical Physics, Cologne, Germany

The Kitaev honeycomb model has become one of the archetypal examples of topological phases of matter. Being one of the few highly frustrated spin models that are exactly solvable, it has shaped our understanding of quantum spin liquid phases in general.

In this talk, we discuss the rich physics arising in generalizations of the Kitaev model to three-dimensional lattice structures. These models have low-energy degrees of freedom that are Majorana fermions, and that in general form metallic states. Depending on the underlying lattice structure, these can be (almost) conventional metals with a Majorana Fermi surface or Dirac semi-metals, where the gapless modes form Fermi lines or even Weyl nodes. The resulting quantum spin liquids differ not only in their experimental signatures, but also in their response to perturbations, such as an external magnetic field or additional interactions.

Invited Talk TT 15.5 Mon 17:15 H20
Landau levels of Majorana fermions in a spin liquid — •Matthias Vojta — Technische Universität Dresden, Germany

Majorana fermions, originally proposed as elementary particles acting as their own antiparticles, can be realized in condensed-matter systems as emergent quasiparticles, a situation often accompanied by topological order. Here we propose a physical system which realizes Landau levels - highly degenerate single-particle states usually resulting from an orbital magnetic field acting on charged particles - for Majorana fermions. This is achieved in a variant of a quantum spin system due to Kitaev which is distorted by triaxial strain. This strained Kitaev model displays a spin-liquid phase with charge-neutral Majorana-fermion excitations whose spectrum corresponds to that of Landau levels, here arising from a tailored pseudo-magnetic field. We show that measuring the dynamic spin susceptibility reveals the Landau-level structure by a remarkable mechanism of probe-induced bound-state formation.