TT 87: Frustrated Magnets: Spin Liquids

Time: Friday 9:30–13:15 Location: H 3010

TT 87.1 Fri 9:30 H 3010

Electrical transport probes of quantum spin liquids — •Raffaele Mazzilli[1], Alex Levchenko[2], and Elio J. König[1] — [1]Max-Planck-Institut für Festkörperforschung, 70569 Stuttgart, Germany — [2]Department of Physics, University of Wisconsin-Madison, Madison, Wisconsin 53706, USA

Quantum spin liquids are an exotic phase of matter characterized by the presence of fractionalized excitation(spinons) and emergent gauge fields. One of the difficulties in probing experimentally a QSL phase comes from the fact that the spinons do not carry an electric charge, ruling out the possibility of using conventional electrical probes. Going beyond conventional transport, we propose two setups of electric probes to characterize a QSL phase. First, we analyze a setup in which a QSL layer is interposed between two metallic layers. In this setup, we apply a current in the first metallic layer and measure the induced voltage on the second one. The momentum transfer is affected by the non-trivial behavior of momentum-carrying spinons and results in a response that will potentially be helpful for the future characterization of candidate QSL materials. The second probe we propose is an STM experiment on a Kondo lattice in which the local moments have non-trivial dynamics (hence forming a QSL phase). We provide the STM response in each of the phase configurations of this system allowing also for the possibility for the conduction electrons and for the spinons to form a superconducting phase. This last setup might find a concrete realization in materials such as TaS_2, $TaSe_2$, and $NbSe_2$ in the 1T, 2H, and 4Hb crystallographic phases.

TT 87.2 Fri 9:45 H 3010

Modifying Quantum Spin Liquid Candidate $NaYbS_2$ — •Rajib Sarkar[1], Ellen Häussler[3], Hubertus Luetjens[2], Christopher Baines[2], Thomas Hicken[2], Thomas Doert[3], and Hans Henning Klauss[1] — [1]Institute of Solid State and Materials Physics, TU Dresden, D-01062 Dresden, Germany — [2]Laboratory for Muon Spin Spectroscopy, PSI, Villigen, Switzerland — [3]Faculty of Chemistry and Food Chemistry, TU Dresden, D-01062 Dresden, Germany

$NaYbS_2$ is a candidate material for a pseudo-$S = 1/2$ based quantum spin liquid on the ideal triangular lattice. Single crystals of the solid solution series $NaYb_{1-x}Lu_xS_2$ could be synthesized over the entire substitution range $0 < x < 1$. The chemical and structural analysis of this series reveals the statistically homogeneous replacement of Yb^{3+} by Lu^{3+} ions. Long-range magnetic order has not been detected in magnetic susceptibility measurements at any x down to 2 K. This suggests $NaYb_{1-x}Lu_xS_2$ as a family of diluted triangular-lattice spin liquids. We started investigating this series at specific doping concentrations by means of zero field (ZF) and longitudinal field (LF) μSR experiments to test for the presence of static magnetism and to investigate the nature of the magnetic ground state.

TT 87.3 Fri 10:00 H 3010

Low-temperature spin state in an organic spin-liquid candidate κ-(BEDT-TTF)$_2$Cu$_2$(CN)$_3$ investigated by magnetization measurements — •Eria Imada[1,2], Yosuke Matsumoto[2], Pal Sudip[3], Naoki Yoneyama[4], Martin Dressel[3], Takahiko Sasaki[5], Kazushi Kanoda[1,2,3], and Hidenori Takagi[1,2,3] — [1]The University of Tokyo, Tokyo, Japan — [2]Max-Planck-Institute, Stuttgart, Germany — [3]University of Stuttgart, Stuttgart, Germany — [4]Yamanashi University, Kofu, Japan — [5]Tohoku University, Sendai, Japan

The ground state of the organic quantum spin liquid candidate, κ-(BEDT-TTF)$_2$Cu$_2$(CN)$_3$, is under debate. We report our detailed DC magnetization M measurements. $M(T)$ on cooling shows a rapid decrease with a clear kink at 6K but an appreciable residual contribution, nearly liner in magnetic field up to 7 T, remains even at 2 K. We discuss possible origin of the low temperature residual contribution.

TT 87.4 Fri 10:15 H 3010

Kondo screening in Kitaev spin liquids with a Fermi surface — •Michel M. J. Miranda[1,2] and Matthias Vojta[1] — [1]Institut für Theoretische Physik and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, 01062 Dresden, Germany — [2]Max-Planck-Institut für Chemische Physik fester Stoffe, Nöthnitzer Straße 40, 01187 Dresden, Germany

Isolated magnetic impurities can be used to probe the low-energy properties of a host system, with the standard Kondo effect in metals being the paradigmatic example. Magnetic impurities have also been discussed as probes of quantum spin liquids and their excitations, and various approximate theoretical treatments have been put forward. In particular, it has been suggested that a spin liquid with a spinon Fermi surface would lead to Kondo screening akin to that in normal metals. Here we study this problem for a particular Kitaev model with a Majorana Fermi surface, realized on the square-octagon lattice. We present a numerically exact solution using Wilson's Numerical Renormalization Group (NRG) which generalizes previous work for the honeycomb-lattice Kitaev model. Our numerical data for the renormalization-group flow and for thermodynamic observables highlight important differences between the Kitaev system and a metal, related to the fractionalization scheme and the influence of the emergent gauge field.

TT 87.5 Fri 10:30 H 3010

2-Form U(1) Spin Liquids: Classical Model and Quantum Aspects — •Kristian Chung[1] and Michel Gingras[2] — [1]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Strasse 38, D-01187 Dresden, Germany — [2]Department of Physics and Astronomy, University of Waterloo, Ontario, N2L 3G1, Canada

In this talk I introduce the concept of 2-form U(1) spin liquids, described by emergent 2-form U(1) gauge fields and supporting fractionalized string excitations. I introduce a frustrated Ising model on the pyrochlore lattice dubbed the "spin vorticity model", constructed to enforce a microscopic zero-curl constraint. I demonstrate that the ground state manifold is a classical spin liquid, with algebraically decaying correlations and an extensive ground state entropy. Each ground state may be decomposed into a collection of closed 2-dimensional membranes, and spin-flips fractionalize into strings attached to open membranes. The emergent gauge structure of this spin liquid is given by the theory of 2-form electrodynamics, which describes 1-dimensional charged strings coupled to a rank-2 anti-symmetric gauge field. Perturbing the classical model with quantum exchange interactions results in an effective "membrane exchange" model of the quantum dynamics, which maps to a strongly-coupled frustrated 2-form U(1) lattice gauge theory. The string excitations are captured by coupling a 1-form string field to the 2-form U(1) gauge field, thus mapping a quantum spin model to a 2-form U(1) gauge-Higgs model. I discuss the possibility of realizing a novel class of quantum phases of matter: 2-form U(1) quantum spin liquids.

TT 87.6 Fri 10:45 H 3010

Spectral Functions in $S = \frac{1}{2}$ Antiferromagnetic Heisenberg Models on the Triangular Lattice — •Markus Drescher[1], Laurens Vanderstraeten[2], Roderich Moessner[3], and Frank Pollmann[1,4] — [1]Department of Physics, Technische Universität München, 85748 Garching, Germany — [2]Center for Nonlinear Phenomena and Complex Systems, Université Libre de Bruxelles, 1050 Brussels, Belgium — [3]Max-Planck-Institut für Physik komplexer Systeme, 01187 Dresden, Germany — [4]Munich Center for Quantum Science and Technology, 80799 Munich, Germany

We consider an extended spin-$\frac{1}{2}$ antiferromagnetic Heisenberg model on the triangular lattice with nearest- and next-nearest-neighbor interactions and an additional scalar chiral term that gives rise to a rich phase diagram comprising putative quantum spin-liquid phases alongside magnetically ordered states with a coplanar 120° order, stripe order and a noncoplanar tetrahedral order. Using large-scale matrix-product-state simulations, we obtain the spectral responses in distinct ordered and liquid regimes of the phase diagram and review our results in the light of analytical predictions such as mean-field theory and spin-wave calculations. We also discuss finite-size effects and the role of different cylinder geometries for the spectral function.

TT 87.7 Fri 11:00 H 3010

Disorder effects in spiral spin liquids: Long-range spin textures, Friedel-like oscillations, and spiral spin glasses — •Pedro Monteiro Cônsoli and Matthias Vojta — Technische Universität Dresden

Spiral spin liquids are correlated states of matter in which a frustrated magnetic system evades order by fluctuating between a set of (nearly) degenerate spin spirals. Here, we investigate the response of spiral spin liquids to quenched disorder in a J_1-J_2 honeycomb-lattice Heisenberg model. At the single-impurity level, we identify different order-by-quenched-disorder phenomena and analyze the ensuing spin textures. In particular, we show that the latter generally display Friedel-like oscillations, which encode direct information about the spiral contour, i.e., the classical ground-state manifold. At finite defect concentrations, we perform extensive numerical simulations and characterize the resulting phases at zero temperature. As a result, we find that the competition between incompatible order-by-quenched-disorder mechanisms can lead to spiral spin-glass states already at low to moderate disorder. Finally, we discuss extensions of our conclusions to nonzero temperatures and higher-dimensional systems, as well as their applications to experiments.

TT 87.8 Fri 11:15 H 3010

Dimensional reduction and incommensurate dynamic correlations in the spin-1/2 triangular lattice antiferromagnet $Ca_3ReO_5Cl_2$ — •S. A. Zvyagin[1], A. N. Ponomaryov[1], J. Wosnitza[1,2], D. Hirai[3], Z. Hiroi[3], M. Gen[3], Y. Kohama[3], A. Matsuo[3], Y. H. Matsuda[3], and K. Kindo[3] — [1]HZDR, Germany — [2]TU Dresden, Germany — [3]ISSP, Japan

The observation of spinon excitations in the spin-1/2 triangular antiferromagnet $Ca_3ReO_5Cl_2$ reveals a quasi-one-dimensional (1D) nature of magnetic correlations, in spite of the nominally 2D magnetic structure. This phenomenon is known as frustration-induced dimensional reduction. Here, we present high-field electron spin resonance spectroscopy and magnetization studies of $Ca_3ReO_5Cl_2$, allowing us to refine spin-Hamiltonian parameters and to investigate peculiarities of its low-energy spin dynamics. We argue that the presence of the uniform Dzyaloshinskii-Moriya interaction (DMI) shifts the spinon continuum in momentum space and, as a result, opens a zero-field gap in the Brillouin zone center. The observed gap is found to be consistent with the structural modulation in the ordered state, suggesting this material as a perfect model triangular-lattice system, where a pure DMI-spiral ground state can be realized.

[1] S.A. Zvyagin et al., Nat. Commun. 13, 6310 (2022)

15 min. break

TT 87.9 Fri 11:45 H 3010

A novel classical spin-liquid with fractionalized bionic charges and chiral field excitations in the pyrochlore lattice — •Daniel Lozano-Gómez[1,2], Yasir Iqbal[3,4], and Matthias Vojta[1,2] — [1]Technische Universität Dresden, Dresden, Germany — [2]Institut für Theoretische Physik and Würzburg-Dresden Cluster of Excellence ct.qmat, Dresden, Germany — [3]Indian Institute of Technology-Madras, Chennai, India — [4]The Quantum Centers in Diamond and Emerging Materials, Chennai, India

Classical spin-liquid phases are generally described by emergent low-temperature gauge symmetries with fractionalized excitations and a system-size-dependent degeneracy of the ground-state manifold. In the study of spin-liquids, the pyrochlore lattice has demonstrated to be fruitful ground in the theoretical and experimental realization of such phases. Indeed, recent work on bilinear spin models in this lattice has identified a variety of classical and quantum spin-liquids whose most prominent examples are spin-ice, quantum spin-ice, higher-rank, and a 2-form spin-liquid. In contrast, much less attention has been devoted to spin models with interactions beyond bilinear spin terms realizing such highly correlated phases. In this work, we present a Hamiltonian composed of a three-body spin term that realizes a novel classical spin-liquid phase. We demonstrate that the ground-state manifold of this Hamiltonian is described by a subspace of the so-called color-ice-state manifold and that a gauge field theory describing the ground-state manifold possesses a chiral term that constraints the emergent gauge fields to follow a right-hand-rule.

TT 87.10 Fri 12:00 H 3010

Signatures of fractionalization in phonon spectral functions — •Josef Willsher[1,2], Urban F. P. Seifert[3], and Johannes Knolle[1,2,4] — [1]TU Munich, Germany — [2]MCQST, Germany — [3]Kavili Institute, Santa Barbara, USA — [4]Imperial College London, UK

A complicating factor in the realization and observation of gapless quantum spin liquids in materials is the ubiquitous presence of other degrees of freedom which may relieve geometric frustration, in particular phonons. We study the U(1) Dirac spin liquid and investigate how the coupling between spin-singlet monopoles and phonons manifests in the spectral properties of the phonons. We find that the critical gauge fluctuations of the algebraic spin liquid lead to a continuum of excitations in the phonon spectrum. A finite-temperature scaling Ansatz predicts a T-dependent Kohn-like anomaly of the phonon dispersion which could provide a universal signature of the Dirac spin liquid. This framework is able to recover the phenomenology of the recently described spin-Peierls instability of this system. We discuss the extension of these results to ultrasound attenuation experiments, as well as their applicability to other gapless spin liquids.

TT 87.11 Fri 12:15 H 3010

Spin-Peierls instability of deconfined quantum critical points — •David Hofmeier[1], Josef Willsher[1,2], Urban Seifert[3], and Johannes Knolle[1,2,4] — [1]TU Munich, Germany — [2]MCQST, Germany — [3]Kavli Institute, UCSB, USA — [4]Imperial College London, UK

Deconfined quantum critical points (DQCPs) are possible phase transitions beyond the Landau paradigm. The original example of a DQCP is the spin-1/2 quantum antiferromagnet on the square lattice which features a second order transition between valence bond solid (VBS) and Néel order. The VBS order breaks a lattice symmetry which should naturally lead to a coupling between phonons and the VBS order parameter. We investigate a field-theoretic description of the DQCP in the presence of a monopole-lattice coupling. We show that treating phonons as classical lattice distortions leads to a relevant monopole-phonon interaction inducing an instability towards the plaquette VBS phase. Consequently, there is a breakdown of the DQCP which generally becomes a first-order transition. Taking into account the full quantum nature of the phonons may alleviate this, where we argue that the DQCP persists above a critical phonon frequency. This work provides an extension of the spin-Peierls instability of algebraic spin liquid phases to a beyond-Landau phase transition, a fact we justify by close analogy with the 1D analogs of deconfined criticality. We discuss the implications of our findings to recent experiments on the Shastry–Sutherland lattice, and indeed argue that this spin-lattice coupling can be used to explain the observed plaquette order.

TT 87.12 Fri 12:30 H 3010

Higher-Order Susceptibilities in Extended Kitaev Models Computed Via Krylov-Space Based Methods — •Marius Möller[1], David Kaib[1], Wolfram Brenig[2], and Roser Valentí[1] — [1]Institute for Theoretical Physics, Goethe University Frankfurt, Max-von-Laue-Strasse 1, 60438 Frankfurt am Main, Germany — [2]Institute for Theoretical Physics, Technical University Braunschweig, 38106 Braunschweig, Germany

Higher Harmonic Generation phenomena and the underlying susceptibilities were recently proposed to potentially provide new insights into fractionalized excitations by showing clearer signatures than the rather featureless continua appearing in linear response. We investigate the possibility of calculating the higher order susceptibilities numerically from Exact Diagonalization Techniques, proposing a Krylov-space based algorithm applicable to various lattice models.

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TT 87.13 Fri 12:45 H 3010

Two-dimensional spectroscopy of quantum spin ice using Husimi cacti — •Mark Potts[1], Roderich Moessner[1], and Owen Benton[1,2] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]Queen Mary University of London, London, United Kingdom

Two-dimensional coherent spectroscopy (2DCS) is a non-linear optical technique that has attracted increasing interest in the search for clear signatures of fractionalisation in exotic quantum phases of matter. Quantum spin ice is an example of such a system, hosting fractionalised spinon excitations often referred to as magnetic monopoles.

We present work analysing the possible application of 2DCS to candidate quantum spin ices as a probe of their fractionalised excitations, in a regime with strong thermal excitation of the gauge field.

In this limit, monopole dynamics are heavily constrained, and can be modelled by effective hopping on dual Husimi cacti graphs. We predict that a sharp 2DCS response can be observed using probe fields with well-defined effective pseudo-momenta when mapped to the Husimi

cacti; a zero-momentum real-space probe field does not respect this condition, and so is predicted to produce a broad 2DCS signal despite the presence of fractionalised excitations. These results are supported by exact diagonalisation computations on a 32-site cluster.

TT 87.14 Fri 13:00 H 3010

Treating anyonic statistics within a full hypergraph decomposition — •Matthias Mühlhauser, Viktor Kott, and Kai Phillip Schmidt — Friedrich-Alexander-Universität Erlangen-Nürnberg

We describe how to execute a full hypergraph decomposition[1] to set up a linked-cluster expansion for the topological phase of Kitaev's Toric Code in a uniform magnetic field. An important challenge for such an expansion is to correctly incorporate the non-local anyonic braiding statistics into the calculations on the clusters. Indeed, the anyonic statistics lead to counter-intuitive effects like clusters which contribute to irreducible one-quasiparticle matrix elements despite hosting no excitation. We explain how to incorporate the non-local statistics within hypergraph expansions for perturbative series expansions of the one-charge gap, the one-flux gap, and the ground-state energy in the thermodynamic limit.

[1] Phys. Rev. E 105, 064110