TT 46: Frustrated Magnets: Spin Liquids

Time: Thursday 9:30–13:00 Location: HSZ 201

TT 46.1 Thu 9:30 HSZ 201

Magnetic and elastic properties of spin ice materials in high magnetic fields — •Nan Tang[1,2], Masaki Gen[3], Mingxuan Fu[2], Huiyuan Man[4], Akira Matsuo[5], Koichi Kindo[5], Akihiko Ikeda[5,6], Yasuhiro H. Matsuda[5], Kazuyuki Matsuhira[7], Yoshimitsu Kohama[5], and Satoru Nakatsuji[2,5] — [1]Experimental Physics VI, Center for Electronic Correlations and Magnetism, University of Augsburg, Augsburg, Germany — [2]Department of Physics, University of Tokyo, Tokyo, Japan — [3]Riken Center for Emergent Matter Science, Saitama, Japan — [4]Geballe Laboratory for Advanced Materials, Stanford University, California, U.S.A. — [5]ISSP, University of Tokyo, Chiba, Japan — [6]Department of Engineering Science, University of Electro-Communications, Tokyo, Japan — [7]Department of Engineering, Kyushu Institute of Technology, Fukuoka, Japan

Spin ice is a prototypical state of frustrated magnets, in which Ising spins form a short-range "2-in, 2-out" correlation instead of a long-range order due to geometrical frustrations of pyrochlore lattice. Local Ising anisotropy induced by the competition between crystal electric field (CEF) effect and magnetic interactions play important roles to stabilize such spin-ice correlations. Generally, frustrated magnets show characteristic magnetostrictive responses and in this study, we measured both magnetization and magnetostriction of classical spin ice $Ho_2Ti_2O_7$ and quantum spin ice $Pr_2Zr_2O_7$ under high magnetic fields to explore the regime beyond the Ising limit. In the talk, we will discuss the influences of CEF splitting and exchange-striction on the magnetostrictive responses in the two spin ice materials.

TT 46.2 Thu 9:45 HSZ 201

XMCD studies of honeycomb lattice compound $RuBr_3$ — •Sahana Roessler[1], X. Wang[1], S. Agrestini[2], Z. Hu[1], C. Guillemard[3], J. Herrero-Martin[3], U. Schwarz[1], M. W. Haverkort[4], and L. H. Tjeng[1] — [1]Max-Planck Institute for Chemical Physics of Solids, Dresden Germany — [2]Diamond Light Source, Oxfordshire, United Kingdom — [3]ALBA Synchrotron Light source, Barcelona, Spain — [4]Institute of theoretical physics, Heidelberg University, Germany.

The high-pressure phase of $RuBr_3$ consisting of a honeycomb lattice [1] is structurally essentially isotypic to the Kitaev quantum spin liquid candidate α-$RuCl_3$. As in α-$RuCl_3$, Ru^{3+} ion in $RuBr_3$ is in $4d^5$ electronic configuration and expected to be in a spin-orbit coupled $J_{\text{eff}} = 1/2$ doublet ground state. Here, we will present the results of X-ray magnetic circular dichroism (XMCD) measurements on $RuBr_3$ performed at the Ru $L_{2,3}$ absorption edges. The spin and orbital moments were determined using the sum rule analysis. In addition, the XMCD spectra were simulated using the full atomic-multiplet cluster calculations within the configuration interaction approach. By comparing the experimental spectra with the theoretical simulations, we determined the ratio of spin to orbital moments along with the values of the crystal field splitting and the spin-orbit coupling in $RuBr_3$. Our results indicated the $J_{\text{eff}} = 1/2$ ground state for $RuBr_3$, which is one of the requisites for the Kitaev quantum spin-liquid behavior. [1] Imai et al., Phys. Rev. B 105, L041112 (2022).

TT 46.3 Thu 10:00 HSZ 201

Structural transition in single crystals of Kagome compound $Y_3Cu_9(OH)_{19}Cl_8$ — •Katharina M. Zoch[1], Pascal Puphal[2], and Cornelius Krellner[1] — [1]Physikalisches Institut, Goethe-Universität Frankfurt, 60438 Frankfurt am Main, Germany — [2]Max-Planck-Institute for Solid State Research, 70569 Stuttgart, Germany

Kagome systems serve as the ideal candidates to obtain an experimental realization of a quantum spin liquid, a class of matter where the spins strongly fluctuate down to lowest temperatures, thus preventing order. $Y_3Cu_9(OH)_{19}Cl_8$ presents a distorted Kagome lattice with a rich magnetic phase diagram [1]. The improved synthesis of phase-pure single crystals crystals via an external gradient method lead to the evidence of subtle structural instabilities at 33 K and 13 K in thermodynamic measurements while preserving the magnetic model of the system. The compound shows a magnetic phase transition at 2.2 K with persistent spin dynamics below the ordered state in powder samples [2]. We present the single crystal growth as well as thermodynamic and magnetic measurements of this compound.

[1] M. Hering et al., npj Comput. Mater. 8, 10 (2022)
[2] Q. Barthelemy et al., Phys. Rev. Mater. 3, 074401 (2019)

TT 46.4 Thu 10:15 HSZ 201

Thermodynamics of the spin liquid candidate $KYbS_2$ — •Franziska Grussler[1], Sebastian Bachus[1], Noah Winterhalter-Stocker[1], Mamoun Hemmida[2], Hans-Albrecht Krug von Nidda[2], Yurii Skourski[3], Philipp Gegenwart[1], and Alexander Tsirlin[4] — [1]Experimental Physics VI, Center for Electronic Correlations and Magnetism, University of Augsburg — [2]Experimental Physics V, Center for Electronic Correlations and Magnetism, University of Augsburg — [3]High Magnetic Field Laboratory, Helmholtz-Zentrum Dresden-Rossendorf — [4]Felix Bloch Institute for Solid-State Physics, University of Leipzig

Triangular antiferromagnets with competing nearest-neighbor and next-nearest-neighbor interactions offer a promising playground for realizing quantum spin liquid behavior. However, detailed nature of this state and its manifestations in real materials remain heavily debated. Here, we show that a quantum disordered, potentially spin liquid state can be realized in the disorder-free triangular antiferromagnet $KYbS_2$ and report its temperature-field phase diagram using heat capacity, dilatometry, magnetocaloric and magnetization measurements down to below 0.1 K. The phase diagram reveals an additional phase between the up-up-down and putative spin liquid phases, so far not observed in other members of the same structural family. Following a systematic analysis of the nuclear contribution and its evolution in the applied field, we conclude that at zero field the magnetic specific heat shows quadratic behavior in the low-T limit in accordance with the expectations for a gapless Dirac spin liquid.

TT 46.5 Thu 10:30 HSZ 201

Anisotropic phonon-spin scattering in the quantum spin liquid canidate $NaYbS_2$ — •Matthias Gillig[1,2], Xiaochen Hong[1,3], Ellen Häussler[2], Philipp Schlender[2], Thomas Doert[2], Bernd Büchner[1,2], and Christian Hess[1,3] — [1]IFW Dresden — [2]TU Dresden — [3]Bergische Universität Wuppertal

A perfect triangular spin lattice and absence of long-range magnetic order down to $T = 260$ mK make the delafossite material $NaYbS_2$ a prime candidate to host a quantum spin liquid ground state. We present the results of heat transport experiments on $NaYbS_2$ in the low-temperature limit ($T < 1$ K), where the in-plane thermal conductivity κ_{ab} shows a peculiar temperature dependence mimicking a potential residual linear term that decays below 500 mK. Application of in-plane magnetic field drastically enhances the thermal conductivity until it saturates in the field polarized limit. This behavior hints at phonon dominated heat transport with very strong magnetic phonon scattering where magnetic field suppresses the phonon scattering off spin fluctuations and the phonon thermal conductivity recovers at high field. In the field-dependence of κ broad features appear that indicate possible field-induced phase transitions in the magnetic system. Within this framework no clear evidence for magnetic heat transport due to spin excitations is observed. The investigation of the anisotropy of κ reveals that the phonon-spin scattering is strongly anisotropic and the out-of-plane coupling of phonons to spin excitations is weakened.

TT 46.6 Thu 10:45 HSZ 201

Thermodynamics studies on RE_3BWO_9 (RE = Nd and Pr) spin-liquid candidate systems — •Ahmed Elghandour[1], P Khuntia[2], and Rüdiger Klingeler[1] — [1]Kirchhoff Institute for Physics, Heidelberg University, Heidelberg, Germany — [2]Department of Physics, IIT Madras, Chennai 600036, India

Boratotungstates exhibit a distorted Kagome structure of rare-earth ions (RE), thereby providing a platform to unveil the pure Kagome physics fully dominated by magnetic frustration of RE moments while avoiding the influence of conduction electrons. We report the thermodynamic properties of poly crystals of RE_3BWO_9 (RE = Nd and Pr) by means of means of DC magnetometry (0.4 - 350 K) and heat capacity studies (0.4 - 270 K). In Nd_3BWO_9, our dc magnetization and c_p data indicate a possible transition at $T = 1\ K$ while there is no evidence of long-range order at higher temperatures. This yields $\frac{\theta}{T_N} = 45$. Isotherm magnetization measured at $T = 400\ mK$, demonstrates saturation up to 7 T at half of the expected saturation magnetization, which we attribute to crystal-field effects. In addition, there are two low field anomalies at $\frac{1}{4}$ and $\frac{1}{8}$ of the theoretical saturation field. In contrast, Pr_3BWO_9 does not signal long-range order down to $T = 90$ mK [5] (i.e., $\frac{\theta}{T_N} > 300$) and M vs B only shows smooth right bending at $T = 400$ mK again with reduced saturation moment (0.8 μ_B/Pr at $B = 7$ T). The data are discussed in terms of an unconventional persistent fluctuating paramagnetic ground state as suggested by recent NMR data [1].

[1] Zeng et al., PRB 104, 155150 (2021)

TT 46.7 Thu 11:00 HSZ 201

Low temperature phase diagram of $PbCuTe_2O_6$ for magnetic fields B || (110) — •Paul Eibisch[1], Christian Thurn[1], Ulrich Tutsch[1], Arif Ata[1], Abanoub R. N. Hanna[2], A. T. M. Nazmul Islam[2], Shravani Chillal[2], Bella Lake[2], Bernd Wolf[1], and Michael Lang[1] — [1]PI Goethe-University Frankfurt — [2]HZ Berlin

The quantum-spin-liquid (QSL) state shows interesting phenomena such as fractional spin excitations and spin entanglement. Here we investigate the spin-liquid-candidate system $PbCuTe_2O_6$ where antiferromagnetic interactions among $s = 1/2$ spins lead to a 3D network of triangles similar to the hyper-Kagome lattice. While first experiments on polycrystalline samples, were found to be consistent with the QSL state [1], a recent study on single crystals showed a far more complex scenario including a ferroelectric transition at $T = 1$ K with strong lattice distortions and a quantum critical behaviour close to $B = 0$ T [2]. For the present study we combine thermodynamic, dielectric and magnetic experiments to investigate the field- and temperature phase diagram of $PbCuTe_2O_6$ for fields up to $B = 14.5$ T parallel to the [110] direction. In addition to the ferroelectric state we find a structurally distorted phase which coincides with the ferroelectric state at low fields but splits above $B = 6$ T as well as a long-range magnetically ordered phase for fields $B > 11$ T. Based on our experimental results we discuss how the elastic, dielectric and magnetic degrees of freedom are coupled.

[1] S. Chillal *et al.*, Nat. Commun. **11**, 2348 (2020)
[2] C. Thurn *et al.*, npj Quantum Materials 6:95 (2021)

15 min. break

TT 46.8 Thu 11:30 HSZ 201

Delafossite magnet $AgCrSe_2$: frustration, short range correlations, and field-tuned anisotropic order — •Michael Baenitz[1], S. Luther[2,3], M. Piva[1], J. Sichelschmidt[1], M. Nicklas[1], H. Zhang[1], B. Schmidt[1], H. Rosner[1], D. Khalyavin[4], P. Manuel[4], J. Wosnitza[2,3], H. Kuehne[2], and M. Schmidt[1] — [1]MPI for Chemical Physics of Solids, D-01187 Dresden, Germany — [2]Hochfeld-Magnetlabor Dresden (HLD-EMFL), Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany — [3]Institut für Festkörper- und Materialphysik, TU Dresden, 01062 Dresden Germany — [4]ISIS Neutron and Muon Source, Rutherford Appelton Laboratory, Chilton, Didcot OX11 OQX, United Kingdom

In contrast to Cr based oxy delafossites (DFs) with predominant antiferromagnetic (afm) nearest neighbor (nn) interaction in the Heisenberg triangular lattice, $AgCrSe_2$ as a non oxy DFs member is characterized by competing interactions (ferromagnetic nn- vs afm third neighbor interaction). Due to this, the magnetism, can be tuned by relatively small magnetic fields, allowing us to probe the H-T phase diagram in great detail. Large single crystals are grown by chemical vapor transport and studied by magnetization, specific heat, and thermal expansion and Cr-electron spin resonance and neutron diffraction as local probes. An anisotropic cycloidal ordering with unusual extended two-dimensional fluctuations is found [1]. The impact of antisymmetric interactions (Dzyaloshinskii-Moriya) due to the noncentrosymmetric polar space group (R3m) is discussed.

[1] M. Baenitz et al. PRB 104, 134410 (2021)

TT 46.9 Thu 11:45 HSZ 201

Dynamical signatures of symmetry broken and liquid phases in an $S = 1/2$ Heisenberg antiferromagnet on the triangular lattice — •Markus Drescher[1], Laurens Vanderstraeten[2], Roderich Moessner[3], and Frank Pollmann[1,4] — [1]TU München, 85748 Garching, Germany — [2]University of Ghent, 9000 Gent, Belgium — [3]Max-Planck-Institut für Physik komplexer Systeme, 01187 Dresden, Germany — [4]Munich Center for Quantum Science and Technology, 80799 Munich, Germany

We present the dynamical spin structure factor of the antiferromagnetic spin-$\frac{1}{2}$ $J_1 - J_2$ Heisenberg model on a triangular lattice obtained from large-scale matrix-product state simulations. The high frustration due to the combination of antiferromagnetic nearest and next-to-nearest neighbour interactions yields a rich phase diagram. We resolve the low-energy excitations both in the 120°-ordered phase and in the putative spin liquid phase at $J_2/J_1 = 0.125$. In the ordered phase, we observe an avoided decay of the lowest magnon-branch, demonstrating the robustness of this phenomenon in the presence of gapless excitations. Our findings in the spin-liquid phase chime with the field-theoretical predictions for a gapless Dirac spin liquid, in particular the picture of low-lying monopole excitations at the corners of the Brillouin zone. We comment on possible practical difficulties of distinguishing proximate liquid and solid phases based on the dynamical structure factor.

TT 46.10 Thu 12:00 HSZ 201

Generic interplay of magnetism and structural dimerization in pressured Kitaev materials — •Bin Shen[1], Franziska Breitner[1], Angel M. Arevalo-Lopez[2], Danil Prishchenko[3], Maximilian Seidler[1], Friedrich Freund[1], Anton Jesche[1], Philipp Gegenwart[1], and Alexander A. Tsirlin[1,4] — [1]EP VI, EKM, University of Augsburg, Germany — [2]University of Lille, France — [3]Yekaterinburg, Russia — [4]Felix Bloch Institute, University of Leipzig, Germany

Quantum spin liquids in the Kitaev honeycomb model feature quantum entanglement and exotic fractionalized spin excitations, thus attracting tremendous attention. However, experimental realization of Kitaev quantum spin liquid phases in real materials has been proven difficult due to the presence of competing interactions beyond Kitaev exchange. Almost all known structurally ordered Kitaev candidate materials host a magnetically ordered ground state. Suppression of the order by various tuning parameters is currently subject of extensive investigations. We explore the possibility of suppressing magnetic order by high-pressure magnetization measurements on several Kitaev materials under hydrostatic pressure and reveal a generic interplay of magnetism and structural dimerization: Upon applying hydrostatic pressure, structural dimerization emerges and becomes visible as step in the temperature dependence of the magnetic susceptibility that shifts to higher temperatures upon further compression. We also investigate how magnetic order disappears once dimerization emerges.

TT 46.11 Thu 12:15 HSZ 201

Variational States for the S=3/2 Kitaev spin liquids — •Willian Massashi Hisano Natori[1,2], Hui-Ke Jin[3], Frank Pollmann[3,4], and Johannes Knolle[2,3,4] — [1]Institut Laue-Langevin — [2]Imperial College London — [3]Technische Universität München — [4]Munich Center for Quantum Technology and Science

The lack of a mapping to free fermion models has for a long time prevented the analytical characterization of Kitaev spin liquids (KSLs) for general values of S. The most complicated of these spin liquids was the S=3/2 KSL, which defied both analytical and numerical techniques. This problem importance increased thanks to recent studies pointing out the relevance of Kitaev interactions on chromium-based van der Waals magnets.

We recently uncovered the ground state of the S=3/2 KHM perturbed by a single-ion anisotropy (SIA) using an SO(6) parton mean-field theory that displayed a remarkable quantitative agreement with DMRG simulations (Nat. Comm. 13, 3813). In this follow-up work, we uncover similarities between the S=3/2 KSL and the Majorana quantum spin-orbital liquids that emerge as ground states of exactly solvable Kugel-Khomskii models. We show that expectation values of several observables can be exactly calculated over a set of parton wavefunctions without Gutzwiller-projection, including the own KHM, quadrupolar parameters and correlation functions. The S=3/2 KSLs are then identified to the Gutzwiller projection of the state in this set minimizing the energy.

TT 46.12 Thu 12:30 HSZ 201

Linked-cluster expansions of perturbed topological phases — •Viktor Kott, Matthias Mühlhauser, and Kai Phillip Schmidt — FAU, Erlangen-Nürnberg, Deutschland

We investigate the robustness of Kitaev's toric code in a uniform magnetic field on the square and honeycomb lattice by perturbative linked cluster expansions using a full graph decomposition. In particular, the full graph decomposition allows to correctly take into account the non-trivial mutual exchange statistics of the elementary anyonic excitations. This allows us to calculate the ground-state energy and excitation energies of the topological phase which are then used to study the quantum phase transitions out of the topologically ordered phase as a function of the field direction.

TT 46.13 Thu 12:45 HSZ 201

Spin-Peierls instability of the U(1) Dirac spin liquid — •Josef Willsher[1], Urban Seifert[2], and Johannes Knolle[1,3,4] — [1]TU Munich, Germany — [2]Kavli Institute, University of California, Santa Barbara, USA — [3]MCQST, Munich, Germany — [4]Imperial College London, UK

Quantum spin liquids are tantalising phases of quantum matter, but experimental evidence of their existence has remained elusive. Recent theoretical and numerical studies have provided evidence that triangular-lattice Heisenberg magnets may host a U(1) Dirac spin liquid (DSL): a state of matter whose low-energy description is given by compact quantum electrodynamics in 2+1 dimensions coupled to four Dirac fermions, which is believed to flow to a strongly interacting conformal fixed point. Monopole operators constitute a strongly relevant perturbation to this fixed point, driving the spin liquid into magnetically ordered or VBS states, but are forbidden by the microscopic (UV) symmetries on the triangular lattice. However, in this work we show that a coupling between certain monopoles and phonons is symmetry-allowed and produces a 2+1-dimensional analog of the spin-Peierls instability for a spin liquid. We study monopole-phonon interactions within a conformal field theory framework and show that the DSL state is generically unstable to a static deformation, precipitating VBS ordering. Finally, we discuss implications for experimental realisations and signatures of the DSL in real 2D materials by addressing a full dynamical quantum model of phonons; here we predict a weak-coupling regime within which the spin-liquid phase remains stable.