# Quantum Spin Liquids 2025:

# Experimental Enigmas & Theoretical Challenges

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Abstract booklet

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# Monday, 6 October 2025

9:30 **From continuum excitations to sharp magnons in a triangular lattice antiferromagnet**
Speaker: Radu Coldea (University of Oxford, U.K.)

We report high-resolution inelastic neutron scattering measurements that observe the evolution of the spectrum as a function of transverse magnetic field in a disorder-free material realization of the Ising-like spin-1/2 triangular lattice antiferromagnet. We reveal how the excitation continuum in zero field transforms via an intermediate-field phase with broadened magnons into a spectrum of sharp magnons in the polarized phase at high field. We propose that the origin of the dominant continuum of excitations in zero field is related to the existence of a manifold of mean-field degenerate ground states and compare the experimental data with the expected spectrum of excitations in this case.

Leonie Woodland, Ryutaro Okuma, J. Ross Stewart, Christian Balz, and Radu Coldea http://arxiv.org/abs/2505.06398.

10:00 **Reentrant Quantum Spin Liquid Behavior in a Triangular-Lattice Antiferromagnet**
Speaker: Andrej Zorko (Jožef Stefan Institute, Ljubljana, Slovenia)

Our recent experimental investigations have discovered a novel family of rare-earth (RE) based triangular-lattice antiferromagnets, $RETa_7O_{19}$ [1, 2], which provide a versatile platform for exploring unconventional quantum phases such as quantum spin liquids (QSLs) and spin supersolids (SSSs). Initial studies identified the neodymium compound, NdTa7O19, as a promising QSL candidate, showing sizable Ising-like spin correlations between the nearest neighbors and persistent spin dynamic, but exhibiting no magnetic ordering even at temperatures much below the exchange-interaction scale in this compound [1].

The rich variety of magnetic anisotropies associated with different REs suggests diverse ground states across the $RETa_7O_{19}$ family. Our recent studies have, indeed, revealed markedly distinct behavior of $ErTa_7O_{19}$. Unlike $NdTa_7O_{19}$, it shows a long-range magnetic order below TN = 110 mK, with fingerprints of the enigmatic SSS state [3]. Strikingly, this ordered state destabilizes upon further cooling, giving way to a reentrant QSL phase characterized by short-range stripe-like spin correlations at a completely different wave vector. This unexpected QSL reentrance highlights the delicate interplay between exchange anisotropy and long-range dipolar interactions.

[1] T. Arh, B. Sana, M. Pregelj, P. Khuntia, Z. Jagličić, M. D. Le, P. K. Biswas, P. Manuel, L. Mangin-Thro, A. Ozarowski, and A. Zorko, Nat. Mater. 21, 416 (2022).
[2] L. Šibav, M. Lozinšek, Z. Jagličić, T. Arh, P. Khuntia, A. Zorko, and M. Dragomir, Cryst. Growth Des. 25, 4646 (2025).
[3] K. Jaksetič, A. Zorko, et al., manuscript in preparation.

11:00 **Spin Liquids and Supersolids in Anisotropic Triangular-Lattice Model**
Speaker: Alexander Chernyshev (University of California, Irvine, USA)

In a recent study [1] of a spin model with competing interactions on a triangular lattice--motivated by significant research in rare-earth and transition-metal compounds that exhibit strong quantum fluctuations and broad spin excitation continua, which are hallmarks of spin-liquid behavior--we provided compelling evidence for a robust spin-liquid phase that remains stable even in the presence of symmetry-breaking anisotropy. Remarkably, we also found that this state retains a higher symmetry than is apparent in the underlying model Hamiltonian, despite explicit symmetry breaking--an effect known as symmetry enrichment.
In the same work, we have also thoroughly mapped the phase diagram of the triangular-lattice antiferromagnet, incorporating realistic anisotropies relevant to actual materials. Among the phases identified is the so-called spin-supersolid, which uniquely combines two forms of order: a regular, patterned arrangement of the spins ("solidity") coexisting with their fluctuating component ("superfluid order"). Recent experiments have confirmed the existence of this unusual phase in real materials, revealing magnetic

behaviors that fall outside traditional frameworks. Our theoretical investigations have also resolved several puzzles surrounding the spin-supersolid, such as the complete lack of its net ferromagnetic moment for S=1/2 systems--a phenomenon that has puzzled both theorists and experimentalists.

[1] C. A. Gallegos, S. Jiang, S. R. White, and A. L. Chernyshev, Phase Diagram of the Easy-Axis Triangular-Lattice J1-J2 Model, Phys. Rev. Lett. 134, 196702 (2025).

11:30 **Exotic phases for spin-1/2 on the triangular lattice**
Speaker: Sylvain Capponi (University of Toulouse, France)

The triangular lattice is at the origin of magnetic frustration both for Ising or Heisenberg models, as shown by Wannier and Anderson respectively. Hence it is a natural testbed to stabilize unconventional phases of matter. In this talk, I will present two recent studies discussing
(i) the possibility of a Dirac spin liquid in the J1-J2 Heisenberg model [1]
(ii) the possibility of a supersolid phase in the XXZ model [2] and its relevance to recent scattering experiments on $K_2Co(SeO_3)_2$

[1] A. Wietek, S. Capponi, and A. Läuchli, Phys. Rev. X 14, 021010 (2024)
[2] S. Capponi and A. Läuchli, in preparation

12:00 **Dynamics of critical spin liquids**
Speaker: Johannes Knolle (Technische Universität Munich, Germany)

I will present latest results on the dynamical response of the quantum spin liquid phases of triangular lattice magnets.

14:00 **Coexisting Bond and Magnetic Frustration in $RCd_3P_3$ Triangular Lattice Antiferromagnets**
Speaker: Stephen Wilson (University of California, Santa Barbara, USA)

Hexagonal lattices with close connectivity can commonly form extended atomic networks of triangular, kagome, and honeycomb patterns, each capable of hosting a broad range of unconventional electronic states. Key examples are unusual states such as quantum disordered magnetic states or compact localized charge states that are stabilized via geometric magnetic or kinetic frustration. In certain scenarios, hexagonal networks can also realize structurally frustrated charge or bond order instabilities that impart lattice fluctuations capable of renormalizing electronic properties. In this talk, I will discuss our work searching for classes of materials where frustration can emerge in two separate sublattices within the same crystal structure, in particular magnetic and bond frustration. Specifically, I will discuss our recent work studying the $RCd_3P_3$ (R=La-Sm) family of compounds as an example of this coexistence.

14:30 **Field Tunable QSL with Finite Spinon Density of States in new delafossite $TlYbSe_2$**
Speaker: Arnab Banerjee (Purdue University, USA)

We introduce the rare-earth delafossite compound $TlYbSe_2$ extending the search for quantum spin liquids in frustrated triangular lattice magnets. While the DC magnetisation suggests magnetic exchange interactions in the order of several Kelvin, the zero-field AC magnetisation and heat capacity measurements reveal no signs of long-range magnetic order down to 20 mK, indicating a quantum-disordered ground state. We observe a spin glass transition around 30 mK at zero field, arguably originating from a small fraction of free spins--with an associated entropy of < 3%, which is suppressed by an applied field of 0.2 T. A broad anomaly in the heat capacity measurements between 2-5 K is indicative of short-range spin correlations. Below 350 mK, we observe a robust linear temperature dependence of the heat capacity, accompanied by the complete absence of long-range order at low fields. We propose that a phenomenological theory, based on the interplay between spinons and thermally excited gauge flux excitations, can account for the linear temperature dependence of the heat capacity and could be widely applicable to similar critical quantum spin liquid candidate materials. The results establish the low-temperature, low-field regime of TlYbSe2 as a prime candidate for field-tunable triangular quantum spin liquid behavior and highlight the importance of thermally excited gauge field excitations.

15:00 **The Heisenberg model on the triangular lattice, again**

Speaker: Federico Becca (University of Trieste, Italy)

By using Gutzwiller-projected Abrikosov fermions, we provide a variational construction of charge-Q monopole excitations in the Heisenberg model on the triangular lattice with nearest-neighbor ($J_1$) and next-nearest-neighbor ($J_2$) couplings. In the highly frustrated regime, singlet and triplet monopoles with $Q$=1 become gapless in the thermodynamic limit. Most importantly, the energies for generic $Q$ agree with field-theoretical predictions, obtained for a large number of gapless fermion modes.
Finally, we discuss how the variational wave function may be extended to describe magnetization curves in both the weakly-frustrated ($J_2$=0) and highly frustrated ($J_2$=1/8) regimes.

16:00 **Triangular Heisenberg model under a magnetic field: Monte Carlo approach**

Speaker: Sasank Budaraju (Technische Universität Munich, Germany)

Understanding the behavior of strongly interacting spin systems under external perturbations such as applied magnetic fields has been a significant and extensively studied topic, both from an experimental and theoretical point of view. Recent experimental studies of triangular lattice materials (e.g certain organic salts and chalcogenides) have observed behavior characteristic of a quantum spin liquid ground state. Understanding the unique signatures of spin liquids under applied magnetic fields would be crucial to reconcile with experimental results, and shed light on the nature of the spin liquid in these compounds.

Our work explores the phase diagram of the J1 - J2 triangular Heisenberg model under a magnetic field, which we investigate using the variational quantum monte carlo approach. The various possible magnetically ordered phases are parametrized using simple variational wavefunctions, and transitions among these phases are probed using standard monte carlo optimization techniques, As a result, we obtain a intuitive understanding of the evolution of the ground state as a function of applied field.
I will present results both in the small J2 regime where the system has 120 degree Neel order at no applied field, and in the spin liquid regime around J2=1/8, where the ground state is a QSL whose exact nature is still debated.

16:15 **Dirac spin liquid, GPU and all that**

Speaker: Zi Yang Meng (The University of Hong Kong)

I will start with the recent experiments on kagome antiferromagnet YCu3(OD)6Br2[Br(1−$x$)(OD)$x$] where the continuum spectra of cone shape is observed in inelastic neutron scattering. Then discuss the model design of the Dirac fermion (spinon) coupled with U(1) gauge field in (2+1) space-time dimension and its quantum Monte Carlo solutions. The phase diagram of such lattice model and the novel phase transitions therein will be explained, with emphases on the physics of magnetized Dirac spin liquid state and the computation methodology of GPU-accelerated hybrid Monte Carlo algorithm.

# Monday, 6 October 2025

16:45 **Chiral spin liquid phase in a square-lattice iridate**
Speaker: B. J. Kim (POSTECH, Pohang, South Korea)

In the early days of high-Tc cuprate research, theorists predicted that chiral spin liquids could strongly compete with the Néel-ordered state, especially when ring-exchange interactions or strong frustration are at play. Despite decades of efforts, direct experimental signatures have remained elusive. In this talk I will share our Raman-scattering evidence for a field-induced chiral spin liquid in $Sr_2IrO_4$. When we ramp up a magnetic field along the c-axis, single-magnon peaks in the B2g channel are gradually suppressed, disappearing entirely above 8 T—signaling the collapse of Néel order. In their place, new excitations emerge in the A2g channel, which theory tells us correspond to pairs of gauge-flux quanta. Even more striking, these modes exhibit clear circular dichroism, demonstrating broken mirror and time-reversal symmetries exactly as expected for a chiral spin liquid. These measurements thus provide the first compelling experimental glimpse of the long-sought chiral spin liquid phase. At intermediate fields, we observe magnons and gauge-flux excitations coexisting at similar energies, hinting at the possibility of controlling emergent gauge fields by pumping magnons with terahertz pulses.

# Tuesday, 7 October 2025

### 9:00 **Gapless Quantum Spin Liquid and Gapped 1/9 Magnetization Plateaus in S = 1/2 Kagome Antiferromagnet**

Speaker: Yuji Matsuda (Los Alamos National Laboratory, USA)

The two-dimensional spin-1/2 kagome Heisenberg antiferromagnet represents a paradigmatic frustrated quantum magnet predicted to host quantum spin liquid states, yet the nature of its ground state remains highly contentious. Two critical unresolved questions persist: (1) whether an excitation gap exists at zero field, and (2) whether fractional magnetization plateaus emerge under applied fields. We address these fundamental issues through comprehensive measurements on the recently synthesized perfect kagome antiferromagnet $YCu_3(OH)_{6.5}Br_{2.5}$.

High-resolution torque magnetometry measurements at ultra-low fields reveal negligible temperature dependence in the magnetic susceptibility of kagome layers down to 50 mK, consistent with gapless low-energy excitations [1]. This behavior contrasts sharply with the absence of a linear-in-temperature specific heat contribution, challenging conventional theoretical models involving fermionic spinon quasiparticles. Magnetization measurements up to 57 T reveal a well-defined plateau at the 1/9 fractional value (~20 T). Temperature-dependent studies of this plateau and magnetocaloric effect measurements confirm the presence of a field-induced spin gap [2].

These findings provide direct experimental evidence for the coexistence of gapless excitations at zero field and gapped behavior at finite fields, shedding light on the complex quantum magnetic phenomenology of kagome antiferromagnets.

[1] S. Suetsugu et al. arXiv:2407.16208
[2] S. Suetsugu et al. Phys. Rev. Lett. 132, 226701 (2024).

### 9:30 **Elementary Excitations in Kagome One-third Plateau and Magnetization of Dipole-octupole Quantum Spin Ice**

Speaker: Yamashita Minoru (The University of Tokyo, Japan)

In this talk, I will introduce two topics from our recent research.

The first topic is about our thermal-transport studies done in the one-third plateau phase of a kagome antiferromagnet In-kapellasite. Although a one-third plateaus phase has been observed in various kagome antiferromagnets, due to the high magnetic fields required to reach the plateau, the details of the elementary excitations have not been thoroughly investigated. Recently, a successful synthesis of a high-quality single crystal of In-kapellasite, InCu3(OH)6Cl3, opened up the possibility to study them in detail. Because of the relatively low spin interaction energy (~11 K), the one-third magnetic plateau can be realized under the moderate magnetic field of around 10 T, allowing us to measure the thermal-transport properties in the plateau phase down to low temperatures. We find a finite residual in the longitudinal thermal conductivity divided by the temperature that increases as approaching the one-third phase and becomes a constant within the phase. We further find that the thermal Hall conductivity shows a sharp change as entering the one-third phase. I will present details of our experimental results and discuss the excitations behind them.

The second topic is our magnetization study done in the dipole-octupole quantum spin ice (DO-QSI) candidate Ce2Hf2O7. Recently, symmetry-enriched DO-QSIs are found to be formed by replacing a quantum spin-1/2 with a pseudospin formed by a doublet of the total angular momentum |J|≥3/2. These dipole-octupole QSIs are suggested to be realized in Ce-based (J=5/2) pyrochlores, including Ce2Hf2O7. But, its spin interaction parameters remained largely unknown. We performed comprehensive magnetization measurements down to 50 mK in a high-quality single crystal of Ce2Hf2O7 along all the principal axes of the pyrochlore structure. We find a kink anomaly in the magnetization measured under the magnetic field B ∥ [111] that appears below 300 mK, concomitantly with a development of a magnetic hysteresis. Our classical Monte-Carlo and quantum exact diagonalization calculations demonstrate that the magnetization curves, including the kink anomaly under B ∥ [111], are well reproduced by the spin-interaction parameters with a dominant octupole interaction and with a QSI ground state, providing direct evidence of an octupole-based QSI in this material. I will also discuss about a possible mechanism behind the magnetic hysteresis.

# Tuesday, 7 October 2025

10:00 **Plateau states of the spin 3/2 kagome antiferromagnet**
Speaker: Chisa Hotta (The University of Tokyo, Japan)

Many gapped spin-1/2 states, including the 1/3, 5/9, and 7/9 magnetization plateaus, are known to host long-range orders characterized by product states of hexagonal loops surrounded by up-spin sites. Their low-energy physics is captured by fully packed loop configurations governed by the kagome ice rule. The role of quantum fluctuations in mixing these states is well understood through an effective mapping from the kagome model to a honeycomb quantum dimer model. Here, we demonstrate that an analogous picture emerges in a spin-3/2 antiferromagnet, though one must account for the larger internal spin degrees of freedom. This approach naturally explains the experimentally observed 1/9 plateau in a Cr-based kagome material.

11:00 **Kagome Heisenberg quantum spin liquids, the case of Herbertsmithite and beyond**
Speaker: Philippe Mendels (Université Paris-Saclay, France)

In my talk I will summarize the experimental state of the art on the emblematic quantum spin liquid herbertsmithite and the "enigmas and challenges" raised by the presence of unavoidable defects. While it is now agreed that the majority of defects are Cu2+ substituting to non-magnetic Zn2+ on the inter-kagome layers site, their impact on the physics has been mainly discussed through neutron inelastic scattering experiments, 17O NMR spectral considerations, 17O NMR and Cu NQR dynamical studies and specific heat experiments. While both NMR/NQR data from our and Imai's group clearly establish the presence of two different dynamical components, the interpretations differ, pointing either to a gapped or an ungapped ground state for what would be the pure kagome Heisenberg antiferromagnet.
Using susceptibility and Cu NQR/17O NMR experiments, we have recently investigated a series of samples with well-characterized Zn/Cu contents. Our results point to a substantial ferromagnetic coupling between Cu's on the interlayer and on the kagome sites, at variance with the commonly admitted quasi-free picture. Also, a temperature scale of ~ 30 K is relevant to the physics associated with defects.
I will present our data and discuss the possible interpretations coping with all experimental facts and the relevance to the low-T physics.
If time permits, I'll shortly present our recent results on the defect-free kagome-based Y-kapellasite which deviates from the ideal Heisenberg model where an applied pressure drives the system from an ordered antiferromagnetic towards a possible quantum spin liquid state.

11:30 **Searching for Kitaev Quantum Spin Liquids in $Rh^{4+}$ Honeycomb Compounds**
Speaker: Sara Haravifard (Duke University, USA)

Kitaev quantum spin liquids (KQSLs) remain at the forefront of condensed matter research owing to their exotic ground states and fractionalized excitations. Among the leading candidates, alpha-RuCl3 exhibits long-range magnetic order below 7 K, which can be suppressed under an external magnetic field of about 8 T to uncover signatures of a KQSL state. Other systems, such as H3LiIr2O6 and (H,Li)6Ru2O6, provide alternative platforms but suffer from vacancy effects and extrinsic interactions that complicate their realization of a pure Kitaev phase. Motivated by the ongoing search for novel KQSL compounds, we have turned to Rh4+(4d5, Jeff = 1/2) honeycomb-based materials, which present a unique opportunity to explore Kitaev physics with moderate spin–orbit coupling. In this talk, I will present our synthesis and characterization of H3LiRh2O6 and discuss its distinctive features in comparison with established Kitaev systems.

# Tuesday, 7 October 2025

12:00 **Probing Emergent Majorana Modes in Kitaev Spin Liquids**
Speaker: Natalia Perkins (University of Minnesota, Minneapolis, USA)

Kitaev spin liquid provide a natural platform for realizing fractionalized quasiparticles, including itinerant Majorana fermions bound to gauge fluxes and lattice defects. In this talk, I will discuss recent theoretical advances in identifying robust experimental probes of such emergent modes. I will show that vacancies bind localized Majorana zero modes, which manifest as sharp in-gap signatures accessible to scanning tunneling microscopy (STM). As a complementary and perhaps more experimentally accessible approach, I will present a planar-junction geometry whose inelastic tunneling conductance encodes the spin correlations of the KSL and reveals vacancy-induced in-gap resonances. Finally, I will emphasize that such lattice defects can arise not only as vacancies but also as magnetic impurities, both acting as natural traps for Majorana modes.

14:00 **Geometry dependence of the thermal Hall effect in chiral spin liquids**
Speaker: Gábor Halász (Oak Ridge National Laboratory, USA)

Recent thermal-transport experiments on the Kitaev magnet $\alpha$-$RuCl_3$ highlight the challenge in identifying chiral quantum spin liquids through their quantized thermal Hall effect. Here, we theoretically propose and experimentally demonstrate that the origin of the thermal Hall effect can be determined by varying the underlying sample geometry through, for example, introducing constrictions. By studying standard phenomenological heat-transport equations based on minimal assumptions, we show that, whereas a conventional thermal Hall effect due to phonons or magnons is completely geometry independent, a thermal Hall effect originating from a chiral fermion edge mode is significantly enhanced by geometric constrictions at low temperatures. Motivated by this result, we measure the thermal Hall effect in both constricted and unconstricted samples of $\alpha$-$RuCl_3$; the comparison of these two measurements reveals a pronounced geometry dependence of the thermal Hall effect and thus provides compelling evidence of a chiral fermion edge mode connected to a field-induced chiral spin liquid.

14:30 **Chiral spin liquids and the even–odd effect in Kitaev systems**
Speaker: Arnaud Ralko (Univesité Grenoble-Alps, France)

We explore chiral spin-liquid phases in multilayer Kitaev systems, emphasizing how dimensionality and even–odd effects [1] shape their excitation spectra and topological properties. Using parton-based approaches and exact methods, we identify how spin–orbit coupling, frustration, and interlayer interactions stabilize both gapless and gapped chiral regimes. As illustrations, we connect these results to the spin-½ and spin-1 Kitaev models [2,3], highlighting common mechanisms and distinctive features. Relevance to candidate materials such as $\alpha$-$RuCl_3$ and Ni-based honeycomb magnets will also be discussed, along with experimentally accessible signatures of chirality and spin fractionalization.

[1] PRB 111, 085152 (2025)
[2] PRL 124, 217203 (2020)
[3] PRB 110, 134402 (2024)

15:00 **Quantum Phase Diagram of the Bilayer Kitaev-Heisenberg Model**
Speaker: Saeed Jahromi (Institute for Advanced Studies in Basic Sciences, Zanjan, Iran)

We study the ground-state phase diagram of the spin-1/2 Kitaev-Heisenberg model on the bilayer honeycomb lattice with large-scale tensor network calculations based on the infinite projected entangled pair state technique as well as high-order series expansions. We find that beyond various magnetically ordered phases, including ferromagnetic, zigzag, antiferromagnetic (AFM) and stripy states, two extended quantum spin liquid phases arise in the proximity of the Kitaev limit. While these ordered phases also appear in the monolayer Kitaev-Heisenberg model, our results further show that a valence bond solid state emerges in a relatively narrow range of parameter space between the AFM and stripy phases, which can be adiabatically connected to isolated Heisenberg dimers. Our results highlight the importance of considering interlayer interactions on the emergence of novel quantum phases in the bilayer Kitaev materials.

## Tuesday, 7 October 2025

16:00 **Public Talk by Subir Sachdev: “100 years of many-particle quantum mechanics: from Bose and Fermi to quantum materials and devices”**

In quantum theory, all particles in the universe are either bosons (named for S.N. Bose, 1924) or fermions (named for E. Fermi, 1926). This fact is crucial to our understanding of the flow of electrons in all materials, including those found in smartphones. In recent decades, it has become clear that certain many-particle systems with complex quantum entanglement can exhibit emergent particles called `anyons’, which are neither bosons nor fermions. Even more intriguing are systems, such as the Sachdev-Ye-Kitaev model, which don’t exhibit any particle-like excitations at all. I will describe how these remarkable many-particle systems are playing a role in our understanding of modern quantum materials, such as the high temperature superconductors, and also in the design of fault-tolerant quantum devices.

Chair: Karlo Penc

17:30 **Public Talk by Ádám Szilágyi (IBM Quantum Ambassador): “IBM Quantum Computing: Real-World Benefits Now and the Road Ahead”**

# Wednesday, 8 October 2025

09:00 **Thermal SU(2) gauge theory of the cuprate pseudogap: reconciling Fermi arcs and hole pockets**
Speaker: Subir Sachdev (Harvard University, USA)

The cuprate pseudogap phase displays Fermi arc spectral weight in photoemission, while recent magnetotransport observations present compelling evidence for hole pockets. We model this by a Fractionalized Fermi liquid (FL*), which was predicted to have hole pockets of fractional area p/8 (where p is the doping), in agreement with the recently observed Yamaji angle. Thermal fluctuations of a SU(2) gauge theory of the background spin liquid of FL* lead the appearance of Fermi arcs in photoemission.

09:30 **Fractionalized orders: unconventional magnets and superconductors**
Speaker: Urban Seifert (University of Cologne, Germany)

Unconventional antiferromagnets that feature time-reversal-symmetry broken spectra at vanishing net magnetization have been of recent interest. These states, dubbed "altermagnets (AM)", can be accounted for in Landau theory frameworks via higher-order multipoles as order parameters. In my talk, I will show that a notion of "altermagnetism" can also be applied to quantum spin liquids which feature fractionalized excitations and therefore lie beyond such an effective Landau theory framework. We present a rigorous symmetry analysis based accounting for the projective implementation of physical symmetries, and construct exactly solvable models for such "fractionalized altermagnets (AM*)". In the second part of my talk, I will turn to an Kondo-lattice system of itinerant electrons coupling to frustrated local moments, and argue that this system supports stable fractionalized superconductivity (SC*).

10:00 **Kinetic Energy Frustration as New Paradigm for Correlated Metals**
Speaker: Cristian Batista (University of Tennessee, USA)

Since Anderson's seminal proposal of a resonating-valence-bond (RVB) ground state in triangular Heisenberg magnets, geometric frustration has become a key paradigm in modern physics, driving the discovery of novel states of matter in quantum magnets. Its application to the exchange interactions that govern Mott insulators has uncovered a wealth of emergent phenomena and continues to shape current research in condensed matter.

In a more recent seminal work, Jan Haerter and Sriram Shastry demonstrated that kinetic-energy frustration gives rise to effective antiferromagnetic interactions in slightly doped triangular Mott insulators. I will argue that this result is just the tip of an iceberg of emergent phenomena—encompassing polaron physics, unconventional pairing, and metallic RVB spin liquids exhibiting spin–charge separation—all driven by kinetic-energy frustration. Moreover, we will explore how the metallic RVB liquid induced by this "counter-Nagaoka" effect emerges as an exact ground state in slightly doped Mott insulators on corner-sharing tetrahedral lattices.

11:00 **New insights into frustrated spin-S chains**
Speaker: Frédéric Mila (EPFL, Lausanne, Switzerland)

The J1-J2 spin-1/2 chain, famous for its exactly dimerized ground state at the Majumdar-Ghosh point J2/J1=1/2 [1], can be generalized to large S in two very different, equally interesting ways: (i) Just increase the spin S in the J1-J2 chain; (ii) Replace the J2 term by a three-site term J3 that leads to a generalized Majumdar-Ghost point [2] at J3/J1=1/[4S(S+1)-2].
(i) The J1-J2 model is naturally realized in zigzag chains, and its physics depends dramatically on the spin: no dimerization for S=1 [3], dimerized phase followed by an unexpected gapless, non-dimerised phase with incommensurate correlations for S=3/2 and 5/2 [4,5]. Using a single mode approximation, we found evidence that this gapless phase is triggered by the condensation of spinons (fractional domain walls that carry spin-1/2), whose dispersion becomes incommensurate inside the gapped, dimerised phase [6]. These

results have direct implications for a recently synthesised spin-5/2 compound that happens to sit in this incommensurate gapless phase.
(ii) For the J1-J3 model, dimerization occurs for all values of the spin, and extensive DMRG simulations have shown that the transition is in the WZW SU(2)_k universality class with k=2S up to S=2 [7], and k=3 resp. 4 for larger half-integer resp. integer values of S [4,8]. The consequences of this transition on the dynamical structure will be discussed in a model that includes both J2 and J3, with clear evidence of deconfined domain walls when the transition becomes first order and their confinement away from it [9].

[1] C. K. Majumdar and D. K. Ghosh, J. Math. Phys. (N.Y.) 10, 1388 (1969); 10, 1399 (1969).
[2] F. Michaud, F. Vernay, S. R. Manmana, and F. Mila, Phys. Rev. Lett. 108, 127202 (2012).
[3] A. Kolezhuk, R. Roth, and U. Schollwöck, Phys. Rev. Lett. 77, 5142 (1996).
[4] N. Chepiga, I. Affleck, F. Mila, Phys. Rev. B 101, 174407 (2020).
[5] N. Chepiga, I. Affleck, F. Mila, Phys. Rev. B 105, 174402 (2022).
[6] A. Sharma, M. Nayak, N. Chepiga, F. Mila, Phys. Rev. B 112, 104401 (2025).
[7] F. Michaud, S. R. Manmana, and F. Mila, Phys. Rev. B 87, 140404(R) (2013).
[8] N. Chepiga, Phys. Rev. B 109, 214403 (2024).
[9| A. Sharma, M. Nayak, N. Chepiga, H. Rønnow, F. Mila, arXiv:2509.06720.

11:30 **Gamma-Matrix spin chains**
Speaker: Ribhu Kaul (Penn State University, USA)

I will discuss the phase diagrams of models of SO(4) symmetric spin chains built from Gamma matrices, in which the spins transform in the spinor representation of Spin(4).

12:00 **Nonlinear Spectroscopy of Quantum Spin Chains**
Speaker: Ciarán Hickey (University College, Dublin, Ireland)

The response of many-body systems to weak perturbations can be cast within the general framework of linear response, in which the response of the system is linearly proportional to the applied perturbation. This framework forms the foundation for many of the most popular tools in use today in condensed matter physics, but does not always resolve all of the key physics at play. In particular, the concrete identification of fractionalized excitations remains an outstanding challenge. In the field of quantum magnetism, the recent application of multi-dimensional coherent spectroscopy, the backbone of non-linear optics, to the THz range of magnetic excitations, has made it possible to push beyond the linear response paradigm and explore dynamical nonlinear magnetic response. In this talk, I will present a brief overview of some of the relevant challenges and opportunities within this nonlinear regime, and discuss its application in the setting of one-dimensional quantum spin chains, whose fractionalized spinon (or domain wall) excitations provide a useful test case to investigate how non-linear spectroscopy can provide new information not accessible within conventional linear response.

14:00 **From spin chains to corner-sharing triangles in the compound family $ACuTe_2O_6$**
Speaker: Bella Lake (Helmholtz Zentrum and TU Berlin, Germany)

Frustration in three-dimensional lattices is most well-studied on the pyrochlore lattice which consists of corner-sharing tetrahedra. Lattices of corner-sharing triangles also have the potential for strong geometrical frustration. An interesting case is the distorted windmill lattice found in materials with the space group P4132 where the magnetic ions lie on the 12d Wyckoff site which is characterized by positional parameter y. Here the magnetic ions form a hyperkagome lattice where each magnetic ion participates in two equilateral triangles. In addition, each magnetic ion also participates in another inequivalent triangle so that there are in fact three equilateral triangles at each site with one being different from the other two. The relative sizes and interaction strengths of these triangles can be controlled by y. This lattice is realized in the compound family ACuTe2O6 A=Sr, Ba, Pb, Ca, where the Cu ions have quantum spin-1/2. Here, in addition to the triangular interactions, there are further neighbor interactions that gives rise to spin chains. In this talk the properties of this family will be discussed. They range from spin chains as found in $SrCuTe_2O_6$ and $BaCuTe_2O_6$ with different types of frustrated interchain interactions due to the weaker triangular interactions, to the spin liquid candidate $PbCuTe_2O_6$ where the triangular interactions are dominant and magnetic order is suppressed due to frustration.

14:30 **Prevalence of highly dynamic magnetism in langbeinites**
Speaker: Ivica Živković (EPFL, Lausanne, Switzerland)

Quantum spin liquids (QSLs) have emerged as promising systems for the observation of entanglement and fractional excitations in magnetic materials. As quantum fluctuations are enhanced in low-dimensional systems, the focus has been predominantly on 1D and 2D systems. Nevertheless, highly frustrated 3D systems have been shown to support a QSL state, as in the pyrochlore and hyper-kagome lattices. A recent report indicated a novel 3D magnetic lattice in $K_2Ni_2(SO_4)_3$, a member of the langbeinite family. The source of its highly dynamic state can be associated with proximity to a specific spin model, based on a trillium lattice of tetrahedra. This family of compounds exhibits a broad chemical variety, with several new compounds synthesized and investigated. Alongside a review of the literature, I will present our efforts in reaching the S=1/2 spin state on this lattice, with an emphasis on the $K_2Ti_2(PO_4)_3$ compound.

15:00 **Spin Liquids on the Tetratrillium Lattice**
Speaker: Matías Gonzalez (University of Bonn, Germany)

The tetratrillium lattice has been recently proposed as the responsible for the dynamical features observed in the S=1 langbeinite compound $K_2Ni_2(SO_4)_3$. Here, show our results on the spin liquid properties of this lattice of tri-coordinated tetrahedra in the Ising, Heisenberg and large-N cases. We find that the system holds a classical fragile spin liquid with exponentially decaying correlations at the lowest temperatures. We also give some insight into the quantum limit by comparing with pseudo-Majorana functional renormalization group calculations.

15:15 **Lieb-Schultz-Mattis constraints for 3D quantum paramagnets**
Speaker: Chunxiao Liu (Laboratoire de Physique des Solides, Orsay)

Quantum paramagnets represent intriguing quantum phases that evade ordering even at absolute zero temperature. While detecting their presence is relatively straightforward, unraveling their fundamental nature can be a challenging task. In this talk, I will present the complete Lieb-Schultz-Mattis (LSM) constraints that we recently obtained in [1] — applicable to all 3D magnets — that prohibit certain 3D quantum paramagnets from being a “trivial” one. I will explain the usage of our results, and highlight the topological response theory underlying these LSM constraints which reveal information about symmetry, excitations, and lattice defects in any 3D magnets.

[1] Liu & Ye, SciPost Phys. 18, 161 (2025).

16:15 **Flux confinement-deconfinement transitions in pyrochlore magnets**
Speaker: Kedar Damle (Tata Institute of Fundamental Research, Mumbai, India)

We argue that a class of spin $S =3/2$ magnets in which strong single-ion easy-plane anisotropy (about the local z axes) competes with exchange couplings featuring comparably strong easy-axis anisotropy (about the same z axes) can display two different low-temperature Coulomb liquid phases, separated by an unusual flux confinement-deconfinement transition. The distinction between the two Coulomb phases is topological.
A similar transition between two Coulomb phases is also expected for a class of $S=1$ magnets. These results rely on extensions of ideas developed in earlier work on such flux confinement-deconfinement

transitions on the 1/3-magnetization plateau expected of kagome lattice magnets with similar competition between easy-plane single-ion anisotropy and eaxy-axis exchange couplings (PRX 15, 011018 (2025)). [coathors: Jay Pandey & Souvik Kundu]

16:45 **Spin-1 liquid on pyrochlore and checkerboard lattices**
Speaker: Kirill Shtengel (University of California, Riverside, USA)

We propose a local, SU(2) and time-inversion symmetric spin-1 Hamiltonian on the 3D pyrochlore and 2D checkerboard lattices. The ground states of this Hamiltonian are known exactly and form an exponentially large degenerate manifold. They are reminiscent of the spin-1 AKLT chains in 1D and similarly to those are characterised by the absence of magnetic order and exponentially decaying spin-spin correlations, which, in turn, strongly indicate a spin gap. Furthermore, these spin-1 systems may also support surface/edge spin 1/2 excitations.
We also consider additional Neel interactions between spins within the same tetrahedron and in two neighbouring tetrahedra and derive the effective Hamiltonian which splits the degeneracy of the ground state manifold.

17:15 **Quantum phases of the antiferromagnetic $J_1$–$J_2$ spin-1 pyrochlore Heisenberg model**
Speaker: Imre Hagymási (HUN-REN Wigner Research Centre for Physics, Budapest)

We investigate the ground state and finite temperature properties of the antiferromagnetic Heisenberg model on the pyrochlore lattice using complementary state of the art numerical methods. Employing large-scale SU(2)-symmetric density matrix renormalization group (DMRG) calculations on clusters of up to 48 spins, we find robust indications of spontaneous lattice symmetry breaking in the nearest neighbor model, including rotation and inversion symmetry breaking in the largest clusters. To access thermodynamic behavior and spin-1 systems, we further combine DMRG with density matrix purification and develop an efficient pseudo-Majorana functional renormalization group (PMFRG) approach that circumvents unphysical spin states at finite temperature. Benchmarking against the nearest neighbor model, we observe excellent agreement between PMFRG and purification for specific heat and susceptibility. Extending to the spin-1 J1-J2 model, both DMRG and PMFRG consistently identify a small but finite nonmagnetic ground state regime up to J2/J1 of about 0.02 (DMRG) 0.035 (PMFRG), beyond which magnetic k=0 long range order emerges. Taken together, our results establish strong evidence for unconventional nonmagnetic phases and symmetry breaking in the pyrochlore Heisenberg antiferromagnet.

# Thursday, 9 October 2025

9:00 **Dipole - Octuple Quantum Spin Ice Ground States and their Possible Realization in Ce-based Pyrochlores**

Speaker: Bruce Gaulin (McMaster University, Canada)

Ce-based pyrochores are comprised on networks of corner-sharing tetrahedral wherein pseudo-S=1/2 degrees of freedom decorate the lattice, carrying both dipole and octupole moments. This allows the possibility of both conventionally ordered and quantum spin ice ground states with either dipolar or octupolar flavour. My talk will focus on our recent progress on the materials synthesis and characterization of three members of this family: Ce2Zr2O7, Ce2Hf2O7 and Ce2Sn2O7, using mostly neutron scattering and low temperature heat capacity.

9:30 **Quantum Spin Ice in Confined Geometries**

Speaker: Jeffrey G. Rau (University of Windsor, Canada)

Quantum spin liquids (QSL) host a range of fascinating phenomena, including a lack of long-range order down to zero temperature, emergent gauge fields and fractionalized excitations. A well-studied example is “quantum spin ice” (QSI), which realizes a three-dimensional U(1) QSL with a well-defined photon excitation and deconfined magnetic and electric charges. In this work, we study the effect of confined geometry on quantum spin ice in experimentally relevant thin film geometries. Classical spin ice (CSI) thin films have been shown to display much of the same physics as bulk CSI, but can realize U(1) or Z2 classical spin liquid phases depending on the boundary conditions. To explore this physics in QSI films, we consider the effect of orphan bonds at the boundaries on the effective Hamiltonian in the QSI phase. Starting from the classical U(1) phase, we find that quantum fluctuations at the boundary renormalize the bulk Ising interactions and modify the photon dispersion. As the strength of these boundary effects increases, the photon mode softens, and the boundary spins partially order into a sub-extensive set of one-dimensional chain states. In contrast, for a system corresponding to the classical Z2 phase, the boundary geometry permits additional string-like operators which induce a photon gap in the semi-classical theory.

10:00 **Perfectly hidden order and $Z_2$ confinement transition in a magnetic monopole liquid**

Speaker: Attila Szabó (Universität Zürich, Switzerland)

Spin ice in a [100] field famously realises a Kasteleyn transition in which the field-polarised state breaks down by a sudden proliferation of strings of flipped spins that span the full system. In this talk, I will discuss a variant of this phenomenon in an alternative version of spin ice, whose degenerate ground states are densely packed monopole configurations. Here, an applied [111] field results in a thermodynamic transition, as indicated by, e.g., specific heat. However, no local order parameter distinguishes the two phases, unlike the standard Kasteleyn transition.

I will show that the transition is in fact a Z_2 topological one, driven by the deconfinement of loops of flipped spins. Short loops are allowed in the monopole-liquid ground state manifold, even in very high fields; as the field is lowered, these loops get longer and longer, until loops of all sizes, including system-spanning ones, proliferate at the transition. While this is not captured by the magnetisation, it has clear signatures in topological and string order parameters, establishing the system as a rare example of perfectly hidden order in a 3-dimensional classical model. Furthermore, by a duality mapping to the 3D Ising model, we demonstrate that the magnetic response of the system scales with the critical exponent not of the susceptibility, but of the *specific heat*, which may serve as a clear diagnostic of this transition into perfectly hidden order in experimental realisations.

# Thursday, 9 October 2025

11:00 **Novel insight into $Tb_2Ti_2O_7$ Flavor modes and mixed dipolar-quadrupolar phases**
Speaker: Sylvain Petit (CEA-CNRS-Université Paris Saclay, France)

Tb2Ti2O7 has remained an enigma in condensed matter physics, and more specifically in the field of frustrated magnetism, for more than twenty-five years [1]. This material evades long-range order down to temperature as low as 20 mK and its ground state exhibits puzzling diffuse magnetic scattering [2,3]. Its low energy spin dynamics includes, on the one hand, an exciton located at about D= 1.5 meV, which shows a significant dispersion [4]; on the other hand, Tb2Ti2O7 also hosts exotic low energy collective dynamics (≈ 0.3 meV), which is believed to be hybrid dipolar-quadrupolar excitations [5,6].

Using polarized inelastic neutron scattering measurements, I will present a review of the characteristics of these low-energy modes, including their dispersion and spectral weight evolution in the Brillouin zone. Strikingly, as a function of an applied magnetic field, these low energy modes show a new example of ''half-moon'' like patterns. I will then describe RPA simulations, based on a Hamiltonian, which includes both dipolar and quadrupolar couplings [7], yielding spin dynamics, which compare quite well with those data. The best set of couplings suggest that Tb2Ti2O7 is one of the very rare examples of quantum spin ice, yet very close to several ordered phases, especially a planar antiferromagnetic dipolar phase and a purely quadrupolar one [8,9].


[1] M. J. P. Gingras and P. A. McClarty. Rep. Prog. Phys., 77, 056501 (2014).
[2] T.Fennell et al. Phys. Rev. Lett., 109(1), 017201 (2012).
[3] T.Fennell et al. Phys. Rev. Lett., 112(1), 017203 (2014).
[4] M.Ruminy et al.Phys. Rev. B, 224431 (2019).
[5] S.Guitteny et al. Phys. Rev. Lett., 111(8), 087201 (2013).
[6] H.Takatsu et al. Phys. Rev. Lett., 116, 217201 (2016).
[7] A. M. Hallas et al. arXiv:2009.05036 (2020).
[8] A. Roll et al, PRR 6 043011 (2024)
[9] A Roll et al, in preparation.


11:30 **High entropy materials as a platform to explore frustrated magnets**
Speaker: Françoise Damay (Laboratoire Léon Brillouin, Paris, France)

High-entropy stabilization has had a major impact in material research over the past few years, as it offers the possibility in alloys and oxides to stabilize new single-phase materials from multiple constituting elements, which exhibit long-range structural order although they are locally randomly chemically disordered. Thanks to the recent discovery of the first entropy-stabilized rare-earth pyrochlores, the use of entropy stabilized compounds can now be extended to the fundamental physics of frustrated magnetism.
A comprehensive study of the first entropy-stabilized terbium pyrochlore Tb2(TiZrHfGeSn)2O7 will be presented, combining a variety of experimental techniques including neutron scattering. Experimental observations are interpreted with a scenario in which the impact of the high entropy is rationalized through oxygen shifts surrounding the rare-earth, directly impacting its crystal field Hamiltonian. This study brings several new elements to the understanding of the elusive ground state of the famous Tb2Ti2O7, in particular with respect to the balance between disorder, quadrupolar interactions and antiferromagnetic exchange between Tb ions which is thought to control its ground state [1].
If time allows, another example of a high-entropy material, crystallizing in the garnet structure which hosts two twisted hyperkagome lattices, will also be presented.


[1] F. Vayer et al., Communications Materials (2024)5:162
(https://doi.org/10.1038/s43246-024-00589-y)

# Thursday, 9 October 2025

12:00 **Non-reciprocal absorption spectroscopy and antiferromagnetic domain detection**
Speaker: Sándor Bordács (Budapest University of Technology and Economics, Hungary)

Absorption of light may become non-reciprocal, — differing for counter-propagating beams even if unpolarized — when all symmetries linking forward and backward propagation are broken. Crucially, non-reciprocal absorption requires the lack of time-reversal and inversion symmetries. As certain (antiferro)magnetic order breaks inversion symmetry the emerging domains can be distinguished by non-reciprocal absorption, thus, they can be detected optically.

In this talk, we will focus on the collinear antiferromagnet LiCoPO4 crystallizing in the centrosymmetric orthophosphate structure. Its antiferromagnetic order breaks inversion symmetry, thus, in the magnetically ordered phase, non-reciprocal absorption becomes allowed. We probed the non-reciprocal absorption for spin as well as for charge excitations by THz and optical spectroscopy, respectively. We revealed strong contrast between the domains that we interpreted in terms of mixed magnetic and electric dipole excitations. At low frequencies we developed a mean-field model to describe the coupled spin and polarization dynamics. In the infrared and visible spectral ranges, the resonance energies showing non-reciprocity can be captured by crystal field excitations.

Furthermore, we leveraged this contrast to image the domain pattern by a simple scanning light microscope. Our results demonstrate that non-reciprocal absorption offers a powerful new contrast mechanism for detecting antiferromagnetic domains, which are of growing interest for spintronics due to their inherent stability and ultrafast dynamics.

[1] V. Kocsis, et al., Phys. Rev. Lett. 121, 057601 (2018).
[2] V. Kocsis, et al., Phys. Rev. B 100, 155124 (2019).
[3] B. Tóth, et al., Phys. Rev. B 110, L100405 (2024).

14:00 **Novel Quantum Spin Liquid states in the S = ½ three-dimensional compound $Y_3Cu_2Sb_3O_{14}$**
Speaker: Avinash Mahajan (Indian Institute of Technology Bombay, India)

The three-dimensional S = 1/2 system Y3Cu2Sb3O14 consists of two inequivalent Cu2+ ions, each forming edge shared triangular lattices. Our magnetic susceptibility χ(T)=M/H, specific heat C_p (T), 89Y nuclear magnetic resonance (NMR), muon spin relaxation (muSR), and electron spin resonance (ESR) measurements on this system confirm the absence of any long-range magnetic ordering and the persistence of spin dynamics down to 0.077 K. From 89Y NMR we find evidence of a transition at about 120 K which we suggest to arise from a fraction of the spins condensing into a singlet (a valence bond solid VBS or a quantum spin liquid QSL) state. A plateau in the muon relaxation rate is observed between 60 K and 10 K (signifying the VBS/QSL state from a fraction of the spins) followed by an increase and another plateau below about 1 K (presumably signifying the VBS/QSL state from all the spins). Our density functional theory calculations find a dominant antiferromagnetic interaction along the body diagonal with inequivalent Cu(1) and Cu(2) ions alternately occupying the corners of the cube. All other near neighbour interactions between the Cu ions are also found to be antiferromagnetic and are thought to drive the frustration.

14:30 **Spin-liquid mimicry in the double hydroxide perovskite $CuSn(OD)_6$ induced by correlated proton disorder**
Speaker: Dmytro Inosov (Technische Universität Dresden, Germany)

The fcc lattice is composed of edge-sharing tetrahedra, making it a leading candidate host for strongly frustrated magnetism, but relatively few face-centered frustrated materials have been investigated. In the hydroxide double perovskite CuSn(OH)6, magnetic frustration of the Cu2+ quantum spins is partially relieved by strong Jahn-Teller distortions. Nevertheless, the system shows no signs of long-range magnetic order down to 45 mK and instead exhibits broad thermodynamic anomalies in specific heat and magnetization, indicating short-range dynamical spin correlations—a behavior typical of quantum spin liquids. We propose that such an unusual robustness of the spin-liquid-like state is a combined effect of quantum fluctuations of the S=1/2 quantum spins, residual frustration on the highly distorted face-centered Cu2+ sublattice, and correlated proton disorder. Similar to the disorder-induced spin-liquid mimicry in YbMgGaO4 and herbertsmithite, proton disorder destabilizes the long-range magnetic order by introducing randomness into the magnetic exchange interaction network. However, unlike the quenched substitutional disorder on the magnetic sublattice, which is difficult to control, proton disorder can, in principle, be tuned through pressure-driven proton ordering transitions. This opens up the prospect of tuning the degree of disorder in a magnetic system to better understand its influence on the magnetic ground state.

15:00 **Fractionalized excitations and Floquet-engineered frustration in quantum simulators**
Speaker: Rhine Samajdar (Princeton University, USA)

In recent years, programmable arrays of Rydberg atoms have provided a versatile setting for simulating strongly correlated quantum matter. On certain lattice geometries, the Ising models describing these systems give rise to emergent Z2 gauge theories, enabling the realization of topological quantum spin liquids (QSLs). In this talk, using fermionic parton constructions, we first characterize the fractionalized excitations of such a synthetic QSL. We identify symmetry fractionalization patterns through the projective symmetry group framework, benchmark candidate QSL states against tensor-network calculations, and provide dynamical predictions for future experiments. To go beyond Z2 QSLs, we then introduce a universal Floquet-based scheme to engineer arbitrary frustrated XXZ spin models in Rydberg lattices. By designing site-resolved modulation patterns with a graph-theoretic method, we achieve precise control over the effective long-range interactions across all Archimedean lattices. This generalization provides an extra degree of tunability to neutral atom arrays, allowing one to probe exotic topological states which may be difficult to realize in solid-state materials.

16:00 **Generic theories for pinch lines and multifold half moons in classical spin liquids**
Speaker: Ludovic Jaubert (CNRS, University of Bordeaux, France)

Classical spin liquids form fluctuating magnetic textures which have to obey local rules imposed by frustration. These rules can sometimes be written in the form of a Gauss law, that appears as singularities known as pinch points in the structure factor. But more exotic forms of electromagnetism are possible, and these zero-dimensional singularities can been extended into multifold shapes or one-dimensional pinch lines.

In this talk we will first present a framework for the design of pinch-line spin liquids in a layered structure of two-dimensional algebraic spin liquids. The rank of the gauge field can be continuously varied along the pinch line, opening original avenues in fractonic matter. We explain how the evolution of the singularity along the pinch line can be understood as the interference pattern of two emergent electric fields, and apply our theory to generic pinch-line models beyond layered structures when relevant.

Then, in a second part, we will extend the recently developed classification of classical spin liquids to a generic theory of interacting-cluster systems. The cluster interaction competes with the emergent Gauss law, stabilising unconventional gauge charges, such as fractons, in the ground-state manifold. As a result, it offers a generic framework for the apparition of half-moon patterns in the equal-time structure factor, and extends their physics to multi-fold and "pinch-line" half moons. Finally, we show how half-moon phases can be tuned across the equivalent of a topological Lifshitz transition.

16:30 **Classical Fracton Ising Spin Liquid on the Octochlore Lattice**
Speaker: Judit Romhányi (University of California, Irvine, USA)

We consider the lattice of corner-sharing octahedra, dubbed the octochlore lattice and explore the phase diagram of Ising spins including first- and second-neighbor interactions within each octahedron. In addition to a spin ice classical spin liquid (CSL), we identify a novel fracton CSL with fractonic excitations restricted

to move in one dimension and yielding a classical U(1) analog of the celebrated X-cube model of fracton topological order. We characterize this fracton liquid from multiple perspectives; via its flat bands with nodal line touchings, as a condensate of spinon bound states, as a foliated fracton phase of intersecting spin vorticity models, and as a bionic spin liquid of intersecting
square ice sheets. This multi-pronged description allows us to achieve a comprehensive understanding of the system's excitations and enables a connection to many recent developments in the understanding of classical spin liquids. This work promotes the realization of fracton CSLs in real materials, provides a constructive method for building classical fracton CSL, and exposes the octochlore geometry as a promising new platform for exploring CSLs in 3D.

17:00 **Fracton quantum spin liquid on a square lattice**

Speaker: Nils Niggemann (ICTP, Trieste, Italy)

Gapless fracton quantum spin liquids are exotic phases described by higher-rank generalizations of electromagnetism, which feature immobile quasiparticles (fractons) coexisting with gapless photon modes. While effective field theories are well understood, microscopic spin models realizing such phases have remained elusive.

In this talk, I will introduce a simple spin model on the square lattice that exhibits clear signatures of both classical and quantum fracton spin liquids, depending on the spin quantum number. Using quantum Monte Carlo simulations, we show that the spin-1 version avoids conventional ordering and matches the predictions of a corresponding fractonic field theory. These results provide strong evidence for a gapless fracton quantum spin liquid with emergent photon excitations.

## Friday, 10 October 2025

9:00 **What can the tools of quantum information theory teach us about quantum magnets ?**
Speaker: Nic Shannon (Okinawa Institute of Science and Technology, Japan)

The search for unconventional phases of matter remains a central theme in condensed matter and statistical physics. However the very things which make these phases interesting: the absence of conventional order parameters; the emergence of fractional excitations; their topological and entanglement properties, also make them difficult to distinguish in experiment. This is particularly true of the hunt for quantum spin liquids in quantum magnets: phases viewed as a "holy grail", but which are also notoriously difficult to diagnose, especially in the presence of disorder.

In this talk we explore how ideas from quantum information could be used to distinguish quantum spin liquids from other competing phases of matter. We consider two systems where the possibility of finding a quantum spin liquid has been widely discussed: quantum spin chains, and triangular lattice antiferromagnets [1,2]. In both cases, we find that inelastic neutron scattering, interpreted in terms of quantum Fisher information, can be used distinguish quantum spin liquids from states driven by disorder. We also highlight some of the pitfalls which arise in the naive application of ideas from quantum information to quantum magnets.

These results suggest that, used carefully, the tools of quantum information could offer a powerful way of interpreting the results of both simulation and experiment on quantum magnets.

[1] S. Sabharwal, T. Shimokawa and N. Shannon, Phys. Rev. Res. 7, 023271 (2025)
[2] T. Shimokawa, S. Sabharwal and N. Shannon, arXiv:2505.11874

09:30 TBA
Speaker: Masaki Oshikawa (The University of Tokyo, Japan)

10:00 **Theory for natural and synthetic square kagome lattice quantum spin liquid candidates**
Speaker: Harald O. Jeschke (Okayama University, Japan)

Quantum spins on the square kagome lattice have long been considered as a highly frustrated system that might host quantum spin liquids. Recently, some material realizations have been discovered in minerals and in synthesized crystals. In particular, the mineral nabokoite has been synthesized and shown to be evolving into a family of quantum spin systems via site substitutions. We investigate both K-nabokoite KCu7TeO4(SO4)5Cl as well as its sister compounds Na-nabokoite, Rb-nabokoite and Cs-nabokoite. We combine density functional theory based energy mapping which allows us to extract the Heisenberg Hamiltonian with classical Monte Carlo simulations and pseudo-Majorana functional renormalization group calculations. Our application of this approach to K-nabokoite yields excellent agreement with the highly nontrivial magnetization behavior [1]. In particular, we manage to identify a quantum spin liquid that is induced by low magnetic field. We can trace the highly degenerate ground states to illuminating effective models. Application of the methodology to the Na, Rb and Cs based sister compounds opens the door to an entire family of compounds with similarities as well as substantial variation.

[1] M. G. Gonzalez, Y. Iqbal, J. Reuther, H. O. Jeschke, Comm. Mater. 6, 96 (2025).
In collaboration with Matias Gonzalez, Yasir Iqbal, Johannes Reuther

11:00 **Dirac and chiral spin liquids on the spin-1/2 square-lattice Heisenberg antiferromagnet**
Speaker: Hong-Hao Tu (Technische Universität Munich, Germany)

In this talk I will revisit the long-standing question of possible quantum spin liquid phases in the spin-1/2 J_1-J_2 Heisenberg antiferromagnet on the square lattice. By combining the Gutzwillerguided DMRG approach with analytical insights, we find compelling evidence that the ground state realizes a Dirac spin liquid, which can be naturally described within the framework of Gutzwiller-projected parton wave functions and their projective symmetry group classification. I will also discuss how chiral spin liquid states emerge when additional interactions are included, and present our results on the transition between different chiral spin liquid phases as the interaction strength is tuned.

11:30 **Stability of critical spin liquids and deconfined criticality**

Speaker: Josef Willsher (MPIPKS, Dresden, Germany)

Critical spin liquids are quantum disordered phases of insulating magnets which exhibit fractionalized gapless excitations and power-law correlations. Quantum spin liquids in this category include the experimentally established 1D Luttinger liquid, as well as the U(1) Dirac spin liquid (DSL) which has been a focus of recent candidate materials searches. In this talk, I will discuss recent works on the stability of critical spin liquids and deconfined quantum critical points upon coupling to the lattice, using a combination of field-theoretic and numerical approaches. We find a generic spin-Peierls instability to valence-bond order in the static phonon limit, and show that the exotic fractionalized phases can be stabilized by tuning the energy scale of the phonons.

11:45 **Collinear Altermagnets and their Landau Theories**

Speaker: Hana Schiff (University of California, Irvine, USA)

Collinear altermagnetism corresponds to compensated magnetic order exhibiting alternating and anisotropic spin splitting of electronic bands, due to distinctive magneto-crystalline symmetries. These systems have attracted interest because of their potential for spintronics applications. We provide a general Landau theory that encompasses all three-dimensional altermagnets, assuming the magnetic order does not enlarge the unit cell. We identify all crystal structures admitting altermagnetism, and reduce to a smaller set of possible Landau theories characterized both with and without spin-orbit coupling (SOC). In the zero SOC limit we determine the possible local multipolar orders that are tied to the spin splitting of the band structure. Importantly, we clarify the bridge between “ideal” SO-free altermagnets and real altermagnets with SOC, and we distinguish the measurable properties and response functions of SOC altermagnets from collinear Néel antiferromagnets.