ASIA-PACIFIC WORKSHOP FOR QUANTUM MAGNETISM

Abstract Booklet

2017-08-27-30

Seoul National University

Day 1

Session 1: 09:00-10:40
Chair: Je-Guen Park

Surprises in the kagome cuprates

Zenji Hiroi
ISSP, University of Tokyo

Our recent activities in the research of the kagome-type copper minerals are reviewed. Volborthite, $Cu_3V_2O_7(OH)_2/2H_2O$, which is now assumed to be a frustrated J_1–J_2 square lattice quantum magnet, shows “hidden” orders at H = 23-28 T between the SDW phase and the 1/3 plateau state. For Cd-kapellasite (CdK), $CdCu_3(OH)_6(NO_3)_2/H_2O$, a complete magnetization curve is measured by the Faraday rotation method in magnetic fields up to 160 T, which uncovers a series of magnon crystallizations on the kagome net.

Magnetic properties of volborthite determined by a coupled-trimer model

Shunsuke Furukawa
University of Tokyo

The natural mineral volborthite hosts layers of spin-1/2 moments forming a kagome lattice. While this material was initially considered as a candidate of a spin-1/2 kagome antiferromagnet, it exhibits rich magnetic behavior which is in many respects distinct from the known features of a kagome antiferromagnet. In particular, recent single-crystal experiments have revealed a wide 1/3 magnetization plateau starting at H=26 T, an incommensurate spin-density-wave phase below H=23 T, and the novel "N" phase inbetween them.

To explain these rich field-induced phenomena, we have performed microscopic modeling of volborthite by means of density functional theory (DFT) with the single-crystal structural data as a starting point. Using DFT+U, we find four leading magnetic exchanges: antiferromagnetic J and J_2, as well as ferromagnetic J' and J_1 with a remarkable hierarchy $J>|J_1|>J_2,|J'|$. Due to the dominance of J, the magnetic planes break up into magnetic trimers. The 1/3-plateau state can be naturally interpreted as a product of polarized trimers, and a wide plateau extending to H=225 T is predicted. Furthermore, we derive an effective pseudospin-1/2 model by restricting ourselves to the lowest-energy doublet on each trimer and treating the inter-trimer couplings perturbatively. This model shows a tendency towards condensation of magnon bound states preceding the plateau, providing a scenario for the observed "N" phase.

Reference: O. Janson, S. Furukawa, T. Momoi, P. Sindzingre, J. Richter, and K. Held, Phys. Rev. Lett. 117, 037206 (2016).

Unusual magnetic state in S = 1/2 J_1-J_2-J_d Kagome Lattice Antiferromagnet $CaCu_3(OH)_6Cl_2$•$0.6H_2O$

Hiroyuki Yoshida
Hokkaido University

We have succeeded in preparing single crystals of the S = 1/2 Kagome lattice antiferromagnet $CaCu_3(OH)_6Cl_2$•$0.6H_2O$, Ca-Kapellasite [1]. This compound crystallizes in the trigonal symmetry with space group P-3m1, having a Kapellasite type structure, a structural polymorph of Herbertsmithite. This contains a perfect Kagome lattice of Cu^{2+} ions, and Ca^{2+} ions locate at the center of the hexagon of the Kagome network. The large discrepancy of the ionic radius of the non-magnetic Ca^{2+} ion and the magnetic Cu^{2+} ion prevents the ion-site mixing as observed in Herbertsmithite. Theoretical calculations have predicted that in the Kapellasite structure, magnetic interactions of a nearest-neighbor J_1, a next- nearest-neighbor J_2, and J_d across the hexagon dominate the ground state of the system, including the spin liquid state, the $\sqrt{3} \times \sqrt{3}$ structure, the q = 0 order, and an unusual magnetic ordered state called Cuboc state with 12-sublattice. These theoretical exploring presents us a new field of magnetism on the study of the Kagome lattice antiiferromagnet, and thus Ca-Kapellasite is one of the ideal compounds to seek an exotic ground state.
Magnetic properties of Ca-Kapellasite were characterized by means of a magnetic susceptibility, a heat capacity, and microscopic probes on the single crystal of Ca-Kapellasite. The 9th order high-temperature series expansion fitting to the magnetic susceptibility revealed the compound possessed magnetic interactions of antiferromagnetic J_1 = 46.8 K, J_d = 12.1 K, and ferromagnetic J_2 = -5.3 K. The magnetic anomaly appears only in the ab-plane direction at T* = 7.2 K. A small peak in the heat capacity at T* indicates the occurrence of a magnetic transition, however the quite tiny peak at T* implies the transition is not a conventional long-range order. Remarkably, T-linear term 5.9 mJ/Cu-mol-K^2 in the heat capacity was observed in spite of the fact that the compound was an insulator. That indicates the existence of an unusual gapless excitation on the ground state of Ca-Kapellasite, and thus it suggests the emergence of a fluctuating ground state. Actually, the compound locates at the multi-critical point of the $\sqrt{3} \times \sqrt{3}$ structure, the q = 0 order, and the Cuboc phase in the J_1-J_2-J_d phase diagram at T = 0 that may cause the formation of a unique magnetic state in our compound. The origin and a magnetic structure of the compound have not been understood yet, but we expect that a novel magnetic state with spin fluctuation is realized in accordance with a strong frustration and a quantum fluctuation on Kagome lattice of $CaCu_3(OH)_6Cl_2$•$0.6H_2O$

1) H. Yoshida et al., J.Phys.Soc.Jpn., 86, 033704 (2017).

Gapless Spin-Liquid Ground State in the S=1/2 Kagome Antiferromagnet

Tao Xiang
Institute of Physics, Chinese Academy of Sciences

The defining problem in frustrated quantum magnetism, the ground state of the nearest-neighbor antiferromagnetic Heisenberg model on the kagome lattice, has defied all theoretical and numerical methods employed to date. We apply the formalism of tensor-network states, specifically the method of projected entangled simplex states, which combines infinite system size with a correct accounting for multipartite entanglement. By studying the ground-state energy, the finite magnetic order appearing at finite tensor bond dimensions, and the effects of a next-nearest-neighbor coupling, we demonstrate that the ground state is a gapless spin liquid. We discuss the comparison with other numerical studies and the physical interpretation of this result.

Session 2: 11:10-12:25
Chair: Je-Guen Park

New Jeff=1/2 Quantum Liquid on Honeycomb Lattice

Kentaro KITAGAWA
University of Tokyo, Department of Physics

Iridium-oxide octahedra arranged on honeycomb lattice can be a toy box for Kitaev quantum spin liquid (QSL) [1], which is exactly solusible in the simple cases. Nevertheless, all of the currently known 2D honeycomb (α-type) and 3D hyperhoneycomb (β) iridates turned out to have a long-range magnetic ordering. We recently found 3 promising candidates for Kitaev QSLs; 2D honeycomb $H(D)_3LiIr_2O_6$ where the inter-honeycomb-layer Li ions are replaced by H(D) ions, and 3D hyperhoneycomb β-Li2IrO3 under pressure. In the candidate materials, any signature of ordering was observed in magnetic susceptibility, specific heat, or XMCD, suggestive of the realization of QSL. To explore QSL physics and exclude the possible glassy ordering, we conducted local probe measurements, 1H/2D/6,7Li-NMR. As evidenced in Fig. 1, $H_3LiIr_2O_6$ is free from static magnetism at 1.2 K (1/100 of $|\theta_{CW}|$) despite the effective moment per Ir of 1.7μB obtained from Curie-Weiss fit of magnetic susceptibility. The spurious portion of static magnetism is only ~0.01μB, which is much smaller than those for herbertsmithite or organic QSL candidates. This means that $H_3LiIr_2O_6$ is the cleanest QSL ever discovered. The observation of NMR shift (intrinsic susceptibility) supports Kitaev QSL picture, whereas NMR relaxation rate or specific heat captured complex temperature/field dependences. The dynamics can be interpreted to a combination of gapless/gapped excitations. High-pressure NMR experiment for β- Li_2IrO_3 at 3.3 GPa showed similar QSL behavior, though the actual crystal structure at high pressures are uncertain at this point.

Electromagnetic Responses of Honeycomb Magnets

Taka-hisa Arima
University of Tokyo / RIKEN

The simple antiferromagnetic order on honeycomb network is a sort of ferroics. The consequent symmetry breaking may induce some novel physical responses. I will discuss such responses in Co4Nb2O9 and CaMn2Bi2.

Thermal and spin currents driven by spinons, Majorana fermions and multiple-magnon molecules

Masahiro Sato
Ibaraki University

Transport phenomena in magnetic materials is being one of hottest topics in condensed matter physics. They have attracted much attention from not only fundamental science but also engineering viewpoints since they are expected to lead to new spintronic devices [1]. In the field of spintronics in magnetic insulators, so far most of studies have focused only on magnon (spin-wave) driven transport phenomena. However, on the top of magnons, various quasiparticles often appear in magnets, depending on the nature of the magnetic systems. This quite contrasts with electron systems. In recent years, we have theoretically and experimentally studied new magnetic transport phenomena driven by different quasiparticles: Spinon spin current in a quasi-one-dimensional magnet Sr_2CuO_3 [2,3], thermal current of Majorana fermions in a Kitaev candidate magnet alpha-$RuCl_3$ [4], and thermal Hall effect driven by multiple-magnon bound states in frustrated magnets [5]. In this talk, I would like to discuss some essential features of these new transport phenomena. Particularly, I will concentrate on the theory of thermal Hall effect driven by magnon pairs (magnon molecules).

[1] See, for example, Spin Current, edited by S. Maekawa, et al (Oxford Univ. Press, 2012).
[2] D. Hirobe, M. Sato, et al, Nature Phys. 13, 30 (2017).
[3] M. Sato, S. Maekawa and E. Saitoh, in preparation.
[4] D. Hirobe, M. Sato, Y. Shiomi, H. Tanaka, and E. Saitoh, Phys. Rev. B 95, 241112 (R) (2017).
[5] E. Takata and M. Sato, in preparation.

Session 3: 14:00-13:15
Chair: Gang Chen

Nonreciprocal magnons in a noncentrosymmetric antiferromagnet

Kittiwit Matan
Mahidol University

Magnons, the spin-wave quanta, are disturbances that embody a wave propagating through a background medium formed by ordered magnetic moments. In an isotropic Heisenberg system, these disturbances vary in a continuous manner around an ordered spin structure, thus requiring infinitesimal energy as a wavevector approaches a magnetic zone center. However, competing anisotropic interactions arising from broken symmetry can favor a distinct static and dynamic spin state causing a shift of the minimum point of the magnon dispersion to a nonreciprocal wavevector. I will present the first direct evidence of these nonreciprocal magnons in a noncentrosymmetric antiferromagnet. They are caused by the incompatibility between anisotropic exchange and antisymmetric Dzyaloshinskii-Moriya interactions resulting in competing collinear and helical spin structures. The nonreciprocity introduces the difference in the phase velocity of the counterrotating modes, resulting in the opposite spontaneous magnonic Faraday rotation of the left- and right-propagating spin-waves. The breaking of spatial inversion and time reversal symmetry is revealed as a magnetic-field-induced asymmetric energy shift, which provides a test for the detailed balance relation of the scattering intensity.

Search for the low-temperature highly correlated phase in the charge-density-wave 1T-TaS_2 compound

Marie Kratochvilova
Institute for Basic Science, Seoul National University

1T-TaS_2 is a prototypical quasi-2D metallic compound which has been under extensive studies due to its intricate interplay of a Mott-insulating ground state and a peculiar charge density-wave (CDW) order. The compound reveals strong electron-phonon coupling responsible for a series of CDW transitions; first, an incommensurate CDW phase below 540 K is established, then a nearly commensurate CDW phase forms at 350 K and finally, a commensurate phase is observed below ~160 K. In this phase, 12 out of 13 Ta^{4+} 5d-electrons form some kind of molecular orbitals in hexagonal star-of-David patterns, leaving one 5d-electron with S = ½ spin free. This orphan quantum spin with a large spin-orbit interaction may form a highly correlated phase of its own. In that case, it is most likely that they will form some kind of a short-range order out of a strongly spin-orbit coupled Hilbert space. In order to investigate the low-temperature magnetic properties, we performed a series of measurements including neutron scattering on the D7 instrument at ILL and muon experiment on the EMU instrument at ISIS. The obtained data indicate the presence of a short-ranged phase and suggest the upper bound for the size of the magnetic moment expected from such an orphan-spin scenario.

Recombination of fractional excitations in frustrated magnets

Masafumi Udagawa
Gakushuin University

Fractionalization is a phenomenon where a natural quantum number of the system, such as charge and spin is fragmented into several components, and takes a smaller value than its basic unit. Recently, exotic possibilities of fractionalization have been discussed in topologically ordered systems. Regarding this fractionalization, "recombination" gives an interesting viewpoint: By recombining fractionalized excitations in a nontrivial way, it is possible to obtain a new phase or collective excitation that are hard to imagine from the original spin or fermionic degrees of freedom.

In this talk, we consider this scenario in the context of frustrated magnetism. For this purpose, we take up frustrated pyrochlore and kagome lattices, and consider J1-J2-J3 Ising model on these lattices. The nearest-neighbor J1 leads to the formation of spin-ice-type degenerate ground states, which support fractional monopole excitations. The monopoles have magnetic charges, which determine their creation-annihilation rule, i.e., positive monopoles pair-annihilate only with negative charges. The farther-neighbor J2 and J3, which we set to be J, introduce short-range interactions between monopoles. Positive (Negative) J leads to attractive (repulsive) interaction between like charges.

In particular, in the case of positive J, the monopole excitations exhibit non-trivial recombination. In this case, like charges tend to form a cluster, however, they are prohibited to pair-annihilate due to the constraint of local charge conservation. As typical cases, we will report the formation of novel classical spin liquid in the kagome model [1], and a novel collective excitation stabilized in the pyrochlore system [2], and discuss their physical consequences for experimental observables.

[1] T. Mizoguchi, L. D. C. Jaubert and M. Udagawa, arXiv:1702.03794, to appear in Phys. Rev. Lett.
[2] M. Udagawa, L. Jaubert, C. Castelnovo, and R. Moessner, Phys. Rev. B 94, 104416 (2016).

Session 4: 15:45-16:35
Chair: Gang Chen

Generic Spin Model of Pyrochlore Spinels

SungBin Lee
KAIST

Motivated by pyrochlore spinels, we discuss generic spin model considering nearest and next nearest neighbors. Albeit both classical and quantum spins on pyrochlores have been extensively studied, the systematic studies of possible spin orderings are still lacking. Here, we derive the generic spin model on symmetry grounds and investigate new types of spin orderings especially induced by anisotropic spin exchanges between next nearest neighbors. We discover several new states : subset of antiferromagnet degenerate ground states such as local XY state, all in all out state and Palmer-Chalker state and multiple q states so called octagonal prism state and rhombohedral like state. Based on our theoretical results, we also discuss relevant materials and experiments

Reorientation of orbital order in MnV_2O_4

Soonchil Lee
KAIST

The simultaneous occurrence of the structural and magnetic phase transitions observed in MnV_2O_4 is one clear example of strong interplay among the spin, orbital and lattice degrees of freedom. The structure of MnV_2O_4 is switched by the magnetic field and the linear magnetostriction is very high. The orbital order mediates the interaction between the spin and the lattice generating these phenomena. In this work, we present experimental evidence of an orbital order in MnV_2O_4 and its reorientation under a rotating magnetic field as obtained by nuclear magnetic resonance(NMR). The shift in the resonance frequency of the V NMR spectrum is symmetrical with respect to 45° as an external magnetic field of 7 T rotates from the c-axis to the b-axis, indicating that the initial easy axis flips to the orthogonal direction most parallel to the field direction. The spectrum of V^{3+} ions splits into four peaks, which is explained by the anisotropic hyperfine field due to orbital order. Reorientation of the orbital order in response to an external magnetic field accompanies the macroscopically observed magnetostriction in MnV_2O_4.

Poster Session: 16:35-18:30

Day 2

Session 5: 09:00-10:40
Chair: Ying-Jer Kao

Quantum Spin Liquid in Kitaev Materials
Yong-Baek Kim
University of Toronto

We discuss recent theoretical studies of possible quantum spin liquid phases in Kitaev-like models on honeycomb lattice. In particular, we investigate a theoretical model designed for RuCl3 and discuss the results in light of existing and future experiments.

Majorana fermions in Kitaev spin liquids
Yukitoshi Motome
The University of Tokyo

The quantum spin liquid is an exotic ground state of insulating magnets, in which any conventional magnetic ordering is prevented by strong quantum fluctuations. A prominent feature of quantum spin liquids is fractionalization of quantum spins into exotic quasiparticles, such as spinons, which affect the low-temperature behavior. Although considerable efforts have been made for candidate materials, experimental identification of quantum spin liquids remains elusive. We here give an overview on our recent theoretical studies on the Kitaev model which provides an exact quantum spin liquid with fractionalization into Majorana fermions. We show how the fractionalized Majorana fermions affect the thermodynamics, spin dynamics, and thermal transport phenomena. The results are discussed in comparison with the experiments in layered iridates and ruthenates.

Majorana Fermions in the Kitaev Quantum Spin System alpha-$RuCl_3$

Sungdae Ji
Max Planck POSTECH/Hsinchu Center

The seminal work of Anderson triggered a great deal of theoretical and experimental efforts to search for the novel quantum spin liquid (QSL) states in matters, and it has become one of central issues in contemporary condensed matter physics. The QSL state, a long-range quantum entangled state, is represented by a topological order and fractionalization of constituent magnetic moments. While the most QSL states have been described by deconfined spinons as an elementary excitation in frustrated magnets, Kitaev's QSL state is exactly derived by fractionalizing the spin excitation into Majorana fermions in a two-dimensional honeycomb lattice, the so-called Kitaev lattice, with the ansatz of bond dependent Ising-like spin interaction. In the past decade, experimental realization of the fascinating Kitaev honeycomb QSL model has been eagerly pursued. In this talk, I will present the experimental evidences of fractionalized Majorana fermions in a high quality α-RuCl3 single crystal. Neutron and x-ray diffraction measurements reveal that the low-temperature crystal structure forms the perfect Ru-honeycomb lattice, which provides an ideal platform for the Kitaev honeycomb quantum spin lattice. Extensive thermodynamic and neutron spectroscopic measurements directly proved fractionalized Majorana fermion excitations as a result of thermal fractionalization of Jeff = ½ pseudospins, which is well reproduces by numerical predictions obtained from the Kitaev model.

Majorana Persisting magnetic fermions in the diluted α-$Ru_{1-x}Ir_xCl_3$

Kwang Yong Choi
Chung-Ang University

The search for Kitaev spin liquids and concomitantly emergent Majorana fermions is one of the most vigorously pursued goals in current condensed matter physics. However, identifying such an exotic state of matter in real Kitaev honeycomb magnets is extremely challenging as non-Kitaev interactions often stabilize a magnetically ordered state. In this talk, we present thermodynamic and spectroscopic measurements on the diluted α-$Ru_{1-x}Ir_xCl_3$, a prime candidate of the Kitaev honeycomb lattice. Our magnetization, specific heat, and muon spin relaxation data reveal that introducing spin vacancies weaken the zigzag antiferromagnetic order towards short-range quasistatic order above x>0.12. At the same time, Raman spectroscopy gives evidence that moderate spin vacancies lead to a drastic suppression of incoherent magnetic excitations without destroying Majorana excitations. This observation paves the experimental way to realize a Kitaev spin liquid in a diluted Kitaev system.

Session 6: 11:10-12:25
Chair: Ying-Jer Kao

Experimental Realization of a new Quantumn Spin Liquid based on a novel frustration mechanism

Yogesh Singh
Indian Institute of Science Education and Research Mohali

We investigate the novel, unexplored magnet $Ca_{10}Cr_7O_{28}$, which has a complex Hamiltonian consisting of several different isotropic interactions and where the ferromagnetic couplings are stronger than the antiferromagnetic ones. We show both experimentally and theoretically that it displays all the features expected of a quantum spin liquid. Thus spin-liquid behaviour in isotropic magnets is not restricted to the simple idealized models currently investigated, but can be compatible with complex structures and ferromagnetic interactions.

How many spin liquids are there in $Ca_{10}Cr_7O_{28}$?

Nic Shannon
OIST

$Ca_{10}Cr_7O_{28}$ is an exotic new magnetic insulator, in which spin-1/2 Cr^{5+} ions form bilayers of a breathing–Kagome lattice. Exchange interactions in $Ca_{10}Cr_7O_{28}$ are confined to bilayers and predominantly ferromagnetic, with a Curie temperature of 2.35 K [1,2]. None the less, no magnetic order is observed down to 19 mK, making $Ca_{10}Cr_7O_{28}$a highly unusual example of two-dimensional quantum spin liquid [1]

In this talk we explore the nature and origin of the spin liquid observed in $Ca_{10}Cr_7O_{28}$, starting from the microscopic model of magnetic interactions proposed by Balz. et al. [1,2]. Using semi-classical molecular-dynamics simulations, we characterise the evolution of spin dynamics in $Ca_{10}Cr_7O_{28}$ in applied magnetic field, making explicit comparison with published inelastic neutron scattering data.

To our surprise, we find that excitations encode not one, but two distinct types of spin liquid, a ``spiral spin liquid'' similar to that studied in square-lattice frustrated ferromagnets [3], and a coulombic spin liquid previously observed in the Kagome-lattice antiferromagnet [4]. We argue that the zero-field quantum spin-liquid ground state in $Ca_{10}Cr_7O_{28}$ is born out of the ``spiral spin liquid'', and interpret scattering at finite energy in terms of the pinch-points of the coulombic spin liquid. We also offer a simple explanation of the spiral spin liquid behaviour, through a mapping onto an effective spin-3/2 honeycomb lattice model [5]

[1] C. Balz. et al., Nat. Phys. 12, 942 (2016)
[2] C. Balz. et al., Phys. Rev. B 95, 174414 (2017)
[3] L. Seabra et al., Phys. Rev. B 93, 085132 (2016)
[4] D. A. Garanin and B. Canals, Phys. Rev. B 59 443 (1999)
[5] H. Yan, R. Pohle and N. Shannon, in preparation.

Striped Magnetic Ground State of the Ideal Kagomé Lattice Compound $Fe_4Si_2Sn_7O_{16}$

Chris D Ling
The University of Sydney

We have used representational symmetry analysis of neutron powder diffraction data to determine the magnetic ground state of $Fe_4Si_2Sn_7O_{16}$, in which the only magnetic ions present are layers of high-spin Fe^{2+} (d6, S = 2) arranged on a perfect kagomé lattice (trigonal space group P-3m1). Below TN = 3.0 K, the spins on 2/3 of these magnetic ions order into canted antiferromagnetic chains, separated by the remaining 1/3 which are geometrically frustrated and show no long-range ordered down to at least T = 0.1 K. Moessbauer spectroscopy shows that there is no static order on the latter 1/3 of the magnetic ions – i.e., they are in a liquid-like rather than a frozen state – down to at least 1.65 K. A heavily Mn-doped sample $Fe_{1.45}Mn_{2.55}Si_2Sn_7O_{16}$ has the same ground state. Although the magnetic propagation vector k = (0, 1/2, 1/2) breaks hexagonal symmetry, we see no evidence for magnetostriction in the form of a lattice distortion within the resolution of our data. To the best of our knowledge, this type of magnetic order on a kagomé lattice has no precedent experimentally and has not been explicitly predicted theoretically. We will discuss the relationship between our experimental result and a number of theoretical models that predict symmetry breaking ground states for perfect kagomé lattices.

Session 7: 14:00-13:15
Chair: SungBin Lee

Magnetic anisotropy due to pseudo-dipolar interactions in iridates and other heavy transition metal

Hiroaki Ishizuka
University of Tokyo

The effective Hamiltonian for iridates and other heavy transition metal oxides often has large anisotropic interactions such as pseudo-dipolar (Kitaev) interactions. Such magnets show rich physics related to quantum/thermal fluctuations such as quantum spin liquid [1] and order-by-disorder [2]. On the other hand, later studies considering generalized effective models relevant to materials found that these phenomena are susceptible to perturbations [3,4]. Therefore, a good understanding on the effective Hamiltonian of each materials is necessary for the experimental study of the phenomena and related physics, as well as to design a material with a desired property. However, so far, there are no experimental method to estimate the magnitude of anisotropic interactions, which is an experimental obstacle for designing materials with the properties of interest. In this work, we theoretically discuss the possibility of experimentally measuring the magnitude of pseudo-dipolar interactions by magnetic torque measurement.

Considering an effective Hamiltonian for honeycomb iridates, we find that the pseudo-dipolar interactions give rise to a magnetic anisotropy with a unique temperature dependence, which allows us to distinguish it from the anisotropy by other mechanisms. We find that a linear combination of this temperature-dependent magnetic torque curve for different directions only depends on the pseudo-dipolar interactions and not on the other effect, such as lattice distortion [5]. This allows an experimental observation of the pseudo-dipolar interactions. Furthermore, in a certain setup, we find that the magnetic anisotropy induced by the fluctuation prefers to point the spins toward different direction depending on the temperature [6].

[1] A. Kitaev, Ann. Phys. 321, 2 (2006).
[2] G. Khaliulin, Phys. Rev. B 64, 212405 (2001).
[3] J. G. Rau, E. K.-H. Lee, and H. Y. Kee, Phys. Rev. Lett. 112, 077204 (2014).
[4] J. Chaloupka and G. Khaliullin, Phys. Rev. B 94, 064435 (2016).
[5] H. Ishizuka, Phys. Rev. B 95, 184413 (2017).
[6] H. Ishizuka and L. Balents, Phys. Rev. B 92, 020411(R) (2015).

Photo-creating supercooled spiral-spin states in a multiferroic manganite

Yu-Miin Sheu
National Chiao-Tung University

We demonstrate that dynamics of the ab-spiral-spin order in a magnetoelectric multiferroic $Eu_{0.55}Y_{0.45}MnO_3$ can be unambiguously probed through optical second harmonic signals, generated via the spin-induced ferroelectric polarization. In the case of relatively weak photoexcitation, the ferroelectric and the spiral-spin order remains interlocked, both relaxing through spin-lattice relaxation in the non-equilibrium state. When the additional optical pulse illuminating sample is intense enough to induced a local phase transition thermally, the system creates a metastable state of the bc-spiral-spin order (with the electric polarization P//c) via supercooling across the first-order phase transition between ab- and bc-spiral. The supercooled state of bc-spiral spin is formed in the thermodynamical ground state of ab-spiral (P//a), displaying a prolonged lifetime with strong dependence on the magnetic field along the a-axis. The observed photo-switching between the two distinct multiferroic states sheds light on novel photoinduced phenomena in spiral-spin multiferroics.

Emergent Charge Condensations at Two-Dimensional Oxide Interfaces and Néel-Type Ferroelectric Domain

Ming-Wen Chu
National Taiwan University

The heterointerface of insulating $LaAlO_3$ (LAO) and $SrTiO_3$ (STO) that are also non-magnetic and orbital-quenched harbors a plethora of emergent phenomena, ranging from interfacial conductivity, interfacial magnetism, interfacial orbital reconstruction, to interfacial superconductivity. With these distinct properties, LAO/STO boasts vast opportunities at oxide heterointerfaces and represents the model system in modern oxide superlattices. To date, a wide spectrum of oxide heterojunctions and interfacial characteristics have been reported. However, the basic question of why there shall be the metallic LAO/STO interface remains elusive, let alone a systematic understanding in the more complex problems of magnetic ordering, orbital physics, and superconducting order parameter at two-dimensional interfaces. Using atomic-resolution imaging and electron spectroscopy, we tackled the origin of the interfacial metallicity in LAO/STO by unit-cell-by-unit-cell characterizations of structural distortions and charge distribution at quantitative atomic accuracy and resolved hidden ferroelectric-like lattice instabilities across the interface, which are rejuvenated by the characteristic epitaxial strain. The hidden polar order parameters in the LAO and STO lattices form an intriguing head-to-head configuration, casting the interface into an electron reservoir and giving rise to the interfacial conductivity. The impact of such strain-rejuvenated ferroelectric-like lattice instabilities on the physics of oxide heterointerfaces is unnoticed in the past [P. W. Lee et al., Nat. Commun. 7, 12773 (2016)] and paves the avenue to address the outstanding problem in the new class of hybrid improper ferroelectrics Ca3Ti2O7, where abundant head-to-head and tail-to-tail ferroelectric domain walls (i.e., homostructural interfaces) coexist and demand for respective screening electrons and holes. Nevertheless, only electrons are available in the n-type titanate. Our atomic-scale studies of the subject unveiled that the material features a hidden antipolar order parameter, which also consists of the structural essence of the domain walls with a 90° rotation across the walls, mimicking Néel-type walls in magnetism. Correlated structural screening for the head-to-head and tail-to-tail domains walls, lifting the conventional electrostatic screening by respective electrons and holes, was demonstrated [M.-H. Lee et al., in revision].

Session 8: 15:45-16:35
Chair: SungBin Lee

Spin-liquid Mott quantum criticality in two dimensions: Destabilization of a spinon Fermi surface an
Ki-Seok Kim
POSTECH

Resorting to a recently developed theoretical device called dimensional regularization for quantum criticality with a Fermi surface, we examine a metal-insulator quantum phase transition from a Landau's Fermi-liquid state to a U(1) spin-liquid phase with a spinon Fermi surface in two dimensions. Unfortunately, we fail to approach the spin-liquid Mott quantum critical point from the U(1) spin-liquid state within the dimensional regularization technique. Self-interactions between charge fluctuations called holons are not screened, which shows a run-away renormalization group flow, interpreted as holons remain gapped. This leads us to consider another fixed point, where the spinon Fermi surface can be destabilized across the Mott transition. Based on this conjecture, we reveal the nature of the spin-liquid Mott quantum critical point: Dimensional reduction to one dimension occurs for spin dynamics described by spinons. As a result, Landau damping for both spin and charge dynamics disappear in the vicinity of the Mott quantum critical point. When the flavor number of holons is over its critical value, an interacting fixed point appears to be identified with an inverted XY universality class, controlled within the dimensional regularization technique. On the other hand, a fluctuation-driven first order metal-insulator transition results when it is below the critical number. We propose that the destabilization of a spinon Fermi surface and the emergence of one-dimensional spin dynamics near the spin-liquid Mott quantum critical point can be checked out by spin susceptibility with a $2k_F$ transfer momentum, where kF is a Fermi momentum in the U(1) spin-liquid state: The absence of Landau damping in U(1) gauge fluctuations gives rise to a divergent behavior at zero temperature while it vanishes in the presence of a spinon Fermi surface.

Unconventional Surface Criticality Induced by Quantum Phase Transitions from 2D AKLT Phase to Neel Order
Fa Wang
Peking University

We will present our studies [Phys. Rev. Lett. 118, 087201 (2017)] about the physical consequence of the gapless surface states of 2D AKLT phase at the bulk quantum phase transition (QPT). We realize the two-dimensional Affleck-Kennedy-Lieb-Tasaki phase on a square lattice and its QPTs to Neel ordered phases by a spin-1/2 Heisenberg model on a decorated square lattice. With large-scale quantum Monte Carlo simulations, we find that even though the bulk QPTs are governed by the conventional 3D O(3) symmetry breaking transition universality class, the gapless surface states induce unconventional universality classes of the surface critical behaviors.

Thermal conductivity in U(1) quantum spin liquids.

Eungook Moon
KAIST

Quantum spin liquids (QSLs) are extraordinary phases which shows intrinsic many body entanglements by quantum fluctuations and geometric frustrations. Recent experiments as in Kitaev honeycomb and pyrochlore systems demonstrate signatures of QSLs and call for deeper theoretical understanding of QSLs. Here, we investigate thermal transport properties of U(1) QSLs on pyrochlore structures. Intriguing scattering mechanisms between emergent particles are considered and transport properties are obtained. We also propose smoking gun experiments for the existence of U(1) QSLs.

Day 3

Session 9: 09:00-10:40
Chair: Nic Shannon

Large anomalous Hall and Nernst effects at room temperature in a magnetic topological metal

Takahiro Tomita
Institute for Solid State Physics, University of Tokyo

It has been recently found that Mn$_3$Sn exhibits a large anomalous Hall effect as the first case in antiferromagnets. Therefore, it is expected that the anomalous Nernst effect, which is the thermoelectric counterpart of the anomalous Hall effect, could be large in the material. Here,in Mn$_3$Sn, we found a large spontaneous anomalous Nernst effect showing 0.35 μV/K at room temperature and 0.6 μV/K at low temperature.

These large Hall and Nernst signals are found to be enhanced by the Berry curvature associated with the Weyl points near the Fermi energy. In our talk, we also propose that the large anomalous Hall and Nernst effects are useful for memory and thermopile devices, respectively.

Quantum Impurity in a Luttinger Liquid

Pochung Chen
National Tsing Hua University

We study correlation functions of the spin-1/2 XXZ model with a single impurity. Numerically, by using a finite system with "infinite boundary conditions" we can simulate a finite region of the impurity systems in the thermodynamic limit. Analytically, we use bosonization and boundary conformal field theory to obtain the leading and sub-leading exponents of the correlation functions. In particular, we calculate <S+S->, <SzSz>, and <JJ> correlation functions. We find excellent agreements between numerical and analytical results. This demonstrates that infinite boundary conditions can be a powerful tool to study quantum impurity systems.

Dynamical reduction of the dimensionality of exchange interactions and the "spin-liquid" phase of κ-(BEDT-TTF)$_2$X

Ben James Powell
University of Queensland

We show that the anisotropy of the effective spin model for the dimer Mott insulator phase of κ-(BEDT-TTF)$_2$X salts is dramatically different from that of the underlying tight-binding model. Intra-dimer quantum interference results in a model of coupled spin chains, where frustrated interchain interactions suppress long-range magnetic order. Thus, we argue, the "spin liquid" phase observed in some of these materials is a remnant of the Tomonaga-Luttinger physics of a single chain. This is consistent with previous experiments and resolves some outstanding puzzles.

B. J. Powell, E. P. Kenny, J. Merino, arXiv:1704.05688

Griffiths Singularities in Quantum Magnets

Yu-Cheng Lin
National Chengchi University

Session 10: 11:10-12:25
Chair: Nic Shannon

What does inelastic neutron scattering measure in quantum spin ices?
Gang Chen
Fudan University

We study the U(1) quantum spin liquid on the pyrochlore spin ice systems. For the non-Kramers doublets such as Pr^{3+} and Tb^{3+}, we point out that the inelastic neutron scattering result not only detects the low-energy gauge photon, but also contains the continuum of the “magnetic monopole” excitations. Unlike the spinons, these “magnetic monopoles” are purely of quantum origin and have no classical analogue. We further point out that the “magnetic monopole” experiences a background dual “π” flux due to the spin-1/2 nature of the local moment when the “monopole” hops on the dual diamond lattice. We then predict that the “monopole” continuum has an enhanced spectral periodicity with a folded Brillouin zone. This prediction can be examined among the existing data on the non-Kramers doublet spin liquid candidate materials like $Pr_2TM_2O_7$ and $Tb_2TM_2O_7$ (with TM = “transition metal”). The application to the Kramers doublet systems and numerical simulation is further discussed. Finally, we present a general classification of distinct symmetry enriched U(1) quantum spin liquids based on the translation symmetry fractionalization patterns of “monopoles” and “spinons”.

Spin excitations in a triangular lattice quantum spin liquid candidate
Jun zhao
Fudan University

Quantum spin liquids (QSLs) are exotic states of matter characterized by emergent gauge structures and fractionalized elementary excitations. The recently discovered triangular lattice antiferromagnet $YbMgGaO_4$ is a promising QSL candidate. In this talk, we report neutron scattering measurements that reveal broad spin excitations covering a wide region of the Brillouin zone in $YbMgGaO_4$. The observed diffusive spin excitation persists at the lowest measured energy and shows a clear upper excitation edge at zero field, which can be naturally accounted for by the particle-hole excitation of a spinon Fermi surface. Moreover, a spectral crossing emerges at the Γ point at the Zeeman-split energy under a weak magnetic field. The corresponding redistribution of the spectral weight and its field-dependent evolution are inconsistent with a magnon behavior, but instead are unique features for fractionalized spinon excitations. Furthermore, we show that the measured dynamic spin structure is consistent with the theoretical prediction based on the inter-band and intra-band spinon particle-hole excitations associated with the Zeeman-split spinon bands. These results provide strong evidence for fractionalized excitations and spinon Fermi surfaces in $YbMgGaO_4$ [1,2].

[1] Yao Shen, Yao-Dong Li, Hongliang Wo, Yuesheng Li, Shoudong Shen, Bingying Pan, Qisi Wang, H. C. Walker, P. Steffens, M. Boehm, Yiqing Hao, D. L. Quintero-Castro, L. W. Harriger, M. D. Frontzek, Lijie Hao, Siqin Meng, Qingming Zhang, Gang Chen and Jun Zhao, Nature, 540, 559-562 (2016).

[2] Yao Shen, Yao-Dong Li, H. C. Walker, P. Steffens, M. Boehm, Xiaowen Zhang, Shoudong Shen, Hongliang Wo, Gang Chen and Jun Zhao arXiv: 1708.06655 (2017).