# imptex12

| Participant | Title | Abstract |
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| Fabien Alet | Impurity spin texture at deconfined quantum critical points | The use of non-magnetic impurities is an elegant and well-exploited strategy to unveil the physics of several condensed matter systems, such as quantum magnets or superconductors. Such impurities induce real-space textures, which are characteristic signatures of the underlying low-temperature states.<br><br>We use spinless impurities to theoretically probe an unconventional quantum critical point between an antiferromagnet and a Valence Bond Crystal. Our large scale quantum Monte Carlo simulations on the SU(2) J-Q model on the square lattice indicate that the spin texture does not obey the universal scaling form expected at a scale invariant quantum critical point, showing a logarithmic form of violation to scaling.<br><br>Extending the model to a higher SU(N) symmetry (with N=3), we find that such logarithmic violations leave place to strong but conventional corrections to scaling. Our results suggest that a correct field-theoretical description of deconfined critical points may require operators that become marginal as N is reduced to 2.<br><br>Work done in collaboration with Argha Banerjee and Kedar Damle. |
| Siddharth Ashok Parameswaran | Nematic Ordering and the Random Field Ising Model in Quantum Hall Valley Ferromagnets | The interplay between quantum Hall ordering and spontaneously broken "internal" symmetries in two-dimensional electron systems with spin or pseudospin degrees of freedom gives rise to a variety of interesting phenomena, including novel phases, phase transitions, and topological excitations. I will focus on a class of multi-valley systems, where the symmetry at issue is a point group element that combines a spatial rotation with a permutation of valley indices. In generic cases, the dispersion relation is anisotropic and favors states where all electrons reside in one of the valleys, which in clean systems leads to valley ferromagnetism with accompanying spatial nematic order via a finite-temperature transition. Weak disorder destroys this valley ferromagnet through domain formation; however, the resulting state still asymptotically exhibits the QHE. I will discuss transport properties in the ordered and disordered regimes, and their relevance to recent experiments in AlAs. I will also briefly comment on a different example, relevant to bilayer graphene, where the valley ferromagnet is fully SU(2) symmetric and hosts stable, electrically charged skyrmionic excitations. |
| John Chalker | Effects of disorder in a quantum spin liquid | We use the Kitaev honeycomb model as a theorists' lab to investigate the effects of impurities in a spin liquid.<br>This model without disorder has been studied intensively as a solvable example of a spin liquid. It has<br>phases of two types -- gapped and gapless -- depending on model parameters, and supports two kinds<br>of excitation, consisting of fermions and fluxes.<br>We show that the model remains solvable in the presence of vacancies and exchange randomness, and<br>we examine the consequences of both types of disorder.<br>The ground state of the clean system has a finite magnetic susceptibility,<br>but we find that vacancies induce local moments. In the gapless phase these are free, with a $g$-factor that depends on model parameters. In the gapped phase, moments are induced around vacancies only in the presence<br>of a magnetic field, but the local susceptibility is very singular. Moreover, a vacancy binds<br>a flux excitation, and this modulates the magnetic response.<br>In the gapless phase the local susceptibility of a single vacancy diverges for small $h$ as $\chi(h)\sim\ln(1/h)$.<br>Local moments formed around nearby vacancies interact, with consequences that depends on whether they occupy the same or opposite sublattices of the honeycomb lattice. For a pair of vacancies on the same sublattice, the local susceptibility in the gapless phase is parametrically larger than for a single vacancy, varying as $\chi(h)\sim1/(h[\ln(1/h)]^{3/2})$. By contrast, weak exchange randomness does not qualitatively alter the susceptibility but has its signature in the heat capacity, which in the gapless phase is power law in temperature with an exponent dependent on disorder strength. |
| Sian Dutton | Hole doping and dimensionality in Cr3+ geometrically frustrated magnets | The divergent effect of dilution and hole doping on the magnetic properties of the complex geometrically frustrated magnet, -CaCr2O4, have recently been shown.[1] I will demonstrate how, by careful control of the reaction conditions, it is possible to hole dope the simpler chromate spinels, ACr2O4 (A = Zn, Mg).[2] In these systems only a small number of holes can be introduced, 2 %, but appreciable changes in both the high temperature magnetic fluctuations and antiferromagnetic ordering temperature, TN, are observed. These changes are highly sensitive to not only the type of dopant introduced but also to cation substitution on the A site. Through analysis of both the thermomagnetic properties and diffraction measurements the nature of the nuclear and structural transitions at TN will be addressed. In an extension of this, the role of dimensionality and the consequences of disorder on the magnetic lattice will be explored in the layered two-dimensional spinel analogue SCGO, SrCr9Ga3O19.[3]<br><br>[1] Dutton S E, Broholm C L and Cava R J 2010 Divergent effects of static disorder and hole doping in geometrically frustrated b-CaCr2O4 Journal of Solid State Chemistry 183 1798-804<br>[2] Dutton S E, Huang Q, Tchernyshyov O, Broholm C L and Cava R J 2011 Sensitivity of the magnetic properties of the ZnCr2O4 and MgCr2O4 spinels to nonstoichiometry Physical Review B 83 064407<br>[3] Dutton S E, Hanson E D, Broholm C L, Slusky J S and Cava R J 2011 Magnetic properties of hole-doped SCGO, SrCr8Ga4-xMxO19 (M = Zn, Mg, Cu) Journal of Physics-Condensed Matter 23 386001 |
| Claudia Felser | Topological insulators from the view point of chemistry | |
| Christian Hess | Spin gap from S=1 impurities in the zigzag Spin-1/2 chain cuprate SrCuO2 | We have studied the low-energy spin excitations in zigzag Spin-1/2 chain cuprate SrCuO2 by means of thermal transport and Nuclear Magnetic Resonance, and investigated the impact of a slight amount of Ni (S=1) impurities. The pure material exhibits a very large spinon heat conductivity which is substantially suppressed already at a Ni doping level of 0.25%, indicating a strong spinon-impurity scattering mechanism. Concomitantly to this suppression the phononic heat conductivity is enhanced. This suggests that strong phonon-spinon scattering is present in the pure material which becomes unimortant upon Ni-doping. 1/T1 data for 1% doping level provide clear evidence for a substantial spin gap of the order of 285K which naturally explains the unconventional data for the phononic heat transport. |
| Kazushi Kanoda | Inhomogeneous states in undoped and doped triangular-lattice organic Mott insulators | Several spin-liquid candidates emerged from organic Mott insulators with quasi-triangular lattices. $\kappa$-(ET)2Cu2(CN)3, which is the first among them, shows no magnetic ordering down to temperatures four orders of magnitude lower than the exchange interaction. However, it exhibits mysterious anomalies around 6K in NMR relaxation rate, specific heat, thermal conductivity and expansivity. This anomaly accompanies an enhanced inhomogeneity as seen in NMR line broadening. Because it is suppressed on Mott transition under pressure, it seems inherent in spin liquid. Another compounds, $\kappa$-(ET)4Hg2.89Br8, is a doped Mott insulator with a nearly triangular lattice—very probably a doped spin liquid. This is a superconductor; however, both the superconductivity and normal state are inhomogeneous at low pressures. Interestingly, they get homogeneous at a certain pressure. The overall behavior points to an inhomogeneous-to-homogeneous quantum phase transition.<br>In the workshop, I discuss the two materials in the light of (intrinsic) inhomogeneity.<br><br>This presentation is based on the collaboration with K. Miyagawa, Y. Shimizu, F. Kagawa, Y. Kurosaki, T. Furukawa, H. Hashiba, H. Oike, H. Kasahara, H. Taniguchi, S. Yamashita, Y. Nakazawa, M. Maesato and G. Saito. |
| Ying-Jer Kao | Quantum antagonism of ferromagnetic order | We study the interplay of superfluidity, glassy and magnetic orders of hardcore bosons with random frustrating interactions.<br>In the classical limit, this model reduces to a $\pm J$ Edwards-Anderson Ising model with concentration $p$ of the ferromagnetic bonds, which hosts a glassy-ferromagnetic transition at a critical concentration $p_c^{\rm cl}\sim 0.77$ on a 3D cubic lattice. Our quantum Monte Carlo simulation results using the worm algorithm show that quantum fluctuations stabilize the coexistence of superfluidity and glassy order ( "superglass"), and shift the (super)glassy-ferromagnetic transition to $p_c> p_c^{\rm cl}$. In contrast, antiferromagnetic order coexists with superfluidity to form a supersolid, and the transition to the glassy phase occurs at a higher $p$. |
| Naoki Kawashima | Quantum Monte Carlo Study of SU(N) J-Q Models | Quantum Monte Carlo is one of powerful tools for clarifying quantum state of matter. Its applications ranges from quantum magnets to optical lattices. Here I review recent developments in the method and how it can be implemented in the world fastest computer. I then focus on how a class of peculiar quantum phase transitions have been discovered by this method. The transition is realized in the antiferromagnetic Heisenberg model extended to the SU(N) symmetry. This second-order phase transition falls out of this Landau-Ginzberg-Wilson paradigm. Some numerical evidences point to realization of such a novel phase transition while the other suggest a weak 1st order transition. In the case of fundamental representation, SU(N) Heisenberg model with no 4-body interactions shows alternating textures of the VBS pattern depending on the value of N. When the ground state is the VBS state, we observed approximately circular distribution of the VBS order parameter, possibly reflecting the U(1) nature of the deconfined critical point. By introducing four-body interactions (Q-term), we can control the quantum fluctuation so that the quantum criticality is realized. We obtained a set of estimates of the critical exponents that seem consistent with the 1/N expansion theory. |

**Dmitry Kovrizhin**

**Multicomponent Skyrmion lattices and their excitations**

We study quantum Hall ferromagnets with a finite density of topological charged spin textures in the presence of internal degrees of freedom such as spin, valley or layer indices, so that the ferromagnet is locally parametrised by a $d$-component complex spinor. In the absence of anisotropies, we find formation of an hexagonal crystal which completely breaks the underlying SU(d) symmetry. The ground state charge density modulation which inevitably exists in Skyrmion crystals vanishes exponentially in $d$. We compute the complete low-energy excitation spectrum, which separates into $d2/2-1$ gapless acoustic magnetic excitations and a magnetophonon excitation.

**Philippe Mendels**

**NMR Imaging Spin Textures in Highly Frustrated Magnets**

Work done at Laboratoire de Physique des solides, Université Paris-Sud 11, Orsay (France)

NMR, through MRI, is famous for its ability to image locally non uniform densities in the human body. In the field of electronic systems it was used in the 70's to reveal both the static and the electronic response of the host metal around magnetic impurities (e.g. CuMn). More recently, there are numerous examples on how relevant it was to probe the normal state and superconducting states of High Temperature Superconductors and S=1 spin chains such as YBa2NiO5. I will first briefly review some of the most salient examples. I will describe how NMR could reveal some features of impurity / disorder induced (or intrinsic) spin textures in Highly Frustrated Magnets. I'll sort out which static and dynamical information can be extracted from such NMR measurements and what would be the ideal, still long to go, route in the context of idealized materials with controlled and minute amount of impurities.

My talk will be illustrated through examples taken on kagome lattices that have been explored in my Orsay group over the last decade from SrCr9pGa12-9pO19 to Herbertsmithite. If the time permits, I'll address a comparison with muSR and macroscopic measurements.

**Olexei Motrunich**

**Effects of nonmagnetic disorder in spin liquid antiferromagnets**

Motivated by recent experiments in Kagome and triangular spin liquid materials, we study textures around non-magnetic impurities in such frustrated antiferromagnets focusing in particular on local susceptibilities (Knight shifts). High temperature series expansion allows quantitative calculations of the local susceptibilities down to T = 0.3 J. At low temperatures, we explore candidate spin liquid proposals with fermionic spinons and calculate the local susceptibilities in the mean field and beyond the mean field by Gutzwiller projection in 2d and by bosonization in quasi-1d. For a spin liquid with a spinon Fermi sea, the local susceptibility textures are particularly strong and oscillate at 2k_F, providing a possible way for probing such a phase.

**Satoru Nakatsuji**

**Novel spin orbital states in quasi-2D frustrated magnets**

Frustrated magnetic materials, where local conditions for energy minimization are incompatible due to the lattice structure, can remain disordered to the lowest temperatures. In this talk, I will present novel low temperature magnetism for two different quasi-2D frustrated magnets.
(1) First material is the quantum spin-liquid candidate, 6H-perovskite Ba3CuSb2O9. This compound is found magnetically anisotropic at the atomic scale but curiously isotropic on mesoscopic length and time scales. We find that the frustration of Wannier's Ising model on the triangular lattice is imprinted in a nano-structured honeycomb lattice of Cu2+ ions that resists a coherent static Jahn-Teller distortion. The resulting two-dimensional random bond spin-1/2 system on the honeycomb lattice has a broad spectrum of spin-dimer-like excitations and low energy spin degrees of freedom that retain overall hexagonal symmetry [1].
(2) Second materials are the quasi-2D triangular lattice antiferromagnets (Ni,Fe)Ga2S4. I will discuss the evidence for exotic magnetic transition found in these systems into a novel spin disordered states at low temperatures [2,3]. Impurity effects, which are strongly dependent on the spin size, will be also presented.

[1] S. Nakatsuji, K. Kuga, K. Kimura, R. Satake, N. Katayama, E. Nishibori, H. Sawa, R. Ishii, M. Hagiwara, F. Bridges, T. U. Ito, W. Higemoto, Y. Karaki, M. Halim, A. A. Nugroho, J. A. Rodriguez-Rivera, M. A. Green, C. Broholm, preprint (2012).
[2] S. Nakatsuji, Y. Nambu, and S. Onoda,Journal of the Physical Society of Japan, Vol. 79, 011003 (2010). Special Topics
[3] P. Dalmas de R´eotier, A. Yaouanc, D. E. MacLaughlin, Songrui Zhao, T. Higo, S. Nakatsuji, Y. Nambu, C. Marin, G. Lapertot, A. Amato, and C. Baines, preprint (2012).

**Masaki Oshikawa**

**Stability of skyrmions in spinor condensates**

We discuss the stability of skyrmions in spinor condensates with (pseudo) spin 1/2, such as Rb Bose-Einstein condensates, in 3 dimensions. In the free space, the skyrmion is unstable against shrinking, despite its nontrivial topology. On the other hand, based on a mechanical analogy, we show that a topological Skyrmion can be stabilized in a suitably chosen potential. A sufficient condition for the existence of a stable skyrmion is formulated, and some simple solutions are constructed.

**Armin Rahmani**

**Fractionalization and topological defects in Kondo lattice models with noncoplanar magnetic ordering**

We show that Kondo lattice models with noncoplanar magnetic ordering, which exhibit spontaneous integer quantum Hall effect, can have fractionalized electronic excitations with anyonic exchange statistics. The fractionalized excitations are bound to the cores of topologically stable vortices in the magnetic order parameter. For highly symmetric states, the vortex charge is half-odd integer, although other, generally irrational, charges are possible for less symmetric states.

**Ioannis Rousochatzakis**

**Dzyaloshinskii-Moriya anisotropy and non-magnetic impurities in the s = 1/2 kagome system ZnCu3(OH)6Cl2**

Motivated by nuclear magnetic resonance experiments on ZnCu3(OH)6Cl2, we present an exact-diagonalization study of the combined effects of nonmagnetic impurities and Dzyaloshinskii-Moriya (DM) interactions in the s=1/2 kagome AFM. The local response to an applied field and correlation-matrix data reveal that the dimer freezing which occurs around the impurity for D=0 persists at least up to D/J0.06, where J and D denote, respectively, the exchange and DM interaction energies. The phase transition to the (Q=0) semiclassical 120° state favored at large D takes place at D/J0.1. However, the dimers next to the impurity sites remain strong up to values DJ, far above this critical point, and thus do not participate fully in the ordered state. We discuss the implications of our results for ZnCu3(OH)6Cl2.

In collaboration with:
S. R. Manmana, A. M. Läuchli, B. Normand, and F. Mila

**Peter Schiffer**

**tba**

**Arnab Sen**

**Orphan spin textures in SCGO and their interactions**

Spin liquids are remarkable states of matter that do not order magnetically even at very low temperatures and show collective phenomena like emergent gauge fields and topological order. Impurities can potentially reveal the underlying correlations in such states that appear deceptively featureless. We consider the archetypal frustrated antiferromagnet SrCr$_{9p}$Ga$_{12-9p}$O$_{19}$ (SCGO) in which Ga ions act as non-magnetic impurities in the magnetic lattice composed of Cr$^{3+}$ $S=3/2$ spins for disordered $p<1$ samples. We demonstrate that a spin in direct proximity to a pair of vacancies (orphan spin) is cloaked by a spatially extended spin texture that encodes the correlations of the parent spin liquid. In this spin liquid regime, the combined object has a magnetic response identical to a classical spin of length $S/2=3/4$, which dominates over the small intrinsic susceptibility of the pure system. This fractional-spin texture leaves an unmistakable imprint on the measured $^{71}$Ga nuclear magnetic resonance (NMR) lineshapes. We also show that these textures interact via an entropic temperature dependent pair-wise exchange interaction that has a logarithmic short-distance dependence, and decays exponentially beyond a thermal correlation length $\xi \sim 1/\sqrt{T}$ and whose sign depends on whether the two orphan spins belong to the same Kagome layer or not.

**Oleg Tchernyshyov**

**Spin waves in a skyrmion crystal**

We derive the spectrum of low-frequency spin waves in skyrmion crystals observed recently in noncentrosymmetric ferromagnets. We treat the skyrmion crystal as a superposition of three helices whose wavevectors form an equilateral triangle. The low-frequency spin waves are Goldstone modes associated with displacements of skyrmions. Their dispersion is determined by the elastic properties of the skyrmion crystal and by the kinetic terms of the effective Lagrangian, which include both kinetic energy and a Berry-phase term reflecting a nontrivial topology of magnetization. The Berry-phase term acts like an effective magnetic field, mixing longitudinal and transverse vibrations into a gapped cyclotron mode and a twist wave with a quadratic dispersion.

**Yoshinori Tokura**

**Emergent electormagnetic phenomena from topological spin textures**

**Simon Trebst**

**Impurity Effects in Highly Frustrated Diamond-Lattice Antiferromagnets**

We consider the effects of local impurities in highly frustrated diamond lattice antiferromagnets, which exhibit large but non-extensive ground state degeneracies. Such models are appropriate to many A-site magnetic spinels. We argue very generally that sufficiently dilute impurities induce an ordered magnetic ground state, and provide a mechanism of degeneracy breaking. The states which are selected can be determined by a "swiss cheese model" analysis, which we demonstrate numerically for a particular impurity model in this case. Moreover, we present criteria for estimating the stability of the resulting ordered phase to a competing frozen (spin glass) one. The results may explain the contrasting finding of frozen and ordered ground states in CoAl2O4 and MnSc2S4, respectively.

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| Hirokazu Tsunetsugu | Magnetic impurities in spin nematic order | Spin nematic oder is a state with broken rotation<br>symmetry in spin space, but magnetic dipole moments are not present. It is interesting to investigate the physics of magnetic impurities in this system introduced by defects, since those<br>impurities may exhibit properties reflecting the nematic order in the host. To be specific, we have studied the system of an antiferro nematic order on the triangular lattice with triangular-shaped impurities. We have found that long-range biquadratic interactions are induced between separated impurities via exchange of gapless excitations in the nematic order. Short-range part also includes anisotropic<br>interaction of bilinear type. I will also talk about a possible implication to unconventional slow spin dynamics observed in the S=1 triangular antiferromagnet $NiGa_2S_4$.<br><br>This talk is based on the collaboration work with Junji Takano:<br>Takano and Tsunetsugu, J. Phys. Soc. Jpn. 80, 094707 (2011). |
| Jeroen van den Brink | Itinerant electrons in frustrated magnets: Emerging chiral insulators, macroscopic degeneracies and [fractional] quantum Hall liquids | Models of itenerant electrons coupled to local spins show a suprising rich spectrum of non-trivial phases, in particular in the presence of competing antiferromagnetic interactions and on frustrated lattices. For the double-exchange model at half-filling on a triangular lattice, for instance, one finds upon increasing superexchange interactions in between a trivial itinerant ferromagnetic and the 120 degree Yafet-Kittel phase a robust scalar-chiral, insulating spin state [1]. On the honeycomb lattice instead, a set of macroscopic degenerate groundstates emerges [2]. On a checkerboard lattice magnetic flux-phases can be stabelized in which Dirac fermions acquire a topological mass, leading to a switchable Quantum Anomalous Hall state [3]. In the presence of additional orbital degrees of freedom, topologically nontrivial band can become very narrow, giving rise to the spontaneous formation of fractional quantum-Hall state [4].<br><br>With: Jorn Venderbos, Stefanos Kourtis, Maria Daghofer, Sanjeev Kumar<br><br>[1] Phys. Rev. Lett. 105, 216405 (2010).<br>[2] Phys. Rev. Lett. 107, 076405 (2011).<br>[3] ArXiv:1202.3340. [4] ArXiv:1109.5955. |
| Matthias Vojta | Vacancies in ordered magnets: Fractional moments and breakdown of linear response | We discuss dilute vacancies in semiclassically ordered antiferromagnets. First, we show that for non-collinear magnets like the triangular-lattice Heisenberg model, the magnetic moment associated with a vacancy is not quantized, but receives non-universal screening corrections due to local relief of frustration. In two dimensions and at finite temperatures, where bulk long-range order is absent, this implies a vacancy-induced magnetic response of Curie form, with a prefactor corresponding to a fractional moment per impurity. Second, we discuss the behavior of an antiferromagnet with a vacancy in an applied magnetic field and argue that the linear-response limit is singular under rather generic conditions. Experimental implications are highlighted. |