**Topological superconductor - Luttinger liquid junctions**

Affleck, Ian  
(University of British Columbia, Physics and Astronomy, Vancouver, Canada)

A junction between a topological superconductor and a Luttinger liquid can exhibit a novel quantum critical point. I will discuss its properties and how it might be experimentally observed.

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**Unconventional excitations in frustrated magnets**

Balents, Leon  
(University of California, Kavli Institute for Theoretical Physics, Santa Barbara, USA)

I will describe recent work from our group on unusual excitations of frustrated magnets with novel ground states, such as quantum spin liquids, spin-orbital liquids, and field-induced states.

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**Stiffness from disorder in triangular Ising thin films**

Batista, Cristian Daniel  
(Los Alamos National Laboratory, Theoretical Division, MS B258, Los Alamos, USA)

I will introduce the thermodynamic phase diagram of a multilayered triangular lattice Ising model (MLTIM) with a finite number of vertically stacked layers. We will see that above a critical number of layers, there is a low temperature reentrance of one or two Berezinskii-Kosterlitz-Thouless (BKT) transitions, which results in an extended pseudo-critical disordered regime down to zero temperature. This low-temperature disordered regime has peculiar properties, such as a negative value of (short-range spin-spin correlations increase with temperature). I will explain the origin of this “stiffness by disorder” by analyzing the RG flow of a low energy effective dimer theory that quantitatively describes the low temperature physics of the MLTIM. I will also derive qualitative features of the global phase diagram by mapping the classical spin model into the single-layer quantum Ising model and show comparisons against Monte Carlo simulations of the original model.

*Work done in collaboration with Yoshitomo Kamiya, Shizeng Lin and Gia Wei Chern

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**Gapless and gapped spin liquids in Heisenberg models**

Becca, Federico  
(SISSA - International School for Advanced Studies, Condensed Matter Sector, Trieste, Italy)

We present our recent numerical calculations on the Heisenberg model on the square and Kagome lattices, showing that gapless spin liquids may be stabilized in highly-frustrated regimes. For the Kagome lattice, we find that a gapless U(1) spin liquid with Dirac cones is competitive with previously proposed gapped spin liquids when only the nearest-neighbor antiferromagnetic interaction is present.[1,2] The inclusion of a next-nearest-neighbor term lead to a Z_2 gapped spin liquid,[3] in agreement with density-matrix renormalization group calculations.[4] In the Heisenberg model on the square lattice with both nearest- and next-nearest-neighbor interactions, a Z_2 spin liquid with gapless spinon excitations is stabilized in the frustrated regime.[5] In all these cases, the magnetically disordered phases can be described by considering Abrikosov fermions coupled to gauge fields.

“Light-cone” dynamics after quantum quenches in spin chains using METTS
Bonnes, Lars
(University of Innsbruck, Institute for Theoretical Science, Innsbruck, Austria)

Signal propagation in the non equilibrium evolution after quantum quenches has recently attracted much experimental and theoretical interest. A key question arising in this context is what principles, and which of the properties of the quench, determine the characteristic propagation velocity. Here we investigate such issues for a class of quench protocols in one of the central paradigms of interacting many-particle quantum systems, the spin-1/2 Heisenberg XXZ chain. We consider quenches from a variety of initial thermal density matrices to the same final Hamiltonian using matrix product state methods. The spreading velocities are observed to vary substantially with the initial density matrix. However, we achieve a striking data collapse when the spreading velocity is considered to be a function of the excess energy. Using the fact that the XXZ chain is integrable, we present an explanation of the observed velocities in terms of "excitations" in an appropriately defined generalized Gibbs ensemble.

The coherent precession of magnetization in antiferromagnets
Bunkov, Yury
(Centre National de la Recherche Scientifique (CNRS), Institut Neel, MCBT, Grenoble, France)

The Bose-Einstein condensation (BEC) corresponds to the formation of a collective quantum state in which macroscopic number of particles is governed by a single wave function. The formation of this state was predicted by Einstein in 1925. The BEC of magnons was first discovered experimentally in superfluid phase of $^3$He-B. It manifests itself by coherent precession of magnetization. Then 6 different states of superfluid $^3$He with BEC formation were observed. In all cases BEC forms by excited non-equilibrium magnons. To excite it the pulse or continuous pumping at nuclear magnetic resonance (NMR) frequency was used. Recently it was found that the BEC formation is also possible in solid antiferromagnets CsMnF3 and MnCO3 with coupled nuclear-electron precession. It shows all properties of coherent spin precession and magnon BEC. The main experimental fact of magnon BEC evidence is the very long time of induction decay signal. It was found an order of magnitude longer than the usual induction decay. It was observed even longer than the T2 of spin system, measured by spin echo technics. These experiments were done by means of usual pulsed NMR and “switch-off” NMR. In the first regime the induction signal is observed after short (about 1 µs) resonant RF pulse. In the second regime the induction signal is observed after long (about hundreds of ms and longer) non-resonant RF pulse (so called “switch-off” NMR). The properties of the signal in the last case are well described in framework of magnon BEC.

Finally, the Bose-Einstein condensation of magnon and extremely long induction decay signal may be found in a many spin system with repulsive interaction of magnons. Owing to a remarkable properties these system may be considered as a quantum Q-bit for a quantum computers.

Cascade of phase transitions in anisotropic triangular antiferromagnets
Chubukov, Andrey
(University of Wisconsin, Physics, Madison, USA)

We consider 2D Heisenberg antiferromagnets on a triangular lattice with spatially anisotropic interactions in a high magnetic field close to the saturation. We show that this system possess rich phase diagram in field/anisotropy plane due to competition between classical and quantum orders: an incommensurate non-coplanar spiral state, which is favored classically, and a commensurate co-planar state, which is stabilized by quantum fluctuations.

We show that the transformation between these two states is highly non-trivial and involves two intermediate phases -- the phase with co-planar incommensurate spin order and the one with non-coplanar double-Q spiral order. The transition between the two co-planar states is of commensurate-
incommensurate type, not accompanied by softening of spin-wave excitations. We show that a different sequence of transitions holds in triangular antiferromagnets with exchange anisotropy, such as Ba$_3$CoSb$_2$O$_9$.

Based on works with O. Starykh, J. Alicea, and W. Jin.

**Magnetic excitations near quantum criticality in the Ising chain CoNb2O6 in transverse field**

**Coldea, Radu**

(University of Oxford, Clarendon Laboratory, Department of Physics, Oxford, United Kingdom)

The Ising chain in transverse field is one of the canonical paradigms for a continuous, field-driven quantum phase transition between spontaneous magnetic order and a quantum paramagnet. The mechanism driving this phase transition has long been predicted to involve the closing of the spin gap at the quantum critical point, where a linearly-dispersive spectrum is expected at low energies. We report neutron diffraction and inelastic neutron scattering measurements that unveil how the magnetic order and excitations evolve in the very close proximity of the transverse-field tuned quantum critical point in the quasi-1D Ising ferromagnet CoNb2O6. Near criticality we observe an essentially gapless spectrum with a linear dispersion along the chain direction at low energies, attributed to neutron scattering by one-dimensional gapless Dirac fermions, the predicted quasiparticles of the quantum critical point. Below the critical field, the weak, frustrated interchain couplings stabilize long-range magnetic order in the form of an incommensurate spin-density-wave magnetic structure.

**BEC of magnons at RT**

**Demokritov, Sergej**

(Westfälische Wilhelms-Universität Münster, Institut für Angewandte Physik, Münster, Germany)

**Plaquette valence--bond solid in the square lattice \$J_{1}$--\$J_{2}$ antiferromagnet Heisenberg model: a bond operator approach**

**Doretto, Ricardo Luís**

(Universidade Estadual de Campinas (UNICAMP), Instituto de Física, Departamento de Física da Matéria Condensada, Campinas - SP, Brazil)

We study the plaquette valence--bond solid phase of the spin--$1/2$ \$J_{1}$--\$J_{2}$ antiferromagnet Heisenberg model on the square lattice within the bond-operator theory. We start by considering four $S$ = 1/2$ spins on a single plaquette and determine the bond operator representation for the spin operators in terms of singlet, triplet, and quintet boson operators. The formalism is then applied to the \$J_{1}$--\$J_{2}$ model and an effective interacting boson model in terms of singlets and triplets is derived. The effective model is analyzed within the harmonic approximation and the previous results of Zhitomirsky and Ueda [Phys. Rev. B {bf 54}, 9007 (1996)] are recovered. By perturbatively including cubic (triplet--triplet--triplet and singlet--triplet--triplet) and quartic interactions, we find that the plaquette valence--bond solid phase is stable within the parameter region $0.34 < J_{2}/J_{1} < 0.59$, which is narrower than the harmonic one. Differently from the harmonic approximation, the excitation gap vanishes at both critical couplings $J_{2} = 0.34, J_{1}$ and $J_{2} = 0.59, J_{1}$.

Interestingly, for $J_{2} < 0.48 J_{1}$, the excitation gap corresponds to a singlet--triplet excitation at the $\Gamma$ point, while for $J_{2} > 0.48 J_{1}$, it is related to a singlet--singlet excitation at the $\{bf X\} = (\pi/2,0)\$ point of the tetramerized Brillouin zone.
Multi-spinon excitations in one-dimensionally entangled magnets

Enderle, Mechthild
(Institut Laue-Langevin, Grenoble, France)

The spin-1/2 Heisenberg antiferromagnetic chain is one of the rare quantum many-body systems that can be solved exactly. Its ground state is a macroscopic singlet entangling all spins in the chain. Its elementary excitations, called spinons, are fractional spin-1/2 quasiparticles created and detected in pairs by neutron scattering.

Exact calculations predict that two-spinon states exhaust only 71% of the spectral weight, the remaining is due to higher-order spinon states. By accurate absolute normalization of our inelastic neutron scattering data on the spin-1/2 Heisenberg antiferromagnetic chain compound CuSO$_4$.5D$_2$O, we account for the full spectral weight to 99(8)%.

Our data thus establish and quantify the existence of higher-order spinon states. We develop a simple picture for understanding multi-spinon excitations based on the observation that, within error bars, the experimental line shape resembles a rescaled two-spinon one.

We further present experimental evidence that multispinon excitations are dramatically enhanced in presence of frustrated interactions.

Light-Cone Effects after Quantum Quenches and Excitations at Finite Entropy

Essler, Fabian
(Oxford University, Theoretical Physics, Oxford, United Kingdom)

Signal propagation in the non equilibrium evolution after quantum quenches has recently attracted much experimental and theoretical interest. A key question arising in this context is what principles, and which of the properties of the quench, determine the characteristic propagation velocity. Here we investigate such issues for a class of quench protocols in one of the central paradigms of interacting many-particle quantum systems, the spin-1/2 Heisenberg XXZ chain. We consider quenches from a variety of initial thermal density matrices to the same final Hamiltonian using matrix product state methods. The spreading velocities are observed to vary substantially with the initial density matrix. However, we achieve a striking data collapse when the spreading velocity is considered to be a function of the excess energy.

Using the fact that the XXZ chain is integrable, we present an explanation of the observed velocities in terms of "excitations" in an appropriately defined generalized Gibbs ensemble.

Anomalous pump-driven spectral weight transfer and spin-charge separation in 1D Mott Insulators

Feiguin, Adrian
(Northeastern University, Physics, Boston, MA, USA)

Skyrion-magnon scattering in chiral magnets

Garst, Markus
(Universität zu Köln, Institut für Theoretische Physik, Köln, Germany)

Chiral magnets support topological skyrion textures due to the Dzyaloshinskii-Moriya spin-orbit interaction. In the presence of a sufficiently large applied magnetic field, such skyrmions are large amplitude excitations of the field-polarized magnetic state. We investigate analytically the interaction between such a skyrion excitation and its small amplitude fluctuations, i.e., the magnons in a clean two-dimensional chiral magnet. The magnon spectrum is found to include two magnon-skyrmion bound states corresponding to a breathing mode and, for intermediate fields, a quadrupolar mode, which will give rise to subgap magnetic and electric resonances. Due to the skyrion topology, the magnons scatter from a Aharonov-Bohm flux density that leads to skew and rainbow scattering, characterized by an asymmetric
differential cross section with, in general, multiple peaks. As a consequence of the skew scattering, a
finite density of skyrmions will generate a topological magnon Hall effect. Using the conservation law for
the energy-momentum tensor, we demonstrate that the magnons also transfer momentum to the skyrmion.
As a consequence, a magnon current leads to magnon pressure reflected in a momentum-transfer force in
the Thiele equation of motion for the skyrmion. This force is reactive and governed by the scattering
cross sections of the skyrmion; it causes not only a finite skyrmion velocity but also a large skyrmion Hall
effect. Our results provide, in particular, the basis for a theory of skyrmion caloritronics for a dilute
skyrmion gas in clean insulating chiral magnets.

Spin dynamics in the N’eel phase of the quasi-one-dimensional Ising-like
antiferromagnet BaCo$_2$V$_2$O$_8$ studied by inelastic neutron scattering

Grenier, Béatrice
(Université Grenoble Alpes, CEA, INAC-SPSMS, GRENOBLE, France)

We will present the remarkable magnetic excitations probed by inelastic neutron scattering in the N’eel
phase of BaCo$_2$V$_2$O$_8$ [1].

This compound is a nice example of a quasi-one-dimensional quantum spin system that can be described
in terms of Tomonaga-Luttinger liquid physics [2]. It consists of Co$^{2+}$ spin-3/2 screw chains,
showing a strong anisotropy and sizable frustration. The low-temperature magnetic state of the Co$^{2+}$
ion is described by a highly anisotropic effective spin-1/2, yielding strong quantum fluctuations. At zero
field, a N’eel antiferromagnetic ordering occurs below $T_N \approx 5.55$~K [3]. At very low temperature
($T < 1.4$~K), when increasing the magnetic field applied parallel to the chains, a quantum phase
transition takes place at $H_C = 3.9$~T [4]. The system thus enters a new phase, where an
incommensurate spin density wave {it collinear} to the field is expected [5], as further confirmed by
neutron diffraction [6].

The inelastic spectrum in zero field reveals remarkable features, emerging from the N’eel phase,
consisting of a series of sharp spin excitations. These discrete modes directly result from the confinement
of spinons due to the attractive linear potential imposed by the staggered molecular field generated by
neighboring chains. Contrary to the case of the ferromagnetic Ising chain compound CoNb$_2$O$_6$ where a
unique set of such discrete excitations has been recently reported [7], the excitation spectrum of
BaCo$_2$V$_2$O$_8$ exhibits both transverse and longitudinal excitations. The observation, for the
first time, of such a series of intense and well-defined longitudinal excitations, will be discussed in the
light of previous work on KCuF$_3$ [8] and BaCu$_2$Si$_2$O$_7$ [9].


Spin and thermal transport in spin chains and ladders

Heidrich-Meisner, Fabian
(LMU Munich, Arnold Sommerfeld Center for Theoretical Physics, Faculty of Physics, Munich, Germany)

The transport properties of one-dimensional, strongly-correlated systems have eluded a full theoretical
understanding for quite a while, despite the existence of in principle exact solutions and powerful
numerical methods. Intensely debated questions include, on the one hand, the possibility of ballistic
transport in integrable systems at finite temperatures, and on the other hand, the emergence of conventional diffusive dynamics in realistic and simple models. Moreover, the quantitative calculation of diffusion constants is relevant to describe experimental results. In this talk, I will address these questions by considering both the linear-response regime and out-of-equilibrium scenarios. I will present numerical results for the spin conductivity of the XXZ chain and show that the temperature dependence of the Drude weight can be obtained in a wide parameter regime in the gapless regime [1]. In the gapped regime of the same model, we calculate the diffusion constant and its dependence on model parameters at high temperatures [2]. Furthermore, we consider XXZ spin ladder as an example of a non-integrable system. The XX model on the ladder, equivalent to hard-core bosons, turns out to be an example of a fairly standard diffusive spin conductor [3]. I will also point out the connection of our results to experiments with quantum magnets realized in real materials [4] or with ultra-cold atomic gases in optical lattices [5].


Heat Transport of Low-Dimensional Quantum Magnets at High Temperature
Heß, Christian
(IFW Dresden, Institute for Solid State Research, Dresden, Germany)

The investigation of transport properties is one of the most fundamental methods in experimental solid state physics, since important information about mobility, scattering, and dissipation of quasiparticles can be obtained. The heat conductivity depends strongly on the nature of the heat-carrying quasiparticles and is well understood for electronic and phononic excitations. Some years ago, a new, magnetic mode of heat transport has been discovered in low-dimensional $S=1/2$ quantum magnets and is intensely studied since then. The magnetic heat conductivity of such quantum magnet materials can be exceptionally large (even at room temperature), dwarfs the phonon heat conduction and thereby leads to an overall magnitude of the heat conductivity which can be comparable to that of metals.

After reviewing the main experimental findings on $S=1/2$ spin planes, spin-ladders, and chains as realized in cuprate materials with large magnetic exchange $\Delta J \sim 2000$ K, this talk focuses on recent results which extend the accessible temperature range towards high temperature, approaching, for the first time, $k_B T \approx J/2$. The resulting fresh experimental input that is needed for rationalizing the high-temperature scattering processes for elementary excitations of the quantum magnets will be discussed.

Finite-temperature dynamics of highly frustrated quantum spin chains
Honecker, Andreas
(Université de Cergy-Pontoise, Laboratoire de Physique Théorique et Modélisation, Cergy-Pontoise , France)

Highly-frustrated magnets are characterized by a (nearly) flat one-triplet excitation band at zero temperature, resulting in correspondingly high degeneracies in the spectrum. Little is known from theoretical studies about the temperature-dependence of this single-particle dispersion and less still concerning multi-particle dynamics at finite temperature. Experimentally, inelastic neutron scattering studies of low-dimensional frustrated systems such as SrCu$_2$(BO$_3$)$_2$ require an interpretation of the thermal evolution of scattering intensities. We investigate these issues using the example of a highly frustrated spin ladder and present numerical results from exact diagonalisation for the dynamic structure factor as a function of temperature.
We find anomalously rapid transfer of spectral weight out of the single-particle band to a wide range of energies. Nevertheless, single- and many-particle excitations persist as sharp spectral features to surprisingly high and even infinite temperatures.

Work in collaboration with Bruce Normand, Renmin University of China, Beijing

**Spin-orbit induced magnetic order and dynamics in insulating iridates**

**Jackeli, George**  
(University of Stuttgart, Institute of Functional Matter and Quantum Technologies, Physics, Stuttgart, Germany)

I will review recent theoretical and experimental results on the effects of spin-orbit coupling in the insulating iridium oxides. Three representative examples will be discussed: (i) single-layer Sr2IrO4, with nearly isotropic magnetic dynamics of Heisenberg-type; (ii) double-layer Sr3IrO7, with large anisotropy gap of Ising-type; and (iii) hexagonal iridates A2IrO3 (A=Li, Na), hosting large bond-directional magnetic anisotropies of Kitaev-type.

**Spin echo and Loschmidt daemons after quantum quenches**

**Kehrein, Stefan**  
(Universität Göttingen, Institut für Theoretische Physik, Fakultät für Physik, Göttingen, Germany)

The notions of thermalization and irreversibility are closely connected. While a lot of work has been done in the past decade on understanding thermalization in closed quantum many-body systems, the topic of irreversibility is much less well investigated. In this talk I will elucidate the connection between thermalization and irreversibility by studying the non-equilibrium dynamics of the transverse field Ising model and the Luttinger model. It will be shown that the non-equilibrium dynamics in these models can be thought of as dephasing leading to a generalized Gibbs ensemble description. This dephasing dynamics can be undone with simple Loschmidt daemons.

**Orbital-dependent singlet dimers and orbital-selective Peierls transitions in transition metal compounds**

**Khomskii, Daniel**  
(Universität zu Köln, II. Physikalisches Institut, Köln, Germany)

We show that in transition metal compounds containing structural metal dimers there may exist in the presence of different orbitals a special state with partial formation of singlets by electrons on one orbital, while others are effectively decoupled and may give e.g. long-range magnetic order or stay paramagnetic. Similar situation can be realized in dimers spontaneously formed at structural phase transitions, which can be called orbital-selective Peierls transition. This can occur in case of strongly nonuniform hopping integrals for different orbitals and small intra-atomic Hund's rule coupling JH. Yet another consequence of this picture is that for odd number of electrons per dimer there exist competition between double exchange mechanism of ferromagnetism, and the formation of singlet dimer by electron on one orbital, with remaining electrons giving a net spin of a dimer. The first case is realized for strong Hund's rule coupling, typical for 3d compounds, whereas the second is more plausible for 4d-5d compounds. We discuss some implications of these phenomena, and consider examples of real systems, in which orbital-selective phase seems to be realized.
**Propulsion of a domain wall by spin waves in an antiferromagnet**

**Kim, Se Kwon**  
(Johns Hopkins University, Physics and Astronomy, Baltimore, USA)

We present a theory of a domain wall (DW) propelled by spin waves in an easy-axis antiferromagnet. Magnons carrying spin $+1$ or $-1$ pass through a static DW without reflection but with their spin reversed, thereby transferring two units of angular momentum to the wall [1,2]. The resulting torque causes staggered magnetization on the domain wall to precess. Tveten et al. [2] have previously found that a precessing DW partially reflects spin waves and that the reflection creates a nonzero reactive force on the domain wall. We have identified a second mechanism of propulsion in this system, which we term redshift: magnons passing through a precessing domain wall lower their frequency and thus emerge with a reduced momentum. The missing momentum is transferred to the DW, causing its acceleration. Finding an exact solution for spin waves on a precessing domain wall with the aid of supersymmetric quantum mechanics [3] has enabled us to develop a simple theory of spin-wave propulsion in this system.


**SU(N) Landau-Zener interferometry**

**Kiselev, Mikhail**  
(The Abdus Salam International Centre for Theoretical Physics (ICTP), Condensed Matter Group, Trieste, Italy)

We propose a universal description of Landau-Zener effect in a three-level system. The problem is formulated in terms of Gell-Mann operators which generate SU(3) algebra and map the Hamiltonian on the effective anisotropic pseudospin $S=1$ model. The vector Bloch equation for the density matrix describing the temporal evolution of three-level crossing problem is also derived and solved analytically for the case where the diabatic states of the SU(3) Hamiltonian form a triangle. This analytic solution is in excellent quantitative agreement with numerical solution of Schroedinger equation for a 3-level crossing problem. The model demonstrates oscillation patterns which radically differ from the standard patterns for two-level Landau-Zener problem. The triangle works as an interferometer and the interplay between two paths results in formation of "beats" and "steps" pattern in the time-dependent transition probability. The characteristic time scales describing the "beats" and "steps" depend on a dwell times in the triangle. These scales are related to the geometric size of interferometer. We discuss SU(2S+1) generalization of Landau-Zener model and its possible realizations in multiple quantum dots and ultra-cold atomic gases.

**Raman Scattering Signatures of Kitaev Spin Liquids in A2IrO3 Iridates**

**Knolle, Johannes**  
(Max-Planck-Institut für Physik komplexer Systeme, Condensed Matter, Dresden, Germany)

We study theoretically the Raman scattering response I(\omega) in the gapless quantum spin liquid phase of the Kitaev-Heisenberg model. The dominant polarization-independent contribution IK(\omega) reflects the density of states of the emergent Majorana fermions in the ground-state flux-sector. The integrability-breaking Heisenberg exchange generates a second contribution, whose dominant part IH(\omega) has the form of a quantum quench corresponding to an abrupt insertion of four Z2 gauge fluxes. This results in a weakly polarization dependent response with a sharp peak at the energy of the flux excitation accompanied by broad features, which can be related to Majorana fermions in the presence of the perturbed gauge field. We discuss the experimental situation and explore more generally the influence of integrability breaking for Kitaev spin liquid response functions.
Magneto-elastic modes and lifetime of magnons in thin yttrium-iron garnet films
Kopietz, Peter
(Universität Frankfurt, Theoretische Physik, Frankfurt, Germany)

We calculate the effects of the spin-lattice coupling on the magnon spectrum of thin ferromagnetic films consisting of the magnetic insulator yttrium-iron garnet. The magnon-phonon hybridisation generates a characteristic minimum in the spin dynamic structure factor which quantitatively agrees with recent Brillouin light scattering experiments. We also show that at room temperature the phonon contribution to the magnon damping exhibits a rather complicated momentum dependence: in the exchange regime the magnon damping is dominated by Cherenkov type scattering processes, while in the long-wavelength dipolar regime these processes are subdominant and the magnon damping is two orders of magnitude smaller. We supplement our calculations by actual measurements of the magnon relaxation in the dipolar regime. Our theory provides a simple explanation of a recent experiment probing the different temperatures of the magnon- and phonon gases in yttrium-iron garnet.

Manipulation of skyrmions with spin transfer torques
Koumpouras, Konstantinos
(Uppsala University, Physics and Astronomy, Uppsala, Sweden)

Magnetic skyrmions are topologically stable chiral spin structures with a whirling configuration. While originally proposed in the context of high energy physics [1], skyrmions have recently become the subject of interest in condensed matter systems. As an example, lattices of skyrmions have been observed in non-centrosymmetric helical magnets where chiral Dzyaloshinsky-Moriya interactions play an important role. In addition to their interesting physics, the skyrmions are promising candidates for future data storage technologies because of their smaller depinning current which they need, the weak influence of defects and their flexibility to avoid pinning centres [2].

In this work we examine how skyrmions can be stabilized and manipulated by the presence of spin currents. The study is based on spin dynamics simulations, using the Uppsala Atomic Spin Dynamics (UpASD) code which is based on the Landau-Lifshitz-Gilbert equations of motion for discrete spins.

Starting from the equilibrium spin spiral state we stabilize skyrmions in two dimensional systems by applying different values of external magnetic field and temperature. We also vary the radius of the skyrmions by considering different strengths of the Dzyaloshinsky-Moriya interactions.

After stabilizing the skyrmions we study the effect of the spin transfer torques in the system and both the rotational and translational motion of the skyrmions is observed. The velocity and the direction of the motion depend on the interplay between several parameters, including the damping of the system, the strength of the current, and the ratio of adiabatic versus non-adiabatic spin transfer torque. Finally, we observe that if there are impurities in the form of voids in the system or open boundaries conditions, then these impurities act as generation centres for new skyrmions.


Magnetic Soft Modes in the Distorted Triangular Antiferromagnet $\alpha$-CaCr$_2$O$_4$
Lake, Bella
(Helmholtz Zentrum Berlin für Materialien und Energie GmbH, Institute of Magnetism, Quantenphänomene in neuen Materialien, Berlin, Germany)

We have explored the phase diagram and excitations of a distorted triangular lattice antiferromagnet. The unique two-dimensional distortion considered here is very different from the 'isosceles'-type distortion that has been extensively investigated. We show that suprisingly it is able to stabilize the 120° spin
structure (typical of the undistorted triangular antiferromagnet) for a large range of exchange interaction values, with new structures found only for extreme distortions. A physical realization of this model is \( \alpha\text{-CaCr}_2\text{O}_4 \). Despite its highly symmetric 120° spin structure, the magnetic excitation spectrum of \( \alpha\text{-CaCr}_2\text{O}_4 \) is very complex. The unique pattern of nearest-neighbor exchange interactions as well as the substantial next-nearest-neighbor interactions place it close to the phase boundary of the 120° structure as is clearly revealed by the observation in neutron scattering of low energy modes acting as soft modes of the neighboring structure. Indeed, fitting to linear spin-wave theory favors a set of exchange parameters within the nearby multi-k phase in contradiction to the observed 120° order, and quantum fluctuations may be necessary to stabilize \( \alpha\text{-CaCr}_2\text{O}_4 \) within the 120° phase.

Spin jam state in a disorder-free frustrated magnet

Lee, Seung-Hun
(University of Virginia, University of Virginia, Department of Physics, Charlottesville, USA)

Can a glassy state exist in the absence of disorder (or quenching)? This long-standing problem in condensed matter physics will be addressed in this talk by discussing glassy states found in frustrated magnets. When spins (or magnetic moments) are arranged in a lattice with triangular motif, the phenomenon of frustration leads to numerous energetically equivalent ground states, and results in exotic states such as spin liquid and spin ice. Here, we report an alternative situation called a spin jam that is induced purely by quantum fluctuations. The frustrated magnet of interest is a triangular network of bipyramids. We found that although classically the ground state is a spin liquid, quantum corrections break the classical degeneracy into a set of aperiodic spin configurations forming local minima in a rugged energy landscape. A consequence of the complex energy landscape is, upon cooling, the system gets trapped in one of the local minima, leading to the glassy spin jam state. These results clearly show that a glassy spin state can be achieved in the absence of disorder.

Magnetoelectric effects and phonon anomalies in the Skyrmion and the helical/conical phase of Cu2OSeO3

Lemmens, Peter
(Technische Universität Braunschweig, Institut für Physik der Kondensierten Materie, Braunschweig, Germany)

In light scattering experiments of Cu2OSeO3 with applied magnetic fields we observe a non-reciprocity in the frequency regime of phonon and magnetic excitations. We analyze our effects based on chiral aspects in its lattice structure and compare the response with the Skyrmion phase.

Magnetic Heat Transport in Spin-Ice Materials

Lorenz, Thomas
(Universität zu Köln, 2. Physikalisches Institut, Köln, Germany)

Topological spin glassiness

Moessner, Roderich
(Max Planck Institute for Physics of Complex Systems, Condensed Matter, Dresden, Germany)

It is a salient experimental fact that a large fraction of candidate spin liquid materials freeze as the temperature is lowered. The question naturally arises whether such freezing is intrinsic to the spin liquid ("disorder-free glassiness") or extrinsic, in the sense that a topological phase simply coexists with standard freezing of impurities. Here, we demonstrate a surprising third alternative, namely that freezing and topological liquidity are inseparably linked. The topological phase reacts to the introduction of
or disorder by generating degrees of freedom of a new type (along with interactions between them), which in turn undergo a freezing transition while the topological phase supporting them remains intact.

**Skyrmion dynamics**

**Mostovoy, Maxim**

(University of Groningen, Zernike Institute for Advanced Materials, Groningen, Netherlands)

Skyrmions form an important class of defects in ordered states with vector order parameters. Their non-trivial topology is a source of rich and interesting physics. First introduced by T. H. R. Skyrme in his unified theory of baryons and mesons, skyrmions have made their way into condensed matter physics as excitations in Quantum Hall ferromagnets and Bose-Einstein condensates. They have been recently observed in magnetic materials with non-centrosymmetric crystal lattices, such as ferromagnetic metallic MnSi and ferromagnetic insulator Cu2OSeO3, using small-angle neutron scattering and Lorentz microscopy. I will discuss mechanisms for stability of skyrmions and new classes of magnetic materials in which these topological defects can be found.

Due to the Berry phase acquired by electrons propagating through a non-coplanar spin texture, a static skyrmion carries unit flux of an effective magnetic field, while a moving skyrmion induces an effective electric field. This gives rise to a complex coupled dynamics of charges and spins mediated by effective gauge fields [1]. It was recently realized that magnons also "feel" the effective magnetic field of skyrmions and that magnon currents produce spin torques that can set skyrmions into motion, which leads to unusual thermoelectric effects [2]. I will discuss the dynamics of collective degrees of freedom for various spin systems hosting skyrmions.

References:

**Topological chiral edge modes and Berry curvature of magnons**

**Murakami, Shuichi**

(Tokyo Institute of Technology, Department of Physics, Tokyo, Japan)

Magnons (spin waves) in ferromagnets form band structure. Their band structure is affected by some kind of spin-orbit coupling, such as the Dyaloshinskii-Moriya interaction or the dipole-dipole interaction. Such "spin-orbit coupling" leads to nontrivial geometrical structure of Bloch waves in $k$-space, characterized by Berry curvature. In general, Berry curvature leads to various intrinsic Hall effects, as is similar to the quantum Hall effect (QHE) and quantum spin Hall effect for electrons. We show that the Berry curvature of magnons leads to thermal Hall effect. We focus on the dipole-dipole interaction, and calculate Berry curvature and thermal Hall effect in magnets with dipole-dipole interaction.

When spatial periodicity is introduced into the magnet, the Berry curvature may lead to nontrivial topological numbers, implying an existence of chiral edge modes, similar to the QHE. Such magnets with artificial periodicities are called magnonic crystals. We theoretically propose magnonic crystals with band gaps, with topological chiral edge modes within the band gap. The number of chiral edge mode is given by a topological number (Chern number), as is similar to QHE. We propose two magnonic crystals, in which the Chern number can be controlled by the lattice constant or by the external magnetic field. The existence and behaviors of these chiral modes can be seen by micromagnetic simulations. We can then see how the chiral edge modes propagate along the edge of the magnonic crystal.
Oral abstracts for QSD14

September 12, 2014

Spinon and Holon Statistics in the Pyrochlore Quantum Spin Liquid
Normand, Bruce
(Renmin University of China, Department of Physics, Beijing, PR China)

We examine the spin and charge excitations of the one-band Hubbard model on the pyrochlore lattice in the quantum spin-liquid regime at half-filling. From the exactly known manifold of ground states, the spin excitations are massive spinons, which are deconfined. This causes immediate spin-charge separation upon doping, creating holonic quasiparticles. We deduce the effective statistics and interactions of both spinons and holons, and consider the evolution of these emergent properties with temperature as thermal fluctuations enlarge the ground manifold.

Spin-wave excitations in the multiferroic compound Ba2CoGe2O7
Penc, Karlo
(Wigner Research Centre for Physics, Institut for Solid State Physics and Optics, Budapest, Hungary)

We studied spin excitations in the magnetically ordered phase of the noncentrosymmetric Ba2CoGe2O7 in high magnetic fields up to 33 T. In the electron spin resonance and far infrared absorption spectra we found several spin excitations beyond the two conventional magnon modes expected for such a two-sublattice antiferromagnet. We show that a multiboson spin-wave theory describes these unconventional modes, including spin-stretching modes, characterized by an oscillating magnetic dipole and quadrupole moment. In particular, the lack of inversion symmetry allows each mode to become electric dipole active and interact with light. Finally, we discuss the signatures of higher energy excitations in inelastic neutron spectrum.

New phenomena from Kitaev interactions
Perkins, Natalia
(University of Wisconsin, Physics Department, Madison, USA)

Magnetic monopoles in quantum spin ice
Petrova, Olga
(Max Planck Institute for the Physics of Complex Systems, Condensed Matter, Dresden, Germany)

Typical spin ice materials can be modeled using classical Ising spins. The geometric frustration of the pyrochlore lattice causes the spins to satisfy ice rules, whereas a violation of the ice constraint constitutes an excitation. Flipping adjacent spins fractionalizes the excitation into two monopoles. Long-range dipolar interactions between magnetic moments give rise to an effective Coulomb interaction between the emergent magnetic charges. In a classical setting, the spin flips arise due to thermal effects and applied magnetic fields. Recent experimental evidence points to quantum fluctuations as another likely source of spin flips. We study the features of quantum spin ice expected to be visible in experiment which distinguish it from the purely classical setting, focusing on both features of the spectrum and signatures in neutron scattering experiments.

Entanglement and dynamics in many-body localized systems
Pollmann, Frank
(Max Planck Institute for the Physics of Complex Systems, Condensed Matter, Dresden, Germany)

Many-body localized phases occur in isolated quantum systems when Anderson localization persists in the presence of finite interactions. It turns out that the entanglement is a very useful quantity to study these phases. First, we focus on the physics in the presence of strong disorder. For this we study the time evolution of simple (unentangled) initial states for a system of interacting spinless fermions in a one
Dynamics and ordering in random spin chains

Prelovsek, Peter
(Jozef Stefan Institute, Ljubljana, Slovenia)

In spite of long history 1D spin systems still offer challenging theoretical questions, mostly regarding finite-temperature dynamical properties and the effects of disorder and randomness. I will first discuss anomalous spin and thermal transport in pure and disordered spin chains. Recent NMR and $\mu$SR experiments on antiferromagnetic spin-chain materials stimulated renewed interest in random-bond quantum models. With the central concept being random singlets I will present the numerical analysis confirming a large span of local spin relaxation times and their anomalous temperature dependence. A weak interchain exchange coupling in such systems leads to a long range antiferromagnetic order, as also observed experimentally. Theoretical results for the ordering temperature as well as for local moments and their probability distribution in quasi-1D systems will be also presented.

Integrable non-equilibrium steady state density operators and exact bounds on ballistic transport

Prosen, Tomaz
(University of Ljubljana, Faculty of Mathematics and Physics, Department of Physics, Ljubljana, Slovenia)

I will explain a fundamental connection between integrability of non-equilibrium steady states of boundary driven markovian master equations for interacting quantum chains and existence of quasi-local conserved operators which is not generated by the standard ("equilibrium") algebraic Bethe ansatz. I will then discuss how existence of quasi-local conserved operators can be implemented to yield strict lower bounds on transport coefficients, such as Drude weights or diffusion constants.

Triplon Hall effect in the Shastry Sutherland material

Ramachandran, Ganesh
(IFW Dresden, ITF - Institute for Theoretical Solid State Physics, Dresden, Germany)

We demonstrate that SrCu$_2$(BO$_3$)$_2$, the well-known realization of the Shastry Sutherland model, hosts topological triplon bands. Their topological nature leads to a measurable thermal Hall signal. The material SrCu$_2$(BO$_3$)$_2$ has small anisotropies arising from Dzyaloshinskii Moriya (DM) interactions, which admix a triplet component into the singlet ground state. The resulting triplon excitations form weakly dispersing bands. We show that an applied magnetic field splits the triplon modes and opens band gaps. Surprisingly, we are left with topological bands with Chern numbers ±2. SrCu$_2$(BO$_3$)$_2$ thus supports topologically protected triplonic edge modes and is a magnetic analogue of the integer quantum Hall effect. At a critical value of the magnetic field set by the strength of DM interactions, the three triplon bands touch once again in a spin-1 generalization of a Dirac cone, and lose their topological character.
Quantum Quenches in the Thermodynamic Limit
Rigol, Marcos
(The Pennsylvania State University, Department of Physics, University Park, USA)

Studies of the quantum dynamics of isolated systems are currently providing fundamental insights into how statistical mechanics emerges under unitary time evolution. Thermalization seems ubiquitous, but experiments with ultracold gases have shown that it need not always occur, particularly near an integrable point. Unfortunately, computational studies of generic (nonintegrable) models are limited to small systems, for which arbitrarily long times can be calculated, or short times, for which large or infinite system sizes can be solved. Consequently, what happens in the thermodynamic limit after long times has been inaccessible to theoretical studies. In this talk, we introduce a linked-cluster based computational approach that allows one to address the latter question in lattice systems. We provide numerical evidence that, in the thermodynamic limit, thermalization occurs in the nonintegrable regime but fails at integrability. A phase transition-like behavior separates the two regimes.

Breaking the Waves – experiments and theories on fractional excitations from 1D to 2D
Ronnow, Henrik M.
(Ecole Polytechnique Federale de Lausanne (EPFL), Institute of Condensed Matter Physics ICMP, Laboratory for Quantum Magnetism LQM, Lausanne, Switzerland)

Neutron and X-ray spectroscopy provide unique insight into the complex nature of excitations of fundamental systems from the simple Heisenberg chain to doped cuprate superconductors. I shall present recent data combined with new theoretical understanding of spin-waves and spinons in 1D and 2D Heisenberg systems.


Laser-induced Nonequilibrium Magnetization Curves in Quantum Magnets
Sato, Masahiro
(Aoyama Gakuin University, Department of Physics and Mathematics, Sagamihara, Japan)

Recently periodically-driven quantum states have attracted much attention [1-6]. In particular, thanks to the recent development of laser science, it is gradually possible to realize various periodically-driven nonequilibrium states by applying laser to solid. The control of electron and spin motions by laser is becoming a hot topic. Several theoretical studies for driven many-body systems have concentrated on non-interacting fermion systems so far. Remarkably, it is shown [1,2] that when a circularly polarized laser is applied to two-dimensional Dirac electron systems on lattices, a topologically-insulating state with a gapless chiral edge mode emerges. Furthermore, experimental signatures of laser-driven electron states in band-insulating materials have been reported very recently [3].

On the other hand, driven nonequilibrium states in “strongly correlated” systems are still open. We are therefore exploring novel nonequilibrium phenomena in correlated systems. In particular, we are focusing on quantum antiferromagnets [4,6] and multiferroic models [5], which are typical simple models for strongly correlated systems in solid. In this conference, we would like to discuss one of our recent results, a new method of generating magnetization curves in a wide class of quantum magnets by utilizing laser “without static magnetic field” [4]. We show that when we apply a circularly polarized laser to general quantum magnets with chirping technique, the magnetization parallel to the laser pointing vector gradually grows as a function of time. Solving time-dependent Schrodinger equation for some realistic quantum spin models numerically, we find the basic condition for realizing ideal laser-induced magnetization curves.
I will discuss in detail this new theoretical proposal for laser-induced magnetization processes in the conference.

References

Waves in the unseen: spin excitations in a quantum spin-nematic
Shannon, Nic
(Okinawa Institute of Science and Technology, Theory of Quantum Matter Unit, Okinawa, Japan)

The possibility of a quantum spin-nematic, a magnetic analogue of a liquid crystal, holds an abiding fascination. There is now good reason to believe that spin-nematic order should occur in a range of frustrated magnets where ferromagnetic and anti-ferromagnetic interactions compete. However the fact that static spin-nematic order does not break time reversal symmetry, and so possesses no dipole moment, makes it extremely difficult to observe. The excitations of spin-nematic order, in contrast, do possess a fluctuating dipole moment, and so should be visible in NMR or inelastic neutron scattering. In this talk I develop a symmetry based description of the long-wavelength excitations of a quantum spin nematic state, and show how it can be used to make concrete predictions for inelastic neutron scattering and NMR T1 relaxation rates.

Two crossovers between spinons and magnons in S=1/2 quantum magnet
Cs$_2$CuCl$_4$.
Smirnov, Alexander
(Russian Academy of Sciences, P. Kapitza Institute for Physical Problems, Moscow, Russian Federation)

The S=1/2 antiferromagnet Cs$_2$CuCl$_4$ with a distorted triangular lattice is a quasi 2D magnet with the spin ordering greatly reduced by zero-point fluctuations. The ordering at temperature $T_{N}$=0.62 K is strongly delayed with respect to Curie-Weiss temperature $T_{\{CW\}}$=4 K. In the temperature range $T_{N} < T < T_{\{CW\}}$ there is a correlated spin-liquid state with a continuum of magnetic excitations [1]. Our electron spin resonance (ESR) study is performed in the frequency range $9<f<350$ GHz. In the spin-liquid phase, it reveals a fine structure of the spinon spectrum in the Brillouin zone center in form of a resonance doublet. This doublet is a signature of the spinon continuum of S=1/2 chains with the uniform Dzyaloshinskii-Moriya interaction [2]. At cooling down to $T_S=0.05$ K, for $f_S=60-120$ GHz this spinon doublet is found to survive deep in the ordered phase. On the other hand, at $f<50$ GHz, the doublet is transformed to an antiferromagnetic resonance (AFMR) signal, marking a variety of ordered phases and field-induced transitions. The frequency of this lower crossover corresponds approximately to the main exchange integral. The coexistence of a low-frequency AFMR and of a spinon mode at a higher frequency may be ascribed to the proximity of a quantum critical point, where oscillations of an order parameter and spinons coexist. However, a consistent theory of such a combined spectrum is still absent. At the increase of the frequency and, hence, of the magnetic field, the spinon doublet collapses at about a half of the saturation field (i.e. above 150 GHz). The collapse of the doublet occurs via a drop of the high-frequency component in a correspondence with the relation between the intensities at the lower and upper boundaries of the spinon continuum of $S_S=1/2$ chain. Further increase of the magnetic field causes magnetic saturation and reveals a new spectrum of $q=0$ excitations in form of an intensive Larmor precession, coexisting with a much weaker mode of the
exchange origin. This high-frequency crossover to a doublet of another kind is due to the transition from the fluctuating spin liquid to a fully polarized saturated phase.

Magnetic anisotropy in a pyrochlore antiferromagnet Er\(_2\)Ti\(_2\)O\(_7\) studied by transverse magnetization and ESR measurements.

**Sosin, Sergey**
(Russian Academy of Sciences, P. Kapitza Institute for physical problems, Moscow, Russian Federation)

Antiferromagnet on a pyrochlore lattice $\text{Er}_2\text{Ti}_2\text{O}_7$ is known by its nontrivial magnetic ordering supposedly stabilized by fluctuations [1]. This "order by disorder" effect assumes the proximity of the system to an XY model of effective spin Hamiltonian due to strong planar anisotropy of magnetic Er\(^{3+}\) ions [2]. However, recent magnetic measurements and theoretical modeling [3] put arguments in favor of less anisotropic properties of a single ion ground state of Er\(^{3+}\) and consequently the deviation from a pure XY model for an effective exchange interaction. Our experimental results provide additional data to clarify this question.

The transverse component of magnetization was measured in magnetic field applied along $\langle 100 \rangle$, $\langle 110 \rangle$ and $\langle 111 \rangle$ axes of an fcc-lattice using a capacitive magnetic torquemeter with a $^3\text{He}$ cryostat (minimum temperature 0.4~K). For $H_{\parallel \langle 100 \rangle}$ the transverse magnetization (TM) is not induced by the field indicating that the initial symmetry of the magnetic structure is conserved under field. In the other two field directions TM arises in the low field ordered phase and drops sharply at the transition into a "saturated" phase ($H_{\parallel \text{H}_s}$). More elaborate electron spin resonance spectra were also obtained. The presence of a nearly Goldstone mode with approximately linear dependence on magnetic field was verified. The gap of this mode at zero field is estimated to be not exceeding 0.3~K. Additional resonance branches appear at $H_{\parallel \text{H}_s}$: a single mode $\nu_{\langle 100 \rangle} \propto (H-H_{\delta \langle 100 \rangle})$ at $H_{\parallel \langle 100 \rangle}$ and two modes $\nu_{\langle 1,2 \rangle} \propto (H-H_{\delta \langle 111 \rangle})$ at $H_{\parallel \langle 111 \rangle}$ with different slopes by field. These $\nu$-values as well as the field behavior of TM contain direct information on both $g$-tensor components and effective spin-Hamiltonian parameters and can be used to test existing theoretical models.


Real-time relaxation and thermalization in quantum magnets: Progress by quantum typicality

**Steinigeweg, Robin**
(Technical University Braunschweig, Institute for Theoretical Physics, Braunschweig, Germany)

We demonstrate that the emergent concept of quantum typicality allows for significant progress in the study of real-time relaxation and thermalization in quantum magnets. To this end, we present numerical results on spin-current autocorrelation functions, as inferred from propagating only a single pure state, drawn at random as a typical representative of the full statistical ensemble. Starting with the antiferromagnetic and anisotropic spin-1/2 Heisenberg chain, we directly compare with existing data from time-dependent density matrix renormalization group and show that quantum typicality is fulfilled.
extremely well at finite temperatures, consistent with a vanishing error in the thermodynamic limit. Since quantum typicality does not underlie a restriction to short times, we obtain Drude weights from chains as long as $L=33$ sites, corresponding to almost 10,000 times larger Hilbert-space dimensions than in existing exact-diagonalization studies. In this way, our results provide for a new benchmark and a fresh insight into current dissipation at the isotropic point. Going beyond integrability, we extend our analysis to generic non-integrable systems and also deduce diffusion constants as a function of integrability-breaking model parameters.


Violation of the Spin Statistics Theorem and the Bose-Einstein Condensation of Particles with Half Integer Spin

Sushkov, Oleg
(University of New South Wales, Physics, Sydney, Australia)

We consider the Bose condensation of particles with spin 1/2. The condensation is driven by an external magnetic field. Our work is motivated by ideas of quantum critical deconfinement and bosonic spinons in spin liquid states. We show that both the nature of the novel Bose condensate and the excitation spectrum are fundamentally different from that in the usual integer spin case. We predict two massive ("Higgs") excitations and two massless Goldstone excitations. One of the Goldstone excitations has a linear excitation spectrum and another has quadratic spectrum. This implies that the Bose condensate does not support superfluidity, the Landau criterion is essentially violated. Results of the present work are generic and can be applied to bosonic spinons in solids and to other particles which for some reason do not respect the spin-statistics theorem.

Semi-classical spin dynamics of the antiferromagnetic Heisenberg model on the kagome lattice

Taillefumier, Mathieu
(Okinawa Institute of Science and Technology, Institute for theoretical physics, Okinawa, Japan)

We investigate the dynamical properties of the classical antiferromagnetic Heisenberg model on the kagome lattice using a combination of Monte Carlo and molecular dynamics simulations. We find that frustration induces a distribution of timescales in the cooperative paramagnetic regime (i.e. far above the onset of coplanarity), as recently reported experimentally in deuterium jarosite. At lower temperature, when the coplanar correlations are well established, we show that the weathervane loop fluctuations control the system relaxation: the time distribution observed at higher temperatures splits into two distinct timescales associated with fluctuations in the plane and out of the plane of coplanarity. The temperature and wave vector dependences of these two components are qualitatively consistent with loops diffusing in the entropically dominated free energy landscape. Numerical results are discussed and compared with the $SO(N)$ model and recent experiments for both classical and quantum realizations of the kagome magnets.
Coherent laser control of quantum multiferroics: A way of generating synthetic Dzyaloshinskii-Moriya interactions

Takayoshi, Shintaro
(National Institute for Materials Science, National Institute for Materials Science, Computational Materials Science Unit, Tsukuba, Japan)

Quantum magnets and multiferroics are known to host rich and exotic quantum many-body phenomena such as various kinds of phase transitions, topological orders, spin liquids, etc. The aim of our theoretical study is to find and propose a scheme to induce nontrivial quantum coherent dynamics in such systems. Our proposal is to use well-controlled lasers and apply them to the materials. The electric and magnetic component of the laser couples to magnets through the Zeeman coupling and, in multiferroics, electric polarization. We search for novel phases provoked by laser application [1]. We can consider the effect of the laser on the system as a time-periodic perturbation to the Hamiltonian. By using the Floquet theory, the original time-dependent system can be mapped to a system governed by an effective static Hamiltonian. The laser induces a "synthetic" field to the effective model and the field can realize nontrivial quantum states [2]. In this presentation, we mainly focus on laser-driven phenomena in quantum multiferroics [3]: magnets with a magnetoelectric coupling between spin and charge degrees of freedom. We show that a new synthetic Dzyaloshinskii-Moriya (DM) interaction is effectively induced by laser through the coupling between spin chirality and electric polarization. We also demonstrate how the DM interaction controls spin spatial structures by numerically solving the time dependent Schroedinger equation.


Doublon-holon dynamics and transport near Mott transition

Tsunetsugu, Hirokazu
(The University of Tokyo, Institute for Solid State Physics, Kashiwa, Japan)

I review our recent works of cluster dynamical mean-field calculations for Mott metal-insulator transition in a frustrated half-filled Hubbard model. The first issue is the dynamics of doublons and holons. The equal-time doublon-holon correlations between nearest-neighbor sites have been investigated by previous VMC calculations, and binding-unbinding transition was discussed. We have studied the dynamic correlations of several configurations between nearest-neighbor sites and also on the same site. We have demonstrated the temporal fluctuations change their nature with controlling Coulomb $U$. In the insulating phase, fluctuations decay quickly after the time scale proportional to the inverse of the hopping integral $t$. In the metallic phase, fluctuations decay much slowly and persist up to very long time. I also compare the results of doublon pair and those of doublon-holon pair. The second issue is the criticality of electric conductivity at the critical end point of Mott transition. We have observed that the critical exponent determined by our cluster DMFT calculations differs from the Ising universality, which is usually attributed to this transition.

Quantum Spin Dynamics probed by Resonant Inelastic X-ray Scattering

van den Brink, Jeroen
(IFW Dresden, Institute for Theoretical Solid State Physics, Dresden, Germany)
Non-linear bond-operator theory and 1/d expansion for coupled-dimer magnets

Vojta, Matthias
(Technische Universität Dresden, Theoretische Physik, Dresden, Germany)

For coupled-dimer Heisenberg magnets, a paradigm of magnetic quantum phase transitions, we develop a systematic expansion in 1/d, the inverse number of space dimensions, using a formulation of the bond-operator technique. We demonstrate the approach for a model of dimers on a hypercubic lattice, which generalizes the square-lattice bilayer Heisenberg model to arbitrary d. We calculate static and dynamic observables at zero temperature in both the singlet and antiferromagnetic phases and show that the 1/d expansion consistently describes the entire phase diagram including the quantum critical point.

Physics with a "perfect" quantum spin ladder

Zheludev, Andrey
(Eidgenössische Technische Hochschule Zürich, Laboratory for Solid State Physics, Zurich, Switzerland)

The Heisenberg S=1/2 quantum spin ladder is perhaps the most studied model in quantum magnetism. Ironically, until recently, there have been no good experimental realizations. Now, finally, one has been found: the organic magnet (C7H10N)2CuBr4 (DIMPY). Not only is DIMPY an almost perfect real-world incarnation of the model, but also, from a purely practical viewpoint, it is uniquely suited for experimental studies, including neutron scattering and other techniques. In my talk I will review a series of such recent experiments [1,2]. In zero field, DIMPY teaches us about multi-magnon continua and bound states. In applied magnetic fields, for low energies, it can be described as an ATTRACTIVE Tomonaga-Luttinger spin liquid, with universal scaling features for thermodynamic quantities and correlation functions. At higher energies, the field-theoretical descriptions of the Heisenberg Hamiltonian break down, and a complex excitation spectrum is revealed. In a most spectacular fashion, all experimental observations are QUANTITATIVELY reproduced by first principles DMRG calculations for a Heisenberg ladder Hamiltonian with just two exchange constants.


Muon precession as a detector of spin polarization in out-of-equilibrium semiconductors: theoretical puzzles and possible resolutions.

Ziman, Timothy
(Centre National de la Recherche Scientifique (CNRS), Institut Laue Langevin, Theory College, Grenoble, France)

We explore theoretical explanations for laser pumped experiments by Torikai, Nagamine, Shimomura and collaborators, that have established that Muonium can be a tool in spintronics for following non-equilibrium spin polarizations of the conduction electrons. In the original experiments on Si the sensitivity was argued to be due to spin exchange with the bound electron in Muonium, but in GaAs an effect is seen even in the case of negatively charge Muonium$^-$ which is difficult to see how spin exchange can give a strong effect in what is an spin singlet state of the two electrons. Estimates for the vacuum bound state of Muonium $^-$ give too weak an effect to be relevant to the experiments. We propose a mechanism to explain the sensitivity of negatively charged Muonium ions to the spin-polarization of semiconductors in terms of the coherent mixing of charge states induced by hybridization with the semiconducting host. We estimate the parameters in a model Hamiltonian for different semiconducting hosts and compare to estimated scattering times for Silicon and n-type GaAs.
Finite temperature and magnetic field transport in 1D quantum magnets
Zotos, Xenophon
(University of Crete, Cretan Center for Quantum Complexity and Nanotechnology, Physics Department, Heraklion - Crete, Greece)

I’ll present recent exact results on the finite temperature and magnetic field magneto-thermal transport in the one dimensional spin-1/2 Heisenberg model obtained using the Bethe ansatz (BA) method. In particular, I’ll discuss the behavior of spin Drude weight as a function of magnetic field down to low temperatures. These new results are based on a previous analysis by the author of the spin Drude weight in zero magnetic field [1] that recently have been independently confirmed by state of the art numerical simulations and an open system Lindblad approach. The new data now allow for a complete evaluation of the thermal conductivity in the presence of a magnetic field and of the Seebeck coefficient. Furthermore, and in relation to this development,

(1) I’ll discuss the thermodynamics, thermal transport and dynamics (ESR), of the spin S=1 easy-plane quasi-one dimensional quantum magnet NiCl2-4SC(NH2)2 (DTN). The analysis is based on an effective spin-1/2 anisotropic (\(\Delta = 1/2\)) Heisenberg model description that is put on a firm basis by comparing the thermodynamics of the S=1 model, obtained using TMRG, with exact BA specific heat and magnetization results for the s=1/2 Heisenberg model. For the thermal conductivity in a magnetic field, I’ll compare numerical data on the S=1 model obtained using exact diagonalization techniques to exact results using the BA method. For the ESR data

[2], using a recently developed BA technique [3]. I’ll show that the extremely sharp line observed in experiments, is due to a singular excitation to a single excited state. It is fascinating that this excited state, highly unusual within BA as it is described by a set of real pseudo-momenta plus one with imaginary part \(\pi/2\), is exactly probed in ESR experiments - it corresponds to a uniform rotation of the total magnetisation.

(2) I’ll discuss the thermal conductivity in a magnetic field of the quasi-one dimensional CuPzN compound that is well described by the isotropic spin-1/2 Heisenberg Hamiltonian. In particular, I’ll analyze the presence of the magnetothermal correction and its relevance in the interpretation of experiments [4] and discuss the extent to which spin-orbit scattering suppresses this correction. Furthermore, I’ll show that this correction becomes significant near the critical fields to the ferromagnetic state.


Spin dynamics in triangular-lattice antiferromagnets Cs2CuBr4 and Cs2CuCl4: high-field ESR studies
Zvyagin, Sergei
(Helmholtz-Zentrum Dresden-Rossendorf, High Magnetic Field Laboratory, Dresden, Germany)

A spin-1/2 Heisenberg antiferromagnet (AF) on a triangular lattice is the paradigmatic model in quantum magnetism. In spite of numerous theoretical studies (which predict a rich variety of grounds states, ranging from a gapless spin liquid to Néel order), many important details of the phase diagram of triangular-lattice AFs remain controversial or even missing. In order to test the theory experimentally, a precise information on the spin-Hamiltonian parameters for the materials of interest is highly demanded. Here, we present results of high-field electron spin resonance (ESR) studies of spin-1/2 Heisenberg AFs Cs2CuCl4 and Cs2CuBr4 with distorted triangular-lattice structures in magnetic fields up to 50 T [1]. In the magnetically saturated phase (H=Hsat), quantum fluctuations are fully suppressed, and the spin dynamics is defined by ordinary magnons. This allows us to accurately describe the magnetic excitation
spectra in both materials and, using the harmonic spin-wave theory, to determine their exchange parameters. The viability of the proposed method was first proven by applying it to Cs$_2$CuCl$_4$, revealing good agreement with inelastic neutron-scattering results. For the isostructural Cs$_2$CuBr$_4$ we obtain $J/k_B=14.9(7)$ K, $J'/k_B=6.1(3)$ K, $[J'/J\sim0.41]$, providing exact and conclusive information on the exchange coupling parameters in this frustrated spin system. The approach has a broader impact and can be potentially used for any quantum magnet with reduced (e.g., by the staggered Dzyaloshinskii-Moriya interaction) translational symmetry, resulting, as predicted, in emergence of a new exchange mode above $H_{sat}$.

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