ISSP International Workshop and Symposium on

Computational Approaches to Quantum Critical Phenomena

(August 9 - 11, 2006)

(Program: Oral Session)

August 9, 2006

9:50- Opening Address

10:00-10:30 **Quantum Monte Carlo study of many-body systems coupled with lattice degrees of freedom**
Takeo Kato (ISSP, University of Tokyo)

10:30-11:00 **Calculation of correlation functions of spin $1/2$ XXX chain**
Minoru Takahashi (ISSP, University of Tokyo)

11:00-11:30 **Dynamics and magnetization process of triangle based low dimensional systems, ring, tube, helix and ball**
Hiroyuki Nojiri (Institute for Materials Research, Touhoku University)

11:30-12:00 **Spin Nematic State in a Triangular Antiferromagnet**
Hirokazu Tsunetsugu (Yukawa Institute for Theoretical Physics, Kyoto University)

12:00-12:30 **Metamagnetism and related critical phenomena in pyrochlore Heisenberg antiferromagnets**
Yukitoshi Motome (Department of Applied Physics, University of Tokyo)

— Lunch —

14:00-14:30 **Emerging spatial structures in SU(N) Heisenberg model**
Naoki Kawashima (ISSP, University of Tokyo)

14:30-15:00 **Quantum Phase Transition between Two Ordered Phases with Unrelated Symmetries**
Kenji Harada (Department of Applied Analysis and Complex Dynamical Systems, Kyoto Univsersity)

15:00-15:30 **Stripe formation in doped Hubbard ladders**
Eric Jeckelmann (Institute for Theoretical Physics, University of Hannover)

16:00-16:30 **Real space renormalization group approach for the corner Hamiltonian**
Kouichi Okunishi (Department of Physics, Niigata University)

16:30-17:00 **The ALPS Project: Open Source Software for Classical and Quantum Lattice Models**
Matthias Troyer (Institut für Theoretische Physik, ETH Hünggerberg)

17:00-17:30 **Universal Relation in Critical Temperature of Strongly Anisotropic Magnets**
Synge Todo (Department of Applied Physics, University of Tokyo)

17:30-18:00 **DMFT results for the spin-$1/2$ Kondo lattice model**
Philipp Werner (Columbia University)

18:00- Poster Session

August 10, 2006

9:00-9:30 **ICAMipedia**
Daniel Cox (Institute for Complex Adaptive Matter of the University of California)

9:30-10:00 **Searching for a supersolid phase in three dimensions**
Takafumi Suzuki (ISSP, University of Tokyo)

10:00-10:30 **A new high field phase in the frustrated 2D dimer spin system $SrCu_2(BO_3)_2$**
Masashi Takigawa (ISSP, University of Tokyo)

11:00-11:30 **Magnetic Quantum Phase Transitions and Critical Behavior in $TlCuCl_3$ and $KCuCl_3$**
Hidekazu Tanaka (Tokyo Institute of Technoloby)

11:30-12:00 **A Bose-Einstein condensate of magnons in anisotropic quantum magnets $BaCuSi_2O_6$ and $NiCl_{2-4}SC(NH_2)_2$**
Marcelo Jaime (National High Magnetic Field Laboratory, Los Alamos National Laboratory)

12:00-12:30 **Geometrical Frustration and Dimensional Reduction at a Quantum Critical Point**
Cristian Batista (Condensed Matter and Statistical Physics, Los Alamos National Laboratory)

— Lunch —

14:00-14:30 **I2CAM Fellowships**
Daniel Cox (Institute for Complex Adaptive Matter of the University of California)

14:30-15:00 **Field-Induced Quantum Critical Phenomena in Quasi-1D Spin Systems**
Toru Sakai (Japan Atomic Energy Agency/Spring-8)

15:00-15:30 **Emergence of Long Period Antiferromagnetic and Ferrimagnetic Orders Due to Anisotropy Modulation in High Spin Heisenberg Chains**
Kazuo Hida (Department of Physics, Saitama University)

16:00-16:30 **Tomonaga-Luttinger liquid induced by a magnetic field in a gapped quasi-1D antiferromagnet**
Masayuki Hagiwara (High Magnetic Field Laboratory, Osaka University)

16:30-17:00 **Quantum Critical "Opalescence"**
Masatoshi Imada (Department of Applied Physics, University of Tokyo)

17:00-17:30 **Phase-space methods for fermions: bounded distributions and stochastic gauses**
Joel Corney (Department of Physics, The University of Queensland)

17:30-18:00 **Highly Correlated Electrons on Triangular Lattice; Mott Criticality, Spin Liquid and Superconductivity**
Kazushi Kanoda (Department of Applied Physics, University of Tokyo)

18:00- Banquet

August 11, 2006

9:00-9:30 **Finite Temperature Effects on the Excitation Spectrum in Quantum Critical Magnetic Insulators**
Christian Rüegg (Department of Physics and Astronomy, University College London

9:30-10:00 **Ion Exchange as a Tool to Explore Two-Dimensional Square Lattice Antiferromagnets**
Hiroshi Kageyama (Department of Chemistry, Graduate School of Science, Kyoto University

10:00-10:30 **Magnetic multipole orders in frustrated ferromagnets**
Tsutomu Momoi (RIKEN)

11:00-11:30 **Duality and finite-size scaling analysis of the two-dimensional diluted Villain model**
Yutaka Okabe (Department of Physics, Tokyo Metropolitan University)

11:30-12:00 **Kondo Problems in Quantum Critical Environments**
Hideaki Maebashi (ISSP, University of Tokyo)

12:00-12:30 **Magnetic structure in inhomogeneous systems and time-dependent systems**
Seiji Miyashita (Department of Physics, University of Tokyo)

— Lunch —

14:00-14:30 **A numerical algorithm for the eigenvalue distribution of non-Hermitian matrices**
Naomichi Hatano (Institute of Industrial Science, University of Tokyo)

14:30-15:00 **The correlation density matrix: new tool for analyzing exact diagonalizations?**
C. L. Henley (Institute of Industrial Science, University of Tokyo)

15:00-15:30 **Ferromagnetism and Quantum Statistics**
Masaki Oshikawa (ISSP, University of Tokyo)

15:30-16:00 **Flowgram method for precise studies of poly-critical points and deconfined criticality as a theory of weak first order transitions**
Nikolay Prokof'ev (Department of Physics, University of Massachusetts, Amherst)

16:00-16:30 **Deconfined quantum criticality in a 2D Heisenberg model with four-spin interactions**
Anders Sandvik (Department of Physics, Boston University)

(Poster Session: Program)

18:00- August 9, 2006

P1 **Spin-triplet superconductivity in the double-chain Hubbard model with ferromagnetic exchange interaction**
Tomonori Shirakawa (Department of Physics, Chiba University)

P2 **Density matrix renormalization group study of dynamics in correlated electron systems with environment**
Hiroaki Matsueda (Department of Physics, Tohoku University)

P3 **Stability of One-dimensional Mott Insulators against Charge Fluctuations by the Density Matrix Renormalization Group Method**
Isao Maruyama (Department of Applied Physics, University of Tokyo)

P4 **Numerical study of diluted orbital**
Takayoshi Tanaka (Department of Physics, Tohoku University)

P5 **Effects of Impurities in Quasi-One-Dimensional Haldane Antiferromagnets**
Munehisa Matsumoto (ETH Zurich)

P6 **Pairing Phase in Bosonic Systems with Correlated Hopping**
Andreas Läuchli (IRRMA - EPF Lausanne)

P7 **Bond-Dilution-Induced Quantum Phase Transitions in Heisenberg Antiferromagnets**
Chitoshi Yasuda (Department of Physics and Mathematics, Aoyama Gakuin University)

P8 **Low-energy properties of one-dimensional spin-orbital model**
Hiroaki Onishi (Advanced Science Research Center, Japan Atomic Energy Agency

P9 **Surface and corner multifractality in two-dimensional symplectic class**
Hideaki Obuse (Condensed Matter Theory Laboratory, RIKEN)

P10 **Non-linear transport in a commensurate CDW and universal KPZ fluctuation**
Takashi Oka (Department of Physics, University of Tokyo)

P11 **Dynamical properties of photoexcited states in one-dimensional dimerized Mott insulators**
Nobuya Maeshima (Institute for Molecular Science)

P12 **Quantum Monte Carlo study of the multiorbital Hubbard model with spin and orbital rotational symmetries.**
Shiro Sakai (Department of Physics, University of Tokyo)

P14 **The Anderson transitions in 3D, 2D, and below 2D**
Yoichi Asada (Department of Physics, Tokyo Institute of Technology)

P15 **Mean field quantum annealing**
Sei Suzuki (Department of Physics, Tokyo Institute of Technology)

P16 **New type of quantum liquid of spinless fermions on an anisotropic triangular lattice**
Chisa Hotta (Aoyama Gakuin University)

P17 **Magnetization plateaux for distorted triangular antiferromagnet Cs_2CuBr_4**
Shin Miyahara (Aoyama Gakuin University)

P18 **Re-entrant quantum phase transitions with respect to the XXZ anisotropy parameter in spin chains**
Kiyomi Okamoto (Department of Physics, Tokyo Institute of Technology)

P19 **Modification of Directed-Loop Algorithm for Continuous Space Simulation of Bosonic Systems**
Yasuyuki Kato (Institute of Solid State Physics, University of Tokyo)

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Abstracts: Oral Session on August 9th

10:00- Quantum Monte Carlo study of many-body systems coupled with lattice degrees of freedom

Takeo Kato (ISSP, University of Tokyo)

Importance of electron-lattice couplings have been recognized for long time in low-dimensional correlated systems like organic conductors. It, however, remains an unsolved problem to consider strong competition between different phases induced by changing dimensionality of the system. In order to approach this problem, I have recently developed a novel algorithm to deal with correlated systems coupled to lattice degrees of freedom based on the stochastic series expansion (SSE) method. By applying it to the spin-Peierls model with interchain exchange interaction, I discuss competition effects between antiferromagnetism and spin-Peierls transition. I also mention other applications of the present algorithm.

10:30- Calculation of correlation functions of spin $1/2$ XXX chain

Minoru Takahashi (ISSP, University of Tokyo)

The calculation of the correlation functions of Bethe ansatz solvable models is very difficult problem. Among these solvable models spin $1/2$ XXX chain has been investigated for a long time. Even for this model only the nearest neighbor and the second neighbor correlations were known. In 1990's Kyoto group gave multiple integral formula for the general correlations. But the integration of this formula is also very difficult problem. Recently these integrals are decomposed to products of one dimensional integrals and correlation functions are expressed by $\log 2$ and Riemann's zeta functions with odd integer argument $\zeta(3)$, $\zeta(5)$, $\zeta(7)$,.... We can calculate density matrix of successive six sites. This means that all correlations in successive 6 sites can be calculated. These method can be extended to XXZ chain. I will review recent progress in the calculations of correlation functions.

11:00- Dynamics and magnetization process of triangle based low dimensional systems, ring, tube, helix and ball

Hiroyuki Nojiri (Institute for Materials Research, Touhoku University)

A spin chirality brings a new internal degree of freedom in spin systems made up of triangular spin rings such as prism, tube, helix and polyhedron. The cross term of the chirality and the spin gives rise to a variety of magnetic properties in such systems. A simple but interesting example is found in the spin ring. A purely adiabatic magnetization process is confirmed by the observation of half-step magnetization. Similar behavior is found in a spin polyhedron of tri-diminished icosihedron, where the ground state is doubly degenerated. In spin polyhedron of huge number of states, the magnetization plateau is found at the 1/3 of saturation and is interpreted by the order by disorder mechanism.
It is also important that the spin chirality is closely connected with the structural chirality. In a triangle ring, the distortion from the regular triangle mostly results in the chiral structure that gives the difference between the upward and the downward directions in the spin ring. When such chiral rings are connected into a chain, a helix of mono-chirality can be formed and the non-linear properties are expected in both dielectric and magnetic sectors.

11:30- Spin Nematic State in a Triangular Antiferromagnet

Hirokazu Tsunetsugu (Yukawa Institute for Theoretical Physics, Kyoto University)

In some triangular antiferromagnets, no magnetic long range order is observed, but specific heat and magnetic susceptibility indicate the presence of gapless excitations. To explain these properties, we have proposed a scenario of spin nematic order and compared the results particularly with $NiGa_2S_4$, a spin-1 system. I will report the effects of quantum fluctuations in the nematic ordered state on observable magnetic properties, and also other characteristic correlations.

12:00- Metamagnetism and related critical phenomena in pyrochlore Heisenberg antiferromagnets

Yukitoshi Motome (Department of Applied Physics, University of Tokyo)

It is well known that the Heisenberg model with classical spins on the highly-frustrated pyrochlore lattice has a massively degenerate ground-state manifold and does not order magnetically at any temperature if the exchange interaction is limited to between nearest-neighbor spins. This fact is not changed by the addition of magnetic field; the degeneracy survives and the magnetization process does not show any characteristic feature up to the saturation field, at any temperature. However this system is in a 'critical' state, and dramatic changes can be expected whenever a perturbation is introduced which lifts the degeneracy of the ground-state manifold. In this presentation we explore the fascinating new effects which arise in an extended Heisenberg model originally introduced to explain the metamagnetic transition seen in Cr spinel oxides, $A\mathrm{Cr_2O_4}$ (A =Cd, Hg). In particular, we consider the consequences of thermal fluctuations on a Heisenberg model perturbed by additional longer-range interactions (which can lead to a variety of different forms of magnetic order), and of additional biquadratic interactions (which favour states with collinear spins). Using classical Monte Carlo simulation and low-temperature expansion techniques, we uncover a range of novel phenomena as a consequence of the delicate interplay among different perturbations; a spin-liquid metamagnetic state which exhibits a 'spin pseudogap' without any long-range magnetic order, a spin-nematic state with quadrupole ordering of spins, and a fluctuation-driven metamagnetic phase.

14:00- Emerging spatial structures in SU(N) Heisenberg model

Naoki Kawashima (ISSP, University of Tokyo)

The ordinary Heisenberg model that possesses the SU(2) symmetry can easily be generalized to higher symmetry simply by regarding a symbol "**S**" in the Heisenberg Hamiltonian as a generator of the SU(N) instead of SU(2). Here we concentrate on the two-dimensional model with symmetric representations, namely, the cases where an SU(N) spin can be expressed as a small number of, say M, bosons with N types. Besides possible connections to electron systems with orbital degeneracy, this model is interesting for several reasons. For example, it is theoretically predicted that, depending on the value of M and N, the SU(N) Heisenberg model may exhibit a quantum disordered state as well as various ground states with non-trivial spatial structures, such as the dimerized state and the striped state. From quantum Monte Carlo simulation, we find that it is indeed true for $M = 1$ but only for $N \geq 5$ where spontaneous dimerization can be observed. The case of $M > 1$ and the possibility of the disordered ground state are also discussed.

14:30- **Quantum Phase Transition between Two Ordered Phases with Unrelated Symmetries**

Kenji Harada (Dept. of Applied Analysis and Complex Dynamical Systems, Kyoto Univ.)

We show results of quantum Monte Carlo simulations for the quasi-one dimensional $S = 1$ biquadratic Heisenberg antiferromagnet. When the spatial anisotropy is varied, a direct phase transition from the spontaneous dimerized phase to the Neel ordered phase is observed. If it is a continuous phase transition, it shows an unconventional critical phenomena that may separate two phases of which the symmetry group of the lower-symmetry phase is not a sub-group of the other.

15:00- **Stripe formation in doped Hubbard ladders**

Eric Jeckelmann (Institute for Theoretical Physics, University of Hannover)

We investigate the formation of stripes in six-leg Hubbard ladders doped away from half filling using the density-matrix renormalization group method. A parallelized code allows us to keep enough density-matrix eigenstates and to study sufficiently large systems to extrapolate the stripe amplitude to the limits of vanishing DMRG truncation error and infinitely long ladders. Our work gives strong evidence for the existence of a long-range ordered stripe phase above a critical coupling U/t in Hubbard ladders.

[1] G. Hager et al., Phys. Rev. B **71**, 075108 (2005)

16:00- **Real space renormalization group approach for the corner Hamiltonian**

Kouichi Okunishi (Department of Physics, Niigata University)

The density matrix renormalization group(DMRG) is a very powerful numerical tool to study 1D quantum many body systems. In my talk, I would like to focus on some fundamental aspects of DMRG particularly of the infinite system size method, which may be a challenging problem to understand the success of DMRG and its implication to the critical phenomena. When considering the theoretical background of DMRG, it is essentially important to analyze the nature of the eigenvalue spectrum of the reduced density matrix. I explain the relation between the reduced density matrix and the corner Hamiltonian, which is a generator of Baxter's corner transfer matrix in 2D classical systems. I then present a novel real-space-renormalization group approach for this corner Hamiltonian and demonstrate it for the $S = 1/2$ XXZ spin chain. I also examine the renormalization group for the $S = 1$ Heisenberg spin chain and then discuss implications of the eigenvalue spectrum of the corner Hamiltonian to DMRG.

16:30- The fate of vacancy-induced supersolidity in ^{4}He

Matthias Troyer (Institut für Theoretische Physik, ETH Hünggerberg)

The supersolid state of matter, exhibiting non-dissipative flow in solids, has been elusive for thirty five years. The recent discovery of a non-classical moment of inertia in solid ^{4}He by Kim and Chan provided the first experimental evidence, although the interpretation in terms of supersolidity of the ideal crystal phase remains subject to debate. Using quantum Monte Carlo methods we investigate the long-standing question of vacancy-induced superflow and find that vacancies in a ^{4}He crystal phase separate instead of forming a supersolid. On the other hand, non-equilibrium vacancies relaxing on defects of poly-crystalline samples could provide an explanation for the experimental observations.
Reference: cond-mat/0605627

17:00- Universal Relation in Critical Temperature of Strongly Anisotropic Magnets

Synge Todo (Department of Applied Physics, University of Tokyo)

A novel universal relation in the critical temperature of quasi-one-dimensional magnets is investigated by the cluster Monte Carlo method. It is found that in the weak interchain coupling regime the critical temperature obeys a chain mean-field like relation with a reduced effective coordination number [1,2]. Furthermore, the renormalized coordination number is universal, i.e. independent of spin size. This universality is rigorously proved for the case of Ising anisotropy by considering a mapping to the quantum Ising model.

[1] C. Yasuda, S. Todo, K. Hukushima, F. Alet, M. Keller, M. Troyer, and H. Takayama, Phys. Rev. Lett. **94**, 217201 (2005).
[2] S. Todo, cond-mat/0606790.

17:30- DMFT results for the spin-$1/2$ Kondo lattice model

Philipp Werner (Columbia University)

I will reformulate a recently developed strong-coupling, continuous-time impurity solver in a manner appropriate for general classes of quantum impurity models. The method will be applied to the dynamical mean field theory of the ferromagnetic- and antiferromagnetic Kondo lattice model. I will show results for the metal-insulator transition and magnetic ordering in the half-filled Kondo lattice and briefly discuss the relationship to orbital selective Mott states in multi-orbital models.

Abstracts: Poster Session on August 9th

P1 **Spin-triplet superconductivity in the double-chain Hubbard model with ferromagnetic exchange interaction**

Tomonori Shirakawa (Department of Physics, Chiba University)

Mechanism of spin-triplet superconductivity has been one of the major issues in the field of strongly correlated electron systems. Here, the ferromagnetic interaction between electrons is believed to play an essential role in the occurrence of triplet superconductivity. In this paper, we study the simplest model in this context: i.e., the model of two Hubbard chains coupled with Heisenberg-type ferromagnetic exchange interaction J. This model may be regarded as the degenerate two-band Hubbard model with the on-site Hund's rule coupling in transition-metal oxides. This model may also be regarded as the Hubbard chains with the interchain ferromagnetic interaction which may come from the ring-exchange mechanism in quasi-one-dimensional organic materials [1].

We use the density-matrix renormalization group (DMRG) method and exact-diagonalization technique on small clusters to calculate the charge gap, spin gap, binding energy, pair correlation functions, etc., as well as the anomalous Green's function of the model. We thereby show that the model contains the state of mobile 'rung-triplet' pairs, i.e., spin-triplet superconductivity, in the wide parameter and filling region. The binding energy, e.g., scales well with J when J is large. We also show that the spin gap corresponding to th Haldane gap for the spin-1 Heisenberg chain opens at half filling, the size of which becomes small away from half filling.

[1] Y. Ohta et al., Phys. Rev. B 72, 012503 (2005).

P2 Density matrix renormalization group study of dynamics in correlated electron systems with environment

Hiroaki Matsueda (Department of Physics, Tohoku University)

We study dynamical properties of one-dimensional correlated electrons coupled with enviroment. There are two topics in this study: one is whether the spin-charge separation is robust in materials where electrons strongly interact with phonons. Since the separation provides novel optical properties such as gigantic third-order nonlinear response, it should be understood how the separation is realized in materials. Starting with the Hubbard-Holstein model at half-filling, we calculate the single-particle excitation spectrum by using the dynamical density matrix renormalization group (DMRG) method. We find that the spin-charge separation is robust in the presence of the electron-phonon coupling. However, both of the spinon and holon branches are affected by phonons. For interpretation of the DMRG results, we propose an effective model for the spectrum that is defined by a superposition of spectra for the Holstein model. The second topic is time evolution of correlated electrons coupled with localized spins. One motivation is ultra-fast photoinduced phase transition recently observed in cuprates, manganites, and organic compounds. Here, the energy dissipation plays a crucial role. Since the exchange energy is large in some oxides, the fast relaxation may be possible by emitting magnon excitations. Starting with the extended double-exchange model, we study the transient spectrum of mobile electrons and time evolution of the spin-spin correlation for localized spins by using the time-dependent DMRG method. We discuss the effect of the spin degrees of freedom on the relaxation.

P3 Stability of One-dimensional Mott Insulators against Charge Fluctuations by the Density Matrix Renormalization Group Method

Isao Maruyama (Department of Applied Physics, University of Tokyo)

Collapse of one-dimensional Mott Insulators due to charge fluctuation is studied by the DMRG method, where the charge fluctuation implies injection of electrons and holes from out of the system. To introduce this “doping” effect, we construct a Hamiltonian, which does not conserve a particle number but still preserves the particle-hole symmetry. Due to the U(1) symmetry breaking term, zero temperature fluctuation of the total particle number is finite even at half filling and is proportional to the inverse of the Coulomb interaction in the strong coupling.

The U(1) symmetry breaking term in the present model can be regarded as a mean field of an inter-chain hopping when we use a string type decoupling. If the inter-chain hopping is irrelevant, total number of the 1D system is conserved and the 1D Mott insulator is realized. Quantum phase transition collapsing the Mott gap is also discussed.

We extend the DMRG method to treat a generic fermionic system with a U(1) symmetry breaking term where its total fermion number is not conserved.

P4 Numerical study of diluted orbital

Takayoshi Tanaka (Department of Physics, Tohoku University)

Various exotic phenomena in correlated electron systems are studied from the view point of the internal degrees of freedom of electron, i.e. charge, spin and orbital degrees of freedom in strong Coulomb interaction. Recently, dilution effects on the orbital ordered state are examined experimentally in $KCuF_3$ which is a prototypical material showing the long range orbital order. It is revealed that, by replacing Cu ion by Zn which does not have the orbital degree of freedom, a reduction of the orbital ordering temperature (T_{oo}) is more remarkable than that in diluted magnets, and T_{oo} disappears at a certain Zn concentration which is lower than the percolation threshold. We investigate theoretically dilution effects in orbital systems.
(1) The classical e_g orbital model is analyzed by the Monte-Carlo (MC) simulation and the cluster expansion method. We show T_{oo} decreases more rapidly by increasing dilution in comparison with the diluted magnets, and reproduce the experimental results in $KCu_{1-x}Zn_xF_3$.
(2) We analyze the two dimensional version of the quantum e_g orbital model, termed the orbital compass model by quantum Monte-Carlo simulation. It is known that at low temperatures, this model shows the orbital alignment along one direction in the two dimensional lattice, i.e. the directional order. We show that the directional ordering temperature decreases by dilution more rapidly than the diluted Ising model, but more slowly than the classical compass model. This result implies that the quantum effects stabilize the directional order.

P5 Effects of Impurities in Quasi-One-Dimensional Haldane Antiferromagnets

Munehisa Matsumoto (ETH Zurich)

For spin-1 quasi-one-dimensional antiferromagnets that have quantum disordered ground states, the effects of magnetic and non-magnetic impurities are investigated utilizing the quantum Monte Carlo method with the continuous-time loop algorithm. Impurity-induced transition temperatures are determined with respect to the concentration of host spins and the nature of the phase transition between the paramagnetic phase and the impurity-doped valence bond solid state is discussed. The qualitative differences between the species of impurities in the impurity-induced phase transitions are discussed by investigating the local magnetic structure around impurities.

P6 Pairing Phase in Bosonic Systems with Correlated Hopping

Andreas Läuchli (IRRMA - EPF Lausanne)

Motivated by the physics of mobile triplets in frustrated quantum magnets, the properties of a two dimensional model of bosons with correlated-hopping are investigated. We study the phase diagram of this system as a function of density and the strength of the correlated hopping term, based on Quantum Monte Carlo simulations in the SSE formulation. We confirm the existence of two different phases, first reported in a mean-field study: a conventional single particle bose condensed phase, and in addition a less studied phase where only pairs of bosons condense. We comment on the performance of the standard single worm SSE in the pairing phase, and on the possibility of using a "double worm" algorithm to improve the efficiency.
This work has been performed in collaboration with K.P. Schmidt and F. Mila (EPF Lausanne).

P7 Bond-Dilution-Induced Quantum Phase Transitions in Heisenberg Antiferromagnets

Chitoshi Yasuda (Department of Physics and Mathematics, Aoyama Gakuin University)

Bond-dilution effects on a ground state of the $S = 1/2$ quantum antiferromagnetic (AF) Heisenberg model consisting of bond-alternating chains on a square lattice was investigated by means of the quantum Monte Carlo simulations with the continuous-imaginary-time loop algorithm. The magnitude of the stronger (weaker) intra-chain interaction is put unity (α) and that of the inter-chain interaction J'. The ground state of the pure system is the dimmer state with a finite spin gap for small α and J'. When spins are randomly removed from the system in the dimer state (site dilution), a spin which formed a singlet pair with the removed spin before dilution becomes nearly free, which we call effective spins. Between two of them, however, there exists the finite interaction J_{mn} mediated by a sea of singlet pairs. Since the effective interaction is AF (ferromagnetic) when the two effective spins are in the different (same) sublattices, an AF long-range order (LRO) is induced with an infinitesimal concentration of site dilution. When stronger bonds are randomly removed from the system in the dimer state (bond dilution), on the other hand, the effective spins are always induced in pairs at both ends of the removed bonds. Since the two spins are located on the different sublattices, a singlet pair is reformed through the short-range effective AF coupling J_{af} of $O(J'^2)$. In contrast to the site-diluted case, there exist two effective interactions. For small concentration of dilution, if J_{af} is sufficiently larger than J_{mn}, the system is in the disordered phase. The phase transition between the disordered and AF-LRO phases occurs when the magnitudes of J_{af} and J_{mn} are equivalent.

P8 **Low-energy properties of one-dimensional spin-orbital model**

Hiroaki Onishi (Advanced Science Research Center, Japan Atomic Energy Agency)

By using a density-matrix renormalization group method, we investigate the ground-state properties and the spin-gap formation of a one-dimensional spin-orbital model, in which the original SU(4) symmetry is broken due to the effect of the Hund's rule coupling.

P9 **Surface and corner multifractality in two-dimensional symplectic class**

Hideaki Obuse (Condensed Matter Theory Laboratory, RIKEN)

We numerically calculated surface and corner multifractal exponents at the critical point of the two-dimensional disordered system with the spin-orbital interaction. We confirm that the surface and the corner multifractal exponent satisfy a certain relation derived from the conformal field theory.

P10 **Non-linear transport in a commensurate CDW and universal KPZ fluctuation**

Takashi Oka (Department of Physics, University of Tokyo)

Solitonic excitations (kinks and anti-kinks) dominate the dynamics of a one dimensional commensurate CDW (e.g. polyacetylene) in finite electric fields. In finite temperature, we predict that the dielectric breakdown of such systems shows features characteristic of the KPZ universality class. We also propose (optical) experiments to verify this phenomenon.

P11 **Dynamical properties of photoexcited states in one-dimensional dimerized Mott insulators**

Nobuya Maeshima (Institute for Molecular Science)

Dynamical properties of photoexcited states are theoretically studied in a one-dimensional Mott insulator dimerized by the spin-Peierls instability. Numerical calculations combined with a perturbative analysis have revealed that the lowest photoexcited state without nearest-neighbor interaction corresponds to an interdimer charge transfer excitation that belongs to dispersive excitations. The adiabatic potential of this excited state as a function of the lattice dimerization has demonstrated that the dimerized phase is destabilized by the photoexcitation from the ground state to this excited state. We also discuss the purely electronic origin of midgap states that are observed in a latest photoexcitation experiment of an organic spin-Peierls compound, K-TCNQ (potassium-tetracyanoquinodimethane).

P12 Quantum Monte Carlo study of the multiorbital Hubbard model with spin and orbital rotational symmetries.

Shiro Sakai (Department of Physics, University of Tokyo)

Combining the Trotter decomposition and a series expansion of the partition function with respect to Hund's exchange coupling, we develop a new quantum Monte Carlo (QMC) algorithm for multiorbital systems with spin and orbital rotational symmetries. While the conventional QMC method has difficulties to treat the spin-flip and the pair-hopping terms of the Hamiltonian, we show that our new approach enables us to simulate these terms efficiently. To demonstrate this, we apply our algorithm for studying ferromagnetism in the two-orbital Hubbard model within dynamical mean field theory (DMFT).
Our results reveal how important it is to account for the correct SU(2) symmetry of Hund's exchange. Otherwise, i.e., for an Ising (Z_2) symmetry, Curie temperatures are grossly overestimated. We also calculate the t_{2g} spectral functions of Sr_2RuO_4 by three-band DMFT calculations with tight-binding parameters from the local density approximation as input and with proper rotational symmetries, which has been impossible before.

P14 The Anderson transitions in 3D, 2D, and below 2D

Yoichi Asada (Department of Physics, Tokyo Institute of Technology)

We report our new precise estimates of the critical exponent for the divergence of the localization length at the Anderson transitions in 3D. We have finally confirmed that the values of the critical exponent for three symmetry classes (orthogonal, unitary, and symplectic) are different. We have also estimated the scaling beta function for the quasi-1D localization length, which indicates that the finite size scaling of the quasi-1D localization length depends on the symmetry in the metallic and critical regions, but not in the strongly localized region.
We also report numerical study of the Anderson transition in systems with spin-orbit coupling in 2D and below. Such systems are an exception to the prediction of Abrahams et. al. that there is no metallic phase in 2D and below. We have estimated the critical exponent for the 2D Anderson transition in systems with spin-orbit coupling, and then studied the quantum transport property in the 2D metallic phase. Our results in the 2D metallic region support the Hikami-Larkin-Nagaoka's prediction that the 2D metals have perfect conductivity. We have also investigated the possibility of an Anderson transition below 2D. Our simulations on the Sierpinski carpet suggest that an Anderson transition occurs even below 2D in the presence of spin-orbit coupling. The lower critical dimension might be between 1D and 2D.

P15 Mean field quantum annealing

Sei Suzuki (Department of Physics, Tokyo Institute of Technology)

Quantum mechanical approaches are attracted in computational sciences. The quantum annealing is a novel technique for optimization of various disordered problems. It utilizes the dynamical motion of quantum state driven by handling quantum fluctuations. As an important direction, we focus on realistic numerical methods to carry out the quantum annealing in classical computers. The mean field quantum annealing, which we discuss, is a rough but non-trivial method. It is applicable to large problem sizes and yields an answer fast. However it is not clear how the mean field method is valid. In our study we investigate the validity of this method for elementary models and clarify the property of this method in comparison with other known optimization techniques. In my presentation, I will report our results of numerical calculation and discuss the limitation of the mean field quantum annealing. I will also present an improvement of the mean field approximation.

P16 New type of quantum liquid of spinless fermions on an anisotropic triangular lattice

Chisa Hotta (Aoyama Gakuin University)

We propose a new type of liquid state of charges in the spinless fermion system on a triangular lattice under strong inter-site Coulomb interactions, V. In the strong coupling limit ($t = 0$), the ground state is classical and disordered due to geometrical frustration. The introduction of small t drives the system to a partially ordered phase which we call a "pinball liquid". A possibly long range ordered Wigner crystal solid coexist with a liquid component which are moving around them like a pinball. This liquid is dominant over wide range of filling, even away from the regular triangle. The phase diagram of the present system on an anisotropic triangular lattice is given and a relevance to the organic crystal, θ-ET_2X is discsussed.

P17 Magnetization plateaux for distorted triangular antiferromagnet Cs_2CuBr_4

Shin Miyahara (Aoyama Gakuin University)

Cs_2CuBr_4 is a new two-dimensional spin-1/2 system, where 1/3 and 2/3-plateaux have been observed in external magnetic fields. It is expected that the magnetic behaviors of the material can be well explained by a spin-1/2 two-dimensional antiferromagnetic Heisenberg model on a distorted triangular lattice. In the model, there are two types of interactions, J_1 and J_2, where J_1 chains are coupled with inter chain interactions J_2. Using an exact diagonalization method, we investigate magnetic properties in the plateau phases. In the 1/3-plateau phase, three-fold degenerate translational symmetry broken ground state is realized. On the other hand, 2/3-plateau has a translationally symmetry broken state where $M = 1$ and $M = 1/3$ chains along J_1 bonds alternate with each other.

P18 Re-entrant quantum phase transitions with respect to the *XXZ* anisotropy parameter in spin chains

Kiyomi Okamoto (Department of Physics, Tokyo Institute of Technology)

I will discuss the re-entrant quantum phase transitions in quantum spin chains when the *XXZ* anisotropy parameter is run. In some cases, for example, we can see the succesive transitions such as TL-Neel-TL-Ferri, where TL means the Tomonaga-Luttinger spin-fluid state. This phenomenon can be found in $S = 1/2$ spin chains having three key words: *XXZ* anisotropy, trimer nature and frustration. We also find that four Berezinski-Kosterlitz-Thouless quantum phase transition lines meet together at one point in the phase diagram on the plane of quantum parameters.

P19 Modification of Directed-Loop Algorithm for Continuous Space Simulation of Bosonic Systems

Yasuyuki Kato (Institute of Solid State Physics, University of Tokyo)

The directed-loop algorithm (DLA) is one of the most robust algorithms for quantum Monte-Carlo simulation, and enjoys very broad applicability. Updates of world-line configurations in DLA are done by a worm, which consists of a pair of discontinuity points moving stochastically on world-lines and altering the state on the line just behind itself. The direction of motion of a discontinuity point is altered only by scattering at vertices that are placed between world-lines or on a single world-line with density determined by the Hamiltonian. However, when one applies the method to a system such as the Bose-Hubbard model with $t \ll U$ (t is the hopping amplitude and U is the on-site energy), the efficiency of the method is low because of high density of vertices due to large U. We improve DLA by omitting the vertices that express the effect of U in this paper. The effect of U is reflected in other procedures. We demonstrate the efficiency of the new method by applying it to the interacting dilute Bose gas system in a discrete space that has the aforesaid difficulty.

Abstracts: Oral Session on August 10th

9:00- ICAM session (I) — ICAMipedia

Daniel Cox (Institute for Complex Adaptive Matter of the University of California)

Prof. Daniel Cox, co-director of ICAM will lead a discussion on contributions to the new ICAMipedia web pages where we can describe to the larger public (other scientists, interested young people, educated public, and our community) the exciting developments of our field.

9:30- Searching for a supersolid phase in three dimensions

Takafumi Suzuki (ISSP, University of Tokyo)

Since the fascinating features of solid helium were presented by torsional oscillator experiments for the solid helium four [1], ordered states on the bosonic lattice models have received a great deal of attention. Recently, the existence of the supersolid phase in the hard-core bosons on the triangular lattice was demonstrated by a numerical calculation [2]. Such bosonic lattices can be experimentally realized by trapping the ultra-cold bosonic atoms into the optical lattices. It is useful to study the ordered states on the bosonic lattice models in order to clarify the characteristics of the supersolid state. In this study, we investigate the ordered states of the hard-core bosons with unfrustrated hopping and nearest-neighbor repulsion on the face-centered cubic (FCC) lattice. The static structure factors and the superfluid density are calculated, using a quantum Monte Carlo method. At the half filling and the three-quarter filling, the ordered phases with the crystalline lattice appear below the critical temperature. However, between the two fillings, there appears the phase in which the long-range diagonal order and the superfluidity coexist. This phase is in contrast to the ordered phases observed for Ising spins [3]. We discuss more details of the supersolid states on the FCC lattice.

[1] E. Kim and M. H. W. Chan, Nature **427**, 225 (2004); Science **305**, 1941 (2004).
[2] S. Wessel and M. Troyer, Phys. Rev. Lett **95**, 127205 (2005).
[3] K. Binder, et. al., Acta metall. **29**, 1655 (1981).

10:00- A new high field phase in the frustrated 2D dimer spin system $SrCu_2(BO_3)_2$

Masashi Takigawa (ISSP, University of Tokyo)

The frustrated 2D dimer spin system $SrCu_2(BO_3)_2$ shows magnetization plateaus at 1/8, 1/4 and 1/3 of the saturated magnetization, where symmetry breaking superlattices of triplets were observed by NMR experiments (Science **298** (2002) 395). How the spin density distribution evolves between the plateaus is a highly non-trivial issue. One possibility is that the hopping of triplets " melts " the superlattice and the Bose-condensed phase with the transverse AF order appears instead. Another possibility is the "supersolid" phase, in which a superlattice of the longitudinal component coexists with the transverse AF order. The nature of the phase may be even more complicated by the presence of Dzyaloshinskii-Moriya interaction, which produces an effective staggered field (J. Phys.:Condens Matter. **17** (2005) L61). We performed ^{11}B NMR experiments in the field up to 31 T above the 1/8-plateau phase. The NMR spectra show discontinuous change upon leaving the 1/8-plateau. However, the maximum hyperfine filed at the B nuclei remains nearly unchanged, indicating that the superlattice of largely polarized triplet dimers still persists above the 1/8 plateau phase. The ordering temperature in the high field phase agrees with the peak of the specific heat reported by Tsujii et al. (cond-mat/0301509). The sharp fine structures of the NMR spectra in the plateau phase, however, become broadened as the field increases. Possible scenarios to explain the evolution of NMR spectra will be discussed. This work was done in collaboration with S. Matsubara1, M. Horvatic, C. Berthier, H. Kageyama and Y. Ueda.

11:00- **Magnetic Quantum Phase Transitions and Critical Behavior in $TlCuCl_3$ and $KCuCl_3$**

Hidekazu Tanaka (Tokyo Institute of Technoloby)

$TlCuCl_3$ and $KCuCl_3$ are magnetically characterized as three-dimensionally coupled spin-dimer system. Their ground states are spin singlets with excitation gaps Δ/k_B of 7.5 K and 31 K, respectively. The origin of the gap is the strong antiferromagnetic exchange interaction in the chemical dimer to form a spin dimer. In a magnetic field, which is higher than the critical field H_c corresponding to the gap, these systems can undergoes magnetic ordering with the transverse-ordered moments [1,2]. The field-induced magnetic quantum phase transition (QPT) in $TlCuCl_3$ has been extensively studied by various techniques. The results obtained were in accordance with theory which describes the field-induced magnetic QPT as the Bose-Einstein condensation of spin triplets [3]. For example, the critical exponent ϕ of the phase boundary defined by $T(H) \propto (H - H_c)^{1/\phi}$ is close to $\phi_{BEC} = 3/2$ derived from the magnon BEC theory [3,4]. Under a hydrostatic pressure P, the gap decreases and closes completely at $P_c = 0.42$ kbar and 8.2 kbar for $TlCuCl_3$ and $KCuCl_3$, respectively [5]. For $P > P_c$, these systems undergoes antiferromagnetic ordering, which is characterized by the same ordering vector as that for the field-induced magnetic ordering. The gap and Néel temperature are presented as functions of pressure. The occurrence of this pressure-induced magnetic QPT is attributed to the decrease of the intradimer interaction and the increase of interdimer interaction with applied pressure. The present results are discussed in connection with recent theory [6,7].

[1] H. Tanaka *et al.*: J. Phys. Soc. Jpn. **70** (2001) 939.
[2] A. Oosawa *et al.*: Phys. Rev. B **66** (2002) 104405.
[3] T. Nikuni *et al.*: Phys. Rev. Lett. **84** (2000) 5868.
[4] N. Kawashima: J. Phys. Soc. Jpn. **73** (2004) 3219.
[5] K. Goto *et al.*: J. Phys. Soc. Jpn. **73** (2004) 3254, cond-mat/0602540.
[6] M. Matsumoto *et al.*: Phys. Rev. B **69** (2004) 054423.
[7] O. Nohadani *et al.*: Phys. Rev. B **72** (2005) 024440.

11:30- A Bose-Einstein condensate of magnons in anisotropic quantum magnets $BaCuSi_2O_6$ and $NiCl_{2-4}SC(NH_2)_2$

Marcelo Jaime (National High Magnetic Field Laboratory, Los Alamos National Lab.)

Quantum magnets $BaCuSi_2O_6$ [1] and $NiCl_{2-4}SC(NH_2)_2$ [2] attracted significant attention in the last years, because magnetic fields can be used to tune a canted antiferromagnetic state regarded as a Bose-Einstein condensate of magnons. The coupling between spin and lattice degrees of freedom, however, was not yet studied in the ordered state. Different anisotropy in their crystallographic lattices and their spin arrangements, spin $S = 1/2$ Cu^{2+} dimers in $BaCuSi_2O_6$ and $S = 1$ Ni^{2+} in $NiCl_{2-4}SC(NH_2)_2$, are responsible for different degree of spin-lattice coupling. While the former only displays weak lattice effects, the later shows a significant magnetostriction that changes sign as the canting angle between spins is reduced and the spin arrangement evolves gradually from AFM at the critical field H_{c1}, to FM at the saturation field H_{c2}. Recent specific heat, magnetocaloric effect and magnetostriction measurements at high magnetic fields will be discussed for these two fascinating compounds.

12:00- Geometrical Frustration and Dimensional Reduction at a Quantum Critical Point

Cristian Batista (Condensed Matter and Statistical Physics, Los Alamos National Lab.)

Competition between ground states near a quantum critical point is expected to lead to unconventional behavior in low dimensional systems. New phases of matter have been predicted, and explanations proposed for unsolved problems including non-Fermi liquid behavior and high temperature superconductivity using two-dimensional (2d) theories. In this talk, I will present a theory that describes the Bose-Einstein condensate (BEC) quantum critical point (QCP) in layered systems with a frustrated inter-layer coupling. I will demonstrate that the main effect of this geometric frustration is to reduce the dimensionality of the QCP (its critical exponents are the ones expected for a 2d system). In addition, I will compare this theory with the first experimental evidence of dimensional reduction at a QCP observed in the Mott insulator $BaCuSi_2O_6$ (Han Purple).

14:00- ICAM session (II) — I2CAM Fellowships

Daniel Cox (Institute for Complex Adaptive Matter of the University of California)

Prof. Daniel Cox will lead a session in which participating junior scientists develop ideas for exchange fellowships through ICAM based upon the science of this meeting.

14:30- Field-Induced Quantum Critical Phenomena in Quasi-1D Spin Systems

Toru Sakai (Japan Atomic Energy Agency/Spring-8)

Using the numerical diagonalization based on the Lanczos algorithm, we investigate the magnetization process of several spin ladder systems with the next-nearest-neighbor interaction, or the ring exchange interaction. The finite size scaling analysis based on the conformal field theory and the recently developped level spectroscopy method reveal that a magnetization plateau would appear at half the saturation magnetization, if the next-nearest-neighbor or ring exchange interaction is sufficiently large. In addition the mean-field approximation for the interladder interaction suggests that the quasi-1D system possibly exihibit a field-induced incommensurate order in some regions close to the magnetization plateau. Several phase diagrams in the ground state of the 1D system are also presented.

15:00- Emergence of Long Period Antiferromagnetic and Ferrimagnetic Orders Due to Anisotropy Modulation in High Spin Heisenberg Chains

Kazuo Hida (Department of Physics, Saitama University)

In integer spin antiferromagnetic Heisenberg chains, the easy plane single-site anisotropy $D(> 0)$ destroys the Haldane ground state leading to the large-D phase while the easy axis single-site anisotropy ($D < 0$) drives the Haldane state into the Neel ordered state. In this context, it is an interesting issue to investigate how the ground states of the quantum spin chains are modified if the easy-axis and easy-plane D-terms coexist in a single chain. In the present study, we investigate the ground states of the high spin Heisenberg chains with period 2 modulation of single site anisotropy. It turns out that various phases such as Haldane phase, large-D phase, Tomonaga-Luttinger liquid phase, Neel phases of various structures and ferrimagnetic phase appear depending on the strength of modulation and spin magnitude.

16:00- Tomonaga-Luttinger liquid induced by a magnetic field in a gapped quasi-1D antiferromagnet

Masayuki Hagiwara (High Magnetic Field Laboratory, Osaka University)

The Tomonaga-Luttinger liquid (TTL) is a universal low-temperature state of gapless, one-dimensional (1D) quantum systems. 1D antiferromagnets having an energy gap are expected to become a TLL, when a strong magnetic field is applied to collapse the energy gap. To date, however, all experimental evidence in these antiferromagnets has been either controversial or circumstantial. In the spin-1 bond-alternating antiferromagnet NTENP, we have observed an unambiguous signature of a TLL: a linear temperature (T) dependence of the magnetic specific heat (C_{mag}). The linear C_{mag} appears only in magnetic fields above the critical value $H_{\mathrm{c}} = 9.3$T and the Sommerfeld constant C_{mag}/T increases as the field is reduced toward H_{c}. This field dependence agrees well with the results of our calculation, providing a conclusive evidence for a TLL.

16:30- Quantum Critical ”Opalescence”

Masatoshi Imada (Department of Applied Physics, University of Tokyo)

Divergent carrier-density fluctuations equivalent to the critical opalescence of gas-liquid transition emerge around a metal-insulator critical point at a finite temperature. In contrast to the gas-liquid transitions, however, the critical temperatures can be lowered to zero, which offers a challenging quantum phase transition. We present a microscopic description of such quantum critical phenomena in two dimensions. The conventional scheme of phase transitions by Ginzburg, Landau and Wilson is violated and an unconventional universality appears. It offers a clear insight into the criticalities of metal-insulator transitions associated with Mott or charge-order transitions. Fermi degeneracy involving the diverging density fluctuations generates emergent phenomena near the endpoint of the first-order transition and must shed new light on remarkable phenomena found in correlated metals like unconventional cuprate superconductors.

17:00- **Phase-space methods for fermions: bounded distributions and stochastic gauses**

Joel Corney (Department of Physics, The University of Queensland)

Gaussian Quantum Monte Carlo Methods are a class of simulation methods based on phase-space representations of quantum states. Successful simulations of the Hubbard model showed that, for this case, GQMC did not suffer the same sort of 'classic' sign problem as other comparable methods. However, GQMC does have its own difficulties. A known issue in phase-space methods is to do with the boundedness of the underlying distribution, and the ability of stochastic equations to sample this distribution. I will cover recent investigations into the type of distributions that arise for interacting systems, the effectiveness of 'stochastic gauges' to control distribution tails, and efficient simulation methods.

17:30- **Highly Correlated Electrons on Triangular Lattice; Mott Criticality, Spin Liquid and Superconductivity**

Kazushi Kanoda (Department of Applied Physics, University of Tokyo)

The layered organics, κ-$(ET)_2X$, are model systems for the study of strongly correlated half-filled-band electrons. Here we present two progresses in the Mott physics through the transport and NMR studies on this family of materials.
One is the Mott criticality in 2D. κ-$(ET)_2Cu[N(CN)_2]Cl$ is a Mott insulator with a quite low critical pressure to Mott transition. The resistance measurements of this material under precisely controlled pressure showed that the first-order Mott transition has a critical endpoint at 40 K, where the resistive jump vanishes and critical pressure derivative of resistance is divergent. Remarkably, the transport critical exponents obtained do not belong to any universality class known so far. The implication of this finding is discussed. A recent NMR study on the Mott criticality is also presented.
The other is the realization of the spin liquid and its Mott transition. The Mott insulator κ-$(ET)_2Cu_2(CN)_3$ has a nearly isotropic triangular lattice and is a model system of frustrated quantum spins. The ^1H and ^{13}C NMR experiments showed no indication of magnetic ordering down to 30 mK. The spins are likely in the quantum liquid state. Under pressure, it undergoes Mott transition to the Fermi liquid which shows superconductivity at low temperatures. We present the pressure-temperature phase diagram and the NMR/transport results on the nature of the spin liquid and superconductivity.
This work is a collaboration with F. Kagawa, Y. Shimizu, Y. Kurosaki, H. Kasahara, T. Kobashi, K. Miyagawa, M. Maesato and G. Saito.

Abstracts: Oral Session on August 11th

9:00- **Finite Temperature Effects on the Excitation Spectrum in Quantum Critical Magnetic Insulators**

Christian Rüegg (Department of Physics and Astronomy, University College London)

The compound $TlCuCl_3$ represents a model system of dimerized quantum spins with strong interdimer interactions. We have investigated the triplet dispersion as a function of temperature by inelastic neutron scattering experiments in zero magnetic field. The description of Troyer, Tsunetsugu, and Würtz provides an appropriate quantum statistical model for dimer spin systems at finite temperature, where many-body correlations become particularly important [Ch. Rüegg et al., Phys. Rev. Lett. **95**, 267201 (2005)]. The temperature-dependence of the excitation spectrum is subsequently investigated by the same experimental technique at finite field around the quantum critical point at H_c, where the triplet gap is closed at $T = 0$ K and field-induced BEC of magnons occurs. The observed renormalization effects in the quantum critical region as well as the phase with long-range magnetic order will be discussed and compare to the zero-field results.

9:30- Ion Exchange as a Tool to Explore Two-Dimensional Square Lattice Antiferromagnets

Hiroshi Kageyama (Dept. of Chemistry, Graduate School of Science, Kyoto Univ.)

Soft chemical approach provides us new routes for the construction of new magnetic materials. Two-dimensional (2D) $S = 1/2$ square-lattice antiferromagnets (CuX)LaB_2AO_7 (X=Cl, Br; B=Nb, Ta) have been obtained by the ion exchange between Dion-Jacobson layered perovskites $RbLaB_2O_7$ and CuX_2. Here the magnetic $[CuX]^+$ layer is well separated by nonmagnetic perovskite slabs so that 2D magnetic properties are expected. The obtained materials shows a variety of magnetic behaviors. (CuCl)$LaNb_2O_7$ has a spin singlet ground state with an energy gap of 2.3 meV to the first excited triplet state [1]. Application of the magnetic field leads to the magnetic order described by the BEC of magnons [2]. On the other hand, (CuBr)$LaNb_2O_7$ undergoes a magnetic ordering of the stripe tope at 31 K and the analysis of the data indicates strong frustration in the layer. It is found that (CuCl)$LaTa_2O_7$ also exhibits a long-range magnetic ordering at 6 K. We have recently succeeded to obtain the solid solution series $(CuCl_xBr_{1-x})Nb_2O_7$ $(0 < x < 1)$ and $(CuCl)La(Nb_{1-y}Ta_y)O_7$ $(0 < y < 1)$, which allows to investigate the magnetic phase diagrams between the spin-liquid state and the antiferromagnetic state. The structural and magnetic properties of these systems will be presented.

[1] H. Kageyama et al., J. Phys. Soc. Jpn. **74** (2005) 1702.
[2] H. Kageyama et al., J. Phys. Soc. Jpn. **74** (2005) 3155.

10:00- Magnetic multipole orders in frustrated ferromagnets

Tsutomu Momoi (RIKEN)

We present a new scenario for the breakdown of ferromagnetic order in two-dimensional quantum magnets with competing ferromagnetic and antiferromagnetic interactions. Dynamical effects lead to the formation of magnon bound states, which undergo Bose-Einstein condensation, giving rise to magnetic multipole order. This scenario is explored in some detail for extended Heisenberg models on a square lattice and a triangular lattice. On a square lattice, two-magnon bound states are most stable, giving rise to bond-centered spin nematic (quadratic) order. In particular, we present numerical evidence confirming the existence of a state with d-wave nematic correlations but no long range spin order, lying between the saturated ferromagnetic and antiferromagnetic phases. On the other hand, in a multiple spin exchange model on a triangular lattice, three-magnon bound states are most stably formed, leading to the appearance of magnetic octupole order.

11:00- **Duality and finite-size scaling analysis of the two-dimensional diluted Villain model**

Yutaka Okabe (Department of Physics, Tokyo Metropolitan University)

The effect of dilution on the phase transition has been extensively studied since the pioneering work by Harris. However, not so much attention has been given to the dilution effect on the Kosterlitz-Thouless (KT) transition. The duality plays an important role in the phase transition. We here investigate the two-dimensional diluted Villain model, which has the exact duality mapping, by using the Monte Carlo simulation with the cluster algorithm. We examine the duality relation which is expected to hold for the two KT transition points of the diluted Villain model. We propose and use an *ab-inito* finite-size scaling analysis for the KT transition.

11:30- **Kondo Problems in Quantum Critical Environments**

Hideaki Maebashi (ISSP, University of Tokyo)

The asymptotic low temperature singularities in the thermodynamic and transport properties of many solids appear to be due to impurities. While several impurity models have quantum critical points (QCP's), where such singularities may be expected, they require special symmetries unlikely to be present in real systems. An alternate possibility is that the environment around the impurities is near a QCP, so that singular low energy fluctuations are present. We investigate the problem which couples such fluctuations of the quantum critical environment to the quantum fluctuation or Kondo effect of ordinary spin-$1/2$ magnetic impurities (not requiring any special symmetries) [1,2]. We show that the problem maps onto a multichannel problem. A variety of fixed points is discovered asymptotically near the QCP. Among these is a new variety of stable fixed point of a multichannel Kondo problem which does not require any channel symmetries. At this point Kondo screening disappears but coupling to the critical spin fluctuations remains. Besides its intrinsic interest, the problem is an essential ingredient in the problem of antiferromagnetic QCP's in heavy fermions.

[1] H. Maebashi, K. Miyake, and C.M. Varma, Phys. Rev. Lett. **88** (2002) 226403.
[2] H. Maebashi, K. Miyake, and C.M. Varma, Phys. Rev. Lett. **95** (2005) 207207.

12:00- Magnetic structure in inhomogeneous systems and time-dependent systems

Seiji Miyashita (Department of Physics, University of Tokyo)

We will discuss ordering structure in inhomogeneous systems and time-dependent systems. The former is motivated by the problem to find in what condition the super-solid state appears. So far, the condition has been studied in uniform system. However, by the recent development of nanoscale design of material and also of the technique of optical lattice, we may control inhomogeneous structure of the lattice. Here we will study a system where the system parameters change in space and study the local ordering patterns. In particular, we explore the possibility to find the coexistence of the spatial density order (DLRO) and the super-fluidity (ODLRO). We study the following spin model (Matsubara-Matsuda model). The latter is motivated by the experiment on the optical lattice where the system is changed from a solid state due to the periodic optical potential to a super-fluid state (BEC). We will discuss the metastable or spinodal phenomena in pure quantum mechanical systems.

14:00- A numerical algorithm for the eigenvalue distribution of non-Hermitian matrices

Naomichi Hatano (Institute of Industrial Science, University of Tokyo)

We have developed a numerical algorithm of computing the eigenvalue distribution of non-Hermitian matrices with the memory size of $O(N)$, where N is the dimension of the matrix. The algorithm basically computes the norm of the Green's function from its largest singular value, which involves (i) the matrix inversion of non-Hermitian matrices by the biconjugate gradient method and (ii) the calculation of the largest eigenvalue of a Hermitized matrix by the Lanczos method.

14:30- The correlation density matrix: new tool for analyzing exact diagonalizations?

C. L. Henley (Institute of Industrial Science, University of Tokyo)

Is there an unbiased way to determine numerically any important correlations, even unforeseen ones, in a lattice model of strongly interacting spins or fermions? Let $\hat{\rho}_A$, $\hat{\rho}_B$, and $\hat{\rho}_{A\cup B}$ be the reduced, many-body density matrices for (respectively) the small clusters A and B, offset by a vector $\mathbf{r}$, and their (disconnected) union. Then all possible correlations are contained in the "correlation density matrix", $\hat{\rho}^{\mathrm{C}}(\mathbf{r}) \equiv \hat{\rho}_{\mathbf{AB}} - \hat{\rho}_{\mathbf{A}} \otimes \hat{\rho}_{\mathbf{B}}$. Via singular-value decomposition we write $\hat{\rho}_{\mathrm{corr}} = \sum_i \lambda_i \hat{\Phi}_i(A)\hat{\Phi}'_i(B)$, where $\hat{\Phi}_i$ and $\hat{\Phi}'_i$ are normalized operators on the respective clusters; the terms represent different correlation functions, their strength given by the magnitudes $|\lambda_i|$.
The procedure, tested on a ladder model of spinless fermions, correctly identified the growth of superconducting correlations, but only a DMRG-based version of the method would have a chance to probe the (Luttinger liquid) criticality. We propose that the correlation density matrix is more promising for *non*-critical states: to detect any strong order in an ordered state, or to confirm the nonexistence of any order in a spin liquid state.

15:00- Ferromagnetism and Quantum Statistics

Masaki Oshikawa (ISSP, University of Tokyo)

Although ferromagnetism has been known to mankind for a long time, its mechanism is rather nontrivial. Ferromagnetism occurs because the electron spins are aligned in the same direction spontaneously, but there is no such explicit fundamental interaction. Rather, it must be caused primarily by quantum effect and spin-independent Coulomb interaction. However, Fermi statistics of electrons is an obstacle to realize ferromagnetism. In fact, Eisenberg and Lieb proved that a wide range of "spin-1/2 boson" models with repulsive interaction has a completely spin-polarized groundstate.
In this talk, I discuss a possible mechanism of ferromagnetism in spin-1/2 fermions. We consider a $U = \infty$ Hubbard model with a magnetic flux, which only couples to the orbital motion and not to the spin. When the flux per plaquette matches the density of fermions, the fermion may be transmutated into boson and the ferromagnetism could be realized. We study the model numerically and find an evidence that the ferromagnetism is indeed realized by the statistical transmutation.
[1] Y. Saiga and M. O., Phys. Rev. Lett. **96**, 036406 (2006).

15:30- **Flowgram method for precise studies of poly-critical points and deconfined criticality as a theory of weak first order transitions**

Nikolay Prokof'ev (Department of Physics, University of Massachusetts, Amherst)

We performed a comparative Monte Carlo study of the easy-plane deconfined critical point (DCP) action and its short-range counterpart to reveal close similarities between the two models for intermediate and strong coupling regimes. For weak coupling, the structure of the phase diagram depends on the interaction range: while the short-range model features a tricritical point and a continuous U(1)×U(1) transition, the long-range DCP action is characterized by the runaway renormalization flow of coupling into a first (I) order phase transition. We develop a "numerical flowgram" method for high precision studies of the runaway effect, weak I-order transitions, and poly-critical points. We prove that the easy-plane DCP action is the field theory of a weak I-order phase transition between the valence bond solid and the easy-plane antiferromagnet (or superfluid, in particle language) for any value of the weak coupling strength. Our analysis also solves the long standing problem of what is the ultimate fate of the runaway flow to strong coupling in the theory of scalar electrodynamics in three dimensions with U(1)×U(1) symmetry of quartic interactions.

16:00- **Deconfined quantum criticality in a 2D Heisenberg model with four-spin interactions**

Anders Sandvik (Department of Physics, Boston University)

I will discuss the valence-bond-solid (VBS) phase and the Neel-VBS quantum phase transition in a 2D $S = 1/2$ Heisenberg model which in addition to the standard nearest-neighbor exchange includes a four-spin interaction (a subset of the fours-spin cyclic exchange terms). Quantum Monte Carlo simulations, carried out in the valence bond basis, show evidence for deconfined quantum criticality in this model. As predicted theoretically, the spin correlation exponent η is anomalously large and there are explicit signs of an emergent U(1) symmetry at the critical point.