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Workshop on Synergies between Field Theory and Exact Computational Methods in Strongly Correlated Quantum Matter

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Booklet of Speakers Abstracts

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A second look at short-range valence bond physics

Wave-functions composed of short-range valence bonds are often considered as good caricatures of non-magnetic "spin liquid" states. Which type of spin liquid is present is however usually not specified. While it is known since a long time that such wave-functions indeed do not support spin order on the square lattice, the behaviour of higher-order correlation functions has never been investigated.

With the help of high-precision Monte Carlo simulations, we show that these wave-functions host non-trivial dimer-dimer critical correlations on the square lattice. The case of three-dimensional bipartite lattices (such as simple cubic or diamond) is very intriguing too: we find at the same type long-range spin order and dipolar four-spin correlations, a reminiscence of the Coulomb phase of hardcore dimers.

We will also present results on a local S=1/2 spin Hamiltonian proposed by Cano and Fendley [Phys. Rev. Lett. 105, 067205 (2010)] which admits nearest neighbour valence bond wave-function(s) as ground-state(s) on the square lattice, and show that it corresponds to a new type of spin liquid state, with gapped spin but gapless non-magnetic excitations. We find that this ground-state is unstable with respect to perturbations, in correspondance with the Rokhsar-Kivelson point of the quantum dimer model.

Work done in collaboration with F. Albuquerque, S. Capponi and M. Mambrini.

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Spin liquids and topological insulators emerging from Dirac fermions

In this talk, I will review aspects of the phase diagram of the Hubbard model on the Honeycomb lattice supplemented by a spin orbit coupling term. A quantum spin liquid phase { as de_ned by the absence of a local order parameter { emerges at the transition between the Dirac fermion semi-metallic state and the antiferromagnetic Mott insulator. This state is robust against spin orbit coupling and is not adiabatically connected to the Z2 topological band insulator. The bulk of the Z2 topological band insulator is robust against the screened Coulomb interaction. On the other hand, edge states are very sensitive to correlations. Substantial magnetic uctuations develop thereby depleting low energy spectral weight in the charge and single particle channels. The above results stem from large scale Quantum Monte Carlo simulations on lattice sizes up to 18_18 unit cells and have been partially published in Refs. [1] and [2].

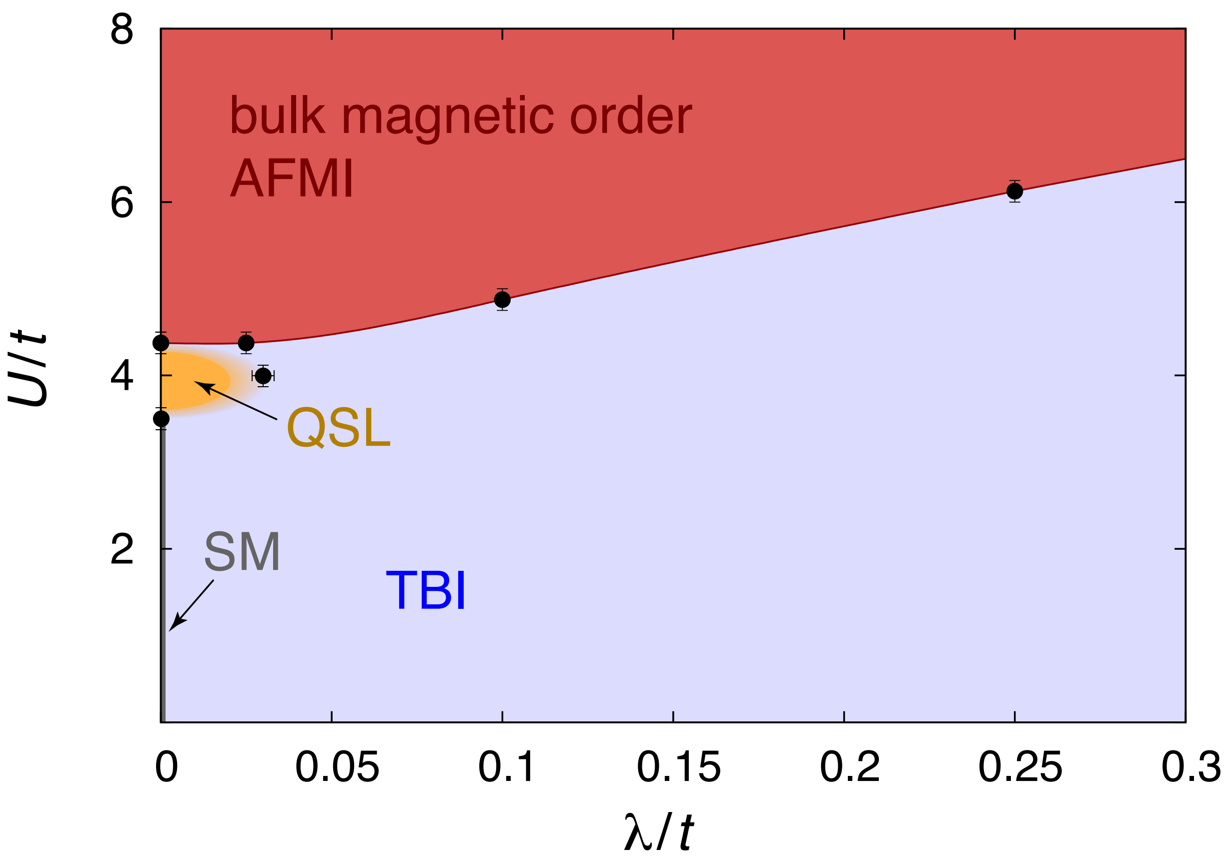

FIG. 1: Phase diagram of the KM-Hubbard model from QMC. Bullets correspond to computed phase boundaries. The four phases are the semi metal (SM), the quantum spin liquid (QSL), the topological or quantum spin-Hall insulator (TBI), and the antiferromagnetic Mott state (AFMI).

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[2] M. Hohenadler, T. C. Lang, and F. F. Assaad, Phys. Rev. Lett. 106, 100403 (2011).

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Generic, realistic, and interesting models of correlated quantum systems

Condensed matter physics has a long history of working with models. But how to choose which one? Some common justifications for choice of model are that it (1) is somehow a generic representative of a class; (2) it is a realistic description of a particular system; or (3) it does interesting things. I'll give my own perspective on some models which may be really worthwhile to study to facilitate progress in condensed matter physics, and what to look at/for in these models.

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Random-singlet phases beyond one spatial dimension

When the linear Heisenberg spin chain is given non-uniform exchange couplings, its ground state becomes frozen in a quasi-static singlet bond pattern. This so-called random-singlet phase has long been understood via a renormalization-group (RG) procedure that decimates the bonds from strongest to weakest; the flow equations indicate that even infinitesimal disorder drives the system toward an infinite-randomness fixed point.

We present a non-RG construction, based on the large-N limit of SU(N), that reproduces the linear-chain result, but which also generalizes to lattices in higher spatial dimension. Beyond a threshold in disorder D and rank N, a random-singlet phase exists and exhibits spin correlations that decay algebraically with characteristic exponents. These predictions are tested against data from Quantum Monte Carlo simulations.

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Exotic critical phenomena in classical systems

I will review work on a range of classical statistical mechanics models that have phase transitions with unusual critical behaviour. The unifying feature of these models is that they are formulated in terms non-local degrees of freedom. One class of this type is based on systems such as close-packed dimer models and frustrated magnets, that have Coulomb phases. Another class involves close-packed loops on lattices. In both instances, the most interesting examples are in three dimensions, and so are potentially equivalent to 2+1 dimensional quantum problems.
Classical Coulomb phases occur in a large class of frustrated magnets and in classical dimer models. In each case we are interested in a macroscopic set of states that are either degenerate ground states of the dominant interaction (for example, nearest-neighbour exchange in a magnet), or satisfy a constraint (in the case of close-packed dimer configurations). We ask what happens when we turn on an additional interaction that lifts this degeneracy and favours ordered states. In this situation we have a phase transition in which the Coulomb phase, with power-law correlations and highly constrained fluctuations, takes the place of a conventional, disordered phase. A central question is how these correlations influence critical phenomena, which may not be describable within the Landau-Ginzburg-Wilson paradigm.
In one of the first works in this area, Alet and collaborators [1] examined crystallisation of close-packed dimers in three dimensions. Viewing this as a quantum system in 2+1 dimensions, dimers map to bosons and the two phasesto a Bose condensate and a Bose Mott insulator [2]. Since the Mott insulator turns out to be at a commensurate fractional filling, the phases on either side of the transition break unrelated symmetries. The transition is therefore expected from Landau theory to be first order, and should have unconventional critical behaviour if it is continuous, as appears to be the case in simulations [1].
Frustrated magnets offer experimentally realised versions of Coulomb phases, and transitions from this phase can potentially be engineered using a Zeeman field or strain. A variety of different types of critical behaviour can arise as a consequence, which can be understood using long-wavelength descriptions and mappings to quantum problems in 2+1 dimensions [3–5]. Models of close-packed loops on a lattice share with systems in a Coulomb phase the feature that their intrinsic degrees of freedom are extended. Recent work has shown that they have as a continuum limit the CP(n−1) sigma model. These models therefore provide access in simulations to ordering transitions in CP (n−1) and may also give a new route to non-LGW critical behaviour [6].

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[2] S. Powell and J. T. Chalker, Phys. Rev. Lett. 101, 155702 (2008); Phys. Rev. B 80, 134413 (2009).
[3] T. S. Pickles, T. E. Saunders, and J. T. Chalker, Europhysics Letters 84 36002 (2008).
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Quantum criticality and confinement effects in the Ising spin chain CoNb2O6

In this talk I will review neutron scattering experiments to explore the phenomenology of quantum criticality in the quasi-one-dimensional (1D) Ising magnet CoNb2O6 in strong applied transverse magnetic fields. I will first describe measurements of the crystal-field energy levels of the Co2+ ions to quantify the Ising character of the magnetic moments. Then I will show measurements in applied transverse magnetic fields that tune the quantum fluctuations and drive the Ising spins to a critical point separating spontaneous magnetic order and paramagnetic phases near 5.5 T. Neutron scattering observe a dramatic change in the character of spin excitations near the critical point, from pairs of domain-wall (kink) quasiparticles in the magnetically-ordered phase, to sharp spin- flip quasiparticles in the paramagnetic phase.

The weak, but finite 3D couplings between the 1D chains enrich the physics by creating a small longitudinal mean field, which this leads to confinement of spin quasiparticles into a rich structure of bound states (Ising mesons). In zero field as many as five bound states are resolved and their energies can be quantitatively described by the theory of weak confinement of 1D gapped fermionic kinks [2]. Just below the critical field the energies of the two lowest bound states approach the "golden ratio", as predicted for the two lightest mesons in a field theory in the scaling limit due to Zamolodchikov [3], giving support to the theoretical proposal that the spectrum near criticality in a weak longitudinal field is governed by a hidden E8 symmetry. To quantify the strength of the interchain couplings we make measurements of the dispersions of the spin-flip quasiparticles in magnetic fields much larger than the critical value, deep in the paramagnetic phase, where we observe a small dispersion bandwidth in the direction transverse to the chains.

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Impurity spin textures at critical points in antiferromagnets

We report on recent studies of the ground state spin texture induced by a missing-spin defect at the critical point of two-dimensional square lattice antiferromagnets on the verge of a continuous quantum phase transition to a valence bond solid ordered phase. The scaling properties of these spin textures are compared to those of analogous textures at a similar transition in SU(3) symmetric magnets and to the scaling properties of spin textures around a missing spin in the power-law Neel ordered critical state of one dimensional antiferromagnets. [collaborators: S. Sanyal, A. Banerjee, and F. Alet].

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Toward a unified description of spin incoherent behavior at zero and finite temperatures

While the basic theoretical understanding of spin-charge separation in one-dimension, known as ``Luttinger liquid theory'', has existed for some time, recently a previously unidentified regime of strongly interacting one-dimensional systems at finite temperature came to light: The ``spin-incoherent Luttinger liquid". This occurs when the temperature is larger than the characteristic spin energy scale. I will present a numerical study of the finite-temperature spectral properties of a one-dimensional fermionic gas in the spin-incoherent regime using the time-dependent density matrix renormalization group method. This approach enables us to quantitatively handle the experimentally relevant and theoretically challenging ``crossover" regime between the Luttinger liquid and spin-incoherent Luttinger liquid limits. I will show that the spin-incoherent state can be described exactly as a generalization of Ogata and Shiba's factorized wave function in an enlarged Hilbert space, using the so-called "thermo-field formalism". Interestingly, this wave-function can also describe the *ground-state* of other model Hamiltonians, such as t-J ladders, and the Kondo lattice.

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Non-Fermi liquid phases for itinerant electrons

Slave particle gauge theories augmented by Gutzwiller type variational wavefunctions offer one of the few theoretical approaches to access strongly correlated gapless phases of spins and bosons in 2d, as discussed in an earlier talk. Here, I will discuss the rospects of extending this approach to describe possible non-Fermi liquid phases of 2d itinerant electrons. I will focus on one slave particle scenario in which the electron's charge sector is placed in a strongly interacting Bose metal phase. Such a state, which is expected to possess Luttinger violating singular surfaces in momentum space, can be fruitfully explored on quasi-1d ladders. A specific t-J type Hamiltonian with a four-site ring exchange term describing electrons hopping on a two-leg ladder is analyzed using both DMRG, variational Gutzwiller wavefunctions and bosonization. Preliminary results give evidence for an exotic quantum state, which is a quasi-1d descendent of a 2d non-Fermi liquid d-wave Metal.

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Anomalous High-Energy Spin Excitations in La_2CuO_4

Inelastic neutron scattering (INS) is used to investigate the collective magnetic excitations of the high temperature superconductor-parent antiferromagnet La_2CuO_4. We find that while the lower energy excitations are well described by spin-wave theory, including one- and two magnon scattering processes, the high-energy spin waves are strongly damped near the (pi,0) position in reciprocal space and merge into a momentum dependent continuum. This anomalous damping indicates the decay of spin waves into other excitations, possibly unbound spinon pairs. Hopefully, our results will encourage detailed calculations of $c^2(q,w)$ using exact computational methods or otherwise.

If time permits, I will also discuss our recent polarized INS measurements on $YBa_2Cu_3O_{6.9}$, which have allowed us to unambiguously isolate the magnetic response. We show that there is strong scattering in the normal state for $E<100$ meV and that this can account for much of the spectral weight from which the “magnetic resonance” forms. In addition, we observe new diffusive contributions for energies less than the resonance energy.

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Quantum Monte Carlo simulation on Deconfined Critical Phenomena

The second order phase transition is generally understood in terms of the spontaneous symmetry breaking. According to the theory of deconfined critical phenomena [1], however, some second-order phase transitions fall out of this Landau-Ginzberg-Wilson paradigm. It is expected that the new category of the continuous transition manifests itself when the Neel state changes into the VBS state in antiferromagnets. Some numerical evidences point to realization of such a novel phase transition while the other suggest a weak 1st order transition. We studied the SU(N) generalization of the Heisenberg antiferromagnet by quantum Monte Carlo simulation with loop algorithm. In the case of fundatmental representation, we observed varying ground state depending on the value of N. When the ground state is the VBS state, we observed approximately circular distribution of the VBS order parameter, possibly reflecting the U(1) nature of the deconfined critical point. By introducing four or more body interactions, we can controle the quantum fluctuation so that the quantum criticality is realized. We obtained a set of estimates of the critical exponents that seem consistent with the 1/N expansion theory.

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The Spinon Gas Model and its Numerical Tests

Several years ago the scenario of "Deconfined Quantum Criticality" (DQC) was proposed, in which spinon de-confinement (liberation of S=1/2 particles) could take place at quantum phase transitions in two-dimensions, separating magnetically ordered and disordered phases. This creates the exciting prospect of fractionalization of excitations in critical systems.
We examine this possibility in the context of a specific quantum spin model (the so-called J-Q model, introduced by Anders Sandvik), for which very accurate Monte-Carlo simulations have been performed. By assuming that the excitations of the critical ground state are linearly dispersing deconfined spinons obeying Bose statistics, we derive expressions for the specific heat and the magnetic susceptibility at low temperature. Comparing with quantum Monte Carlo results for the J-Q model, we find excellent agreement, including a previously noted logarithmic divergence of the susceptibility. These results provide strong evidence for spinon deconfinement at the quantum critical point of the J-Q model.

Ref: A.W.Sandvik, V.N. Kotov, and O.P. Sushkov, "Thermodynamics of a Gas of Deconfined Bosonic Spinons in Two Dimensions," Physical Review Letters 106, 207203 (2011)

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Nonmagnetic states in frustrated quantum magnets:
From Rokhsar Kivelson models to spin liquids in weak Mott insulators

In the first part of this presentation I will revisit the long-standing question of the phase diagram of the square lattice Rokhsar-Kivelson quantum dimer model. Using exact diagonalization, quantum Monte Carlo techniques as well as field theoretical considerations we provide evidence for a V/t dependent crossover length scale in the confining phase (V<1) below which the system exhibits U(1) symmetric behavior. In the V/t regime accessible to us, the system ultimately locks into a columnar phase (ie for system size scales beyond the crossover scale). In the second part of the talk, I will report on our ongoing effort to derive and simulate effective spin models which capture the spin liquids in the vicinity of the Mott metal-insulator transition in several half filled **Hubbard models.**

Roger MELKO
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Measuring Entanglement Entropy in Quantum Monte Carlo

Condensed matter physicists have begun exploiting the use of entanglement as a resource for studying quantum materials. When the groundstate of a many-body system is divided into two subregions separated by a boundary, the entanglement entropy between subregions typically obeys an "area law", scaling as the boundary size. Sub-leading corrections to the area law can provide new universal numbers at critical points and exotic topological phases. In 1D critical systems, exact numerical simulations have successfully connected the scaling of entanglement entropy to the central charge of related conformal field theories. However, in 2D and higher, the absence of entanglement entropy estimators in scalable numerical methods has hampered similar calculations. In this talk, I will discuss recent developments in calculating Renyi entanglement entropies using finite-temperature and ground-state projector quantum Monte Carlo techniques. Examples of universal subleading corrections to the area law at 2D critical points and in a Z2 topological spin liquid phase will be shown. This paves the way for future work in comparing universal quantities obtained from numerical simulations with higher-dimensional quantum field theories.

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Exotic phases and emergent gauge fields through frustration

Frustration in magnetic systems can give rise to new and unusual phases. Most prominently, recent years have seen the identification of a number of 'topological phases' exhibiting an emergent gauge field. While frustrated magnets can often be simulated efficiently, for example thanks to the development of Monte Carlo cluster algorithms, the emergent phases in turn lend themselves to field-theoretic treatments, permitting substantial analytical progress even in higher dimensions. The physics of spin ice, with its unusual phase transitions and exotic monopole excitations, is a case in point, as is that of the compound SCGO, which exhibits classical spin fractionalisation. In this talk, we give an overview over such phenomena and provide some details of the numerical and analytical approaches employed.

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Search for Bose-metal type phases in models with ring exchanges

I will introduce models of bosons or spins with ring exchanges that are candidates for realizing unusual gapless metal-like phases in two dimensions. I will review slave particle gauge theories as one theoretical construction of such phases. I will then focus on a hard-core boson model on the square lattice and will specialize to the ring-only model. On one hand, the slave particle gauge theory can be analyzed completely in this case and reproduces so-called Exciton Bose Liquid (EBL) theory proposed by Paramekanti et al ten years ago. We will discuss some lessons for such parton-gauge theories from this connection, in particular for Gutzwiller-projected wave functions. On the other hand, I will review numerical searches for the EBL phase and will present a hard-core boson model with extended ring exchanges that realizes the EBL and allows confronting the theory with unbiased numerical results.

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Confinement, duality, and topology of gauge fields in CP^{N-1} and QED models in 2+1 dimensions

We discuss the confinement properties in different theories of "quantum spinondynamics". One important point to be addressed in this talk concerns the nature of the phase transitions in these models. Recent numerical results in 3D loop models by Nahum et al. (arxiv:1104.4096) indicate that a quantum critical point exists in the phase diagram of the compact CP1 model. This result confirms earlier numerical calculations by Takashima et al. [PRB 72, 075112 (2008)], who also find a second-order phase transition. In the latter case the model is the compact version of the CP1 model underlying the so called "deconfined quantum criticality" phenomenon. The results for the compact model differ from the ones for the non-compact CP1 model, where a first-order phase transition between an antiferromagnetic and a valence-bond solid state was found [Kuklov et al., PRL 101, 050405 (2008)]. We analyze these results with respect to the essential topological properties and duality aspects of the compact model. We will also discuss the compact CP1 model from a renormalization group perspective and show how it connects to the numerical results by Nahum et al. and Takashima et al. Another important topic to be addressed in the talk is on the relation between the compact CP1 model and the J-Q model. In this context we will discuss some models in the light of the recent numerical findings by Sandvik [Phys. Rev. Lett. 104, 177201 (2010)] and Banerjee et al., [Phys. Rev. B 82, 155139 (2010)], which seem to imply the existence of a quantum critical point of a completely new type.

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Entanglement spectrum and boundary theories with projected entangled-pair states

In many physical scenarios, close relations between the bulk properties of quantum systems and theories associated to their boundaries have been observed. In this work, we provide an exact duality mapping between the bulk of a quantum spin system and its boundary using Projected Entangled Pair States (PEPS). This duality associates to every region a Hamiltonian on its boundary, in such a way that the entanglement spectrum of the bulk corresponds to the excitation spectrum of the boundary Hamiltonian. We study various specific models, like a deformed AKLT, an Ising-type, and Kitaev's toric code, both in finite ladders and infinite square lattices. In the latter case, some of those models display quantum phase transitions. We find that a gapped bulk phase with local order corresponds to a boundary Hamiltonian with local interactions, whereas critical behavior in the bulk is reflected on a diverging interaction length of the boundary Hamiltonian. Furthermore, topologically ordered states yield non-local Hamiltonians. As our duality also associates a boundary operator to any operator in the bulk, it in fact provides a full holographic framework for the study of quantum many-body systems via their boundary.

Ref.: J. Ignacio Cirac, Didier Poilblanc, Norbert Schuch, Frank Verstraete, Phys. Rev. B (in press).

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Excitations in Spin Ladders – from Low Energies to the Complete Spectrum

Quantum spin ladders are exceptional model systems. On the one hand, they show non-trivial phenomena ranging from enhanced quantum fluctuations due to their one-dimensional structure to a rich phase diagram with several quantum critical points and related critical phases; on the other hand, they are sufficiently 'simple' to allow us to aim at a fully quantitative understanding of all of their magnetic properties. Synergies between field theory, exact computational methods (both DMRG and ED), and other approaches (e.g. bond operators) have in recent years enabled amazing progress in this direction [1, 2], whereas it was high-precision experimental work on a number of novel model materials triggering the renewed interest in spin ladders [3]. I will present both experimental and theoretical work focusing on the elementary excitations of the quantum spin ladder in all its phases: as a function of temperature, magnetic field, disorder, doping, and frustration.

[1] P. Bouillot et al., Phys. Rev. B 83, 054407 (2011).
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Future visions; synergies between quantum field theories and numerical calculations with microscopic hamiltonians

I will survey recent progress in numerical studies of insulating quantum spin models, and discuss their impact on our understanding of new classes of quantum many body states. **I will present some ideas on extending these studies to metallic systems, across quantum phase transitionswith Fermi surface reconstruction and superconductivity.**

Dong-Ning SHENG
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DMRG study of the novel quantum phases for frustrated spin and boson systems

I will review recent numerical progress based on DMRG calculations in studying frustrated spin (or boson) systems on ladders. I will present numerical evidence of strong-coupling phases for quasi-one-dimensional systems as ladder descendants of candidate models for 2D "Bose metal" and spin liquid phases, which possess surfaces of gapless excitations. I will present a close comparison between numerical results and slave-particle descriptions, which will allow us to characterize these phases in detail and identify signatures reflecting the parent 2D states. I will also discuss the progress and challenging in approaching 2D limit for studying of these frustrated spin (and boson) models.

Rajiv R. P. SINGH
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Series Expansion Studies of Quantum Antiferromagnets

We discuss a variety of series expansion methods that have been used to study phase transitions and other thermodynamic properties of quantum antiferromagnets. The most well known of these is the High Temperature Expansions, where thermodynamic properties are expanded in a power series in inverse temperature 1/T. Another method is the Ising series expansions, which can be used to study ground state properties and excitation spectra of magnetically ordered systems at T=0. A third method is an expansion around dimerized Hamiltonians, that can be used to study Valence Bond Crystal phases of the system. In addition, Numerical Linked Cluster expansions at finite or zero temperature, can be used to study systems with short correlation length, but no apparent small parameter. In all cases, series extrapolation methods can be used to study phase transitions and critical phenomena. Recent application of these methods include studies of Kagome Lattice Heisenberg Models as well as Entanglement Entropy and Mutual Information of XXZ models in two dimensions.

Erik SORENSEN
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Canada

Impurity entanglement in spin chains

When impurities are present in a system they can dramatically change the entanglement. In this talk I will focus on one-dimensional spin chains with a single impurity where a close connection to field theoretical results can be made. Several measures of the impurity contribution to the entanglement have been proposed and many results are available for both gapped and gapless models. I will discuss some of these results obtained either from field theory, variational calculations or numerical DMRG calculations. A particularly interesting model is the J_1-J_2, S=1/2 quantum spin chains with an impurity at the boundary. This quantum impurity model has a gapless (J_2<J_2^c) and a gapped phase (J_2>J_2^c) and in the gapless phase it is in the universality class of the single channel Kondo model where quite detailed predictions about the impurity entanglement from field theory can be confirmed by numerical calculations. Here, the presence of the impurity induces a length scale the so called Kondo screening cloud that determines the scaling of the impurity entanlement.

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Overview of Landau and non-Landau quantum critical points; field theories and microscopic quantum models

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Critical scaling in a trap

Physical systems are generally inhomogeneneous, while homogeneous systems are often an ideal limit of experimental conditions. An important issue of the theory of critical phenomena is how critical behaviors develop in inhomogenous systems. In particular, we consider interacting particles confined within a limited region of space by an external potential. The effects of the inhomogeneous trapping potential are discussed in the framework of the trap-size scaling theory.

A theoretical description of how criticality develops in the presence of the confining enternal field is of great importance for experiments. In particular, it is relevant for experiments of Bose-Einstein condensation in diluted atomic vapors and of cold atoms in optical lattices are set up with a harmonic trap, which provide great opportunities to investigate the interplay between quantum and statistical behaviors in particle systems, and, in particular, at the transitions between their thermodynamic and/or quantum phases.

These results should represent a good example of cross-fertilization between theory (in particular, scaling, renormalization-group and field theory) and numerics (exact diagonalization, Monte Carlo methods, DMRG).

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Anomalous elasticity in disordered superfluids, superconductors and magnets: Optimal fluctuations, renormalization group, and simulations

We investigate the effects of layered quenched randomness on superfluids, superconductors, and planar magnets. By using optimal fluctuation theory, we gain a qualitative understanding of the phase diagram which displays an unusual intermediate phase between the conventional long-range ordered phase at low-temperatures and the disordered high-temperature phase. In this intermediate phase, which is part of the Griffiths region, the stiffness perpendicular to the random layers displays anomalous scaling behavior, with a continuously variable anomalous exponent, while the order parameter and the stiffness parallel to the layers both remain finite. More formally, the intermediate phase appears as a line of fixed points within a strong-disorder renormalization group approach. We also describe large-scale Monte-Carlo simulations which confirm that these fixed points are accessible starting from realistic bare systems. Finally, we discuss the universality of these results as well as possible experiments.

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Cubic Interactions and Quantum Criticality in Dimerized Antiferromagnets

Dimerized quantum antiferromagnets can be driven through a quantum phase transition from a dimerized phase into a magnetically ordered state upon tuning the exchange parameters. In recent years, the critical properties in such dimerized antiferromagnets were examined in detail, based on large-scale quantum Monte Carlo simulations, which reported deviations from O(3) universality for specific two-dimensional geometries, in particular for the staggered-dimer antiferromagnet. Symmetry arguments and microscopic calculations exhibit that a nontrivial cubic term arises in the relevant order-parameter quantum field theory, related to three-particle interactions among the triplet excitations within the paramagnetic phase of this model. The consequences of such cubic terms are explored using a combination of analytical and numerical methods.
Complemented by finite-temperature quantum Monte Carlo simulations, these results lead to the conclusion that critical exponents in dimerized antiferromagnets are identical to that of the standard O(3) universality class, but with anomalously large corrections to scaling for these specific dimerization geometries.

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Field theories of pure and doped 2D quantum antiferromagnets and high-precision tests based on quantum Monte Carlo

The physics of pure and lightly doped quantum antiferromagnets can be addressed with two complementary methods of theoretical physics. On the one hand, the low-energy physics of these systems, which is dominated by the magnon Goldstone bosons, can be described with a systematic low-energy effective field theory. On the other hand, very precise Monte Carlo data can be obtained with efficient cluster algorithms.
The two methods complement each other in an ideal manner. In particular, by comparing Monte Carlo data with effective theory prodictions, the a priori unknown low-energy parameters of the effective theory, such as the staggered magnetization density, the spin stiffness, and the spin wave velocity can be determined with fraction of a per mille precision. The analytic construction of systematic effective field theories for magnons and doped holes or electrons on square and honeycomb lattices as well as the numerical cluster algorithm methods are described in detail.