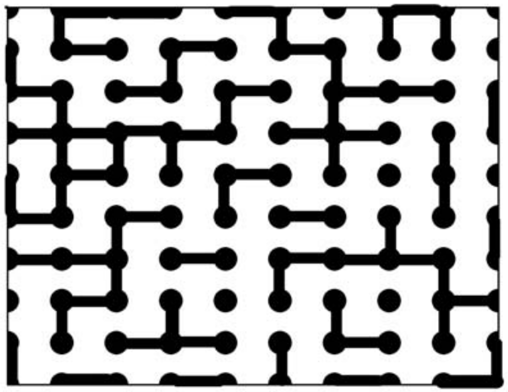
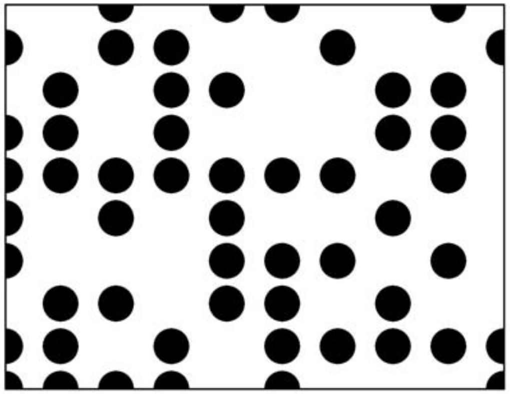
CAREER: Properties of Doped Quantum Spin Liquids

Stephan Haas, University of Southern California, DMR Award #-0089882



bond dilution (left)
and
site dilution (right)



Quantum Percolation:

Percolation occurs in a wide variety of contexts, ranging from blood vessel formation to clusters of atoms deposited on substrate surfaces. In this project we ask whether the classical picture of permeating networks applies to strongly fluctuating quantum systems. Two-dimensional antiferromagnets on disordered lattices provide an ideal framework to address this question. Recent studies of quantum antiferromagnets on square lattices with homogeneous site and bond dilution have found a classical geometric percolation transition between magnetic order and disorder. In our study, we show how non-homogeneous bond dilution can lead to percolative quantum phase transitions. This quantum percolation introduces a new class of two-dimensional spin liquids, characterized by an infinite percolating network with vanishing antiferromagnetic order parameter.

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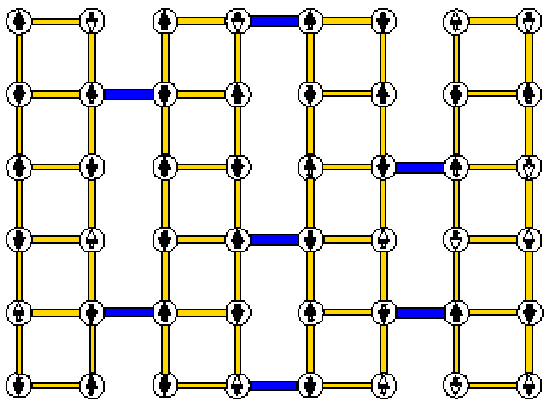
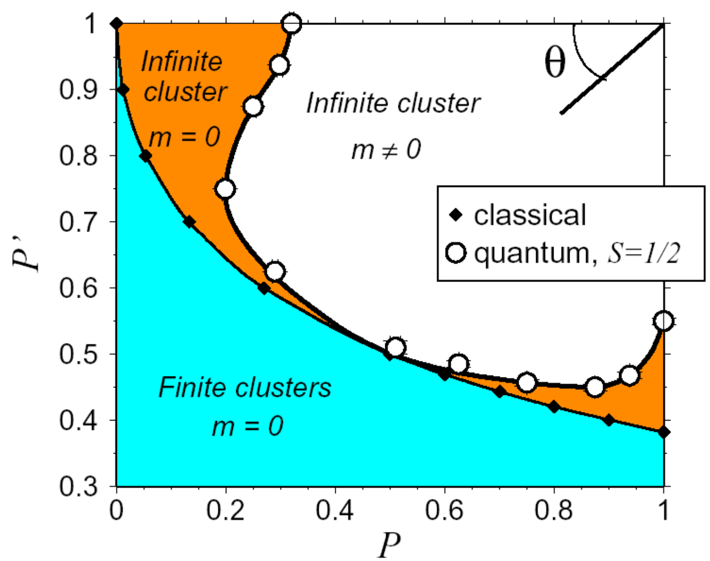


Quantum percolation in a Heisenberg model with bond dilution.

The interplay between lattice disorder and quantum fluctuations in low-dimensional quantum spin systems can be very intriguing. For example, in two-dimensional systems quantum fluctuations may lead to the destruction of long-range antiferromagnetic order before the percolation threshold is reached. We have recently studied anisotropic bond dilution favoring dimer-like or ladder-like structures in the geometrical texture of the system shown in the above figure. We found that this type of disorder induces a substantial shift in the onset of antiferromagnetic order with respect to geometrical percolation, giving rise to a genuine quantum phase transition driven by disorder effects.

An extensive quantum Monte Carlo study of this model allows us to monitor a continuous crossover from classical to quantum-corrected percolation, shown in the figure below. By changing the probabilities of formation of dimer (P) or ladder (P`) shaped clusters, we find a phase diagram featuring geometrically and antiferromagnetically ordered (white) and disordered (blue) phases, defining the classical percolation threshold given by the solid symbols. Furthermore, we observe a new quantum spin liquid regime (orange), characterized by an infinite percolating network with a vanishing antiferromagnetic order parameter (m).



Phase diagram of the bond-diluted Heisenberg model on a square lattice, Rong Yu, Tommaso Roscilde, Stephan Haas (2004).

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Our group currently consists of six graduate students, two postdocs, and the PI. We work on topics related to quantum magnetism, unconventional superconductivity, and nanotechnology. We investigate microscopic models of interacting electronic systems, and use numerical techniques to find their phase diagrams, ground state properties, and excitation spectra. Recently, we have applied the Stochastic Series Expansion Method to study field induced phase transitions in quantum spin liquids, developed optimization algorithms to construct nanoscale opto-electronic devices, and applied BCS theory to investigate the consequences of unconventional superconductivity in strongly correlated materials.

Omid Nohadani

David Parker

Rong Yu

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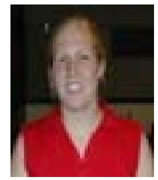
The USC Computational Condensed Matter Physics Group



Amy Cassidy

Jason Thalken

Tommaso Roscilde

Stephan Haas

July 2004, USC Workshop for Physics High School Teachers

As part of the educational component of this CAREER award, I am organizing an annual workshop at USC for high school physics teachers which involves 20 participating teachers from Southern California. The three day program offers lectures, labs, demonstrations, and discussions on science education. The co-organizers are our director of the general education physics labs at USC and two experienced physics teachers from Los Angeles.

Further educational & outreach activities: Departmental Graduate Student Advisor, Los Angeles Physics Teachers Association, California Science Fair.