

# Research Opportunities

Chris Henley group

Research Opportunities meeting, Fri Nov. 13 2008

My research interests are spread over several distinct subjects. All involve interesting spatial dependences – symmetries or complicated patterns.

I divide them into four quadrants:

- The NSF grant (quadrants 1 and 2) mostly covers interacting, many-body quantum systems.
- The DOE grant (quadrants 3 and 4) is more materials-oriented, covering atomic or macromolecular structures in classical systems.

# 1. Frustrated magnets (NSF)

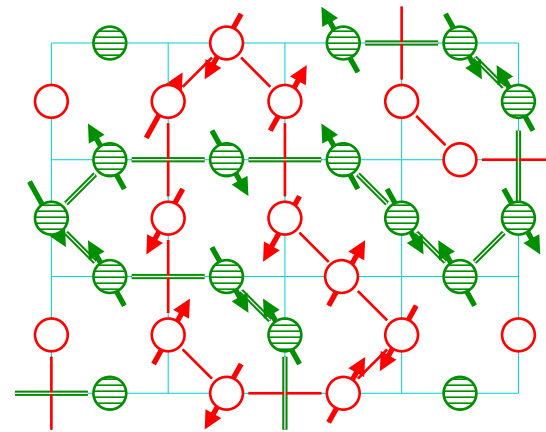
We study (quantum) spins on *highly frustrated* lattices. That means there is no single ground state in which all the interactions are simultaneously minimized, but instead a large number of practically degenerate states.

When the spins are length  $1/2$ , frustrated systems are promising places to find interesting exotic phases, such as “spin liquids” or fractional-charge states.

My aim for the future is the role of disorder (impurities) in highly frustrated magnets. We’re currently studying the composition law of normal modes on (fractal) **percolation clusters**. (Percolation refers to the critical behavior when a system is diluted to the threshold where it becomes disconnected.)

Several physical models have disorder which itself has the constraints and correlations of a highly frustrated system, like the

spins forming loops in Fig. 1(b).

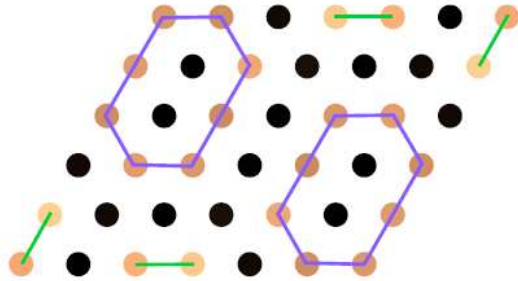


Another topic is “non-abelian height models”, a simple way to realize “topological order” This exotic property was mainly known in quantum-many-body states such as the quantized Hall effect, but we can realize a baby version of it in some classical systems.

## 2. Strongly interacting fermions (NSF)

I work with simplified models, in the spirit of the Hubbard model. My aim is to work the borderline between analytic and computational physics, figuring out how to detect interesting (perhaps exotic) behaviors from exact diagonalizations I am collaborating with Garnet Chan (Cornell, Chemistry), a computational chemist who develops schemes to treat interacting systems in  $d > 1$  dimensions.

My student Sumiran Pujari is doing simple phenomenology to help analyze the Séamus Davis group's STM data on high- $T_c$  cuprates, such as the coupling of some phonon modes to the superconductivity.

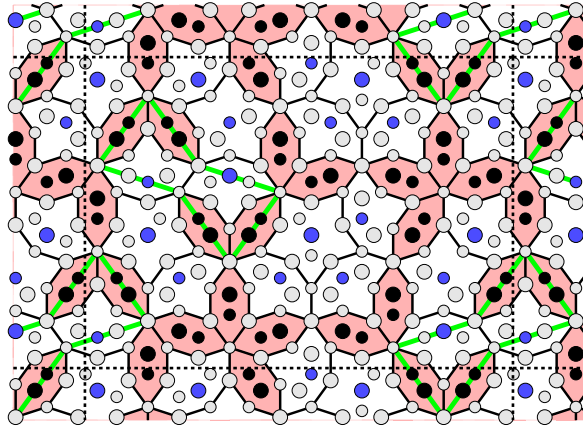


We are investigating the (probably exotic) ground states of the “supersymmetric” Fendley-Schoutens Hamiltonian, which have lurking, unexplained mathematical regularities. The model has fermions hopping on a lattice, forbidden to be next to another fermion, and which a potential energy which counts the number of un-forbidden sites. Exact diagonalization of 10 fermions on the  $6 \times 7$  system shown gave a ground state wavefunction with exactly zero energy and the fermions are spontaneously localized hopping on the tracks shown.

## 4. Quasicrystal structures (DOE)

A quasicrystal has a symmetry (e.g. 5-fold) incompatible with crystal periodicity, yet retains translational order (has Bragg diffraction peaks) as well as local chemical order. Do “Penrose matching rules” dictate a virtually unique ground state in real quasicrystals, or does the order emerge from a “random tiling” (ensemble of nearly degenerate configurations).

I mainly continue this with Dr. Marek Mihalkovič (Slovakia) and with undergraduates We predict the microscopic structure (using effective interatomic potentials derived from ab-initio calculations) and do statistical physics of the random-tiling state. Three years ago we discovered a semi-realistic model in which microscopic pair interactions implement Penrose matching rules!



*Fig. 3. Simulation of*

*Al<sub>0.70</sub>Ni<sub>0.21</sub>Co<sub>0.09</sub> decagonal quasicrystal. [M. Mihalkovič et al, Phys. Rev. B 65, 104205 (2002)]. Large and small circles are atoms from the two layers; gray=Al, blue=Co, black=Ni. “Hexagon”, “boat”, and “star” tiles can be seen at two different scales.*

Along with this, I’m interested in the mathematical problem of optimum packings of spheres with two sizes.

### 3. Biological physics (DOE)

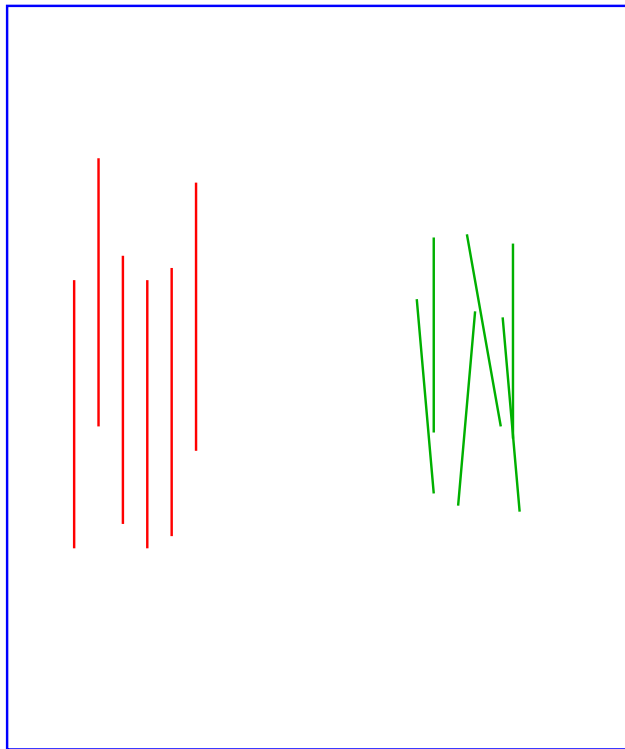
I'm interested in problems from biological physics which heavily involve symmetry, geometry, and the packing of identical units.

We [Steve Hicks] are modeling the formation of the “capsid” (shell) of viruses, which is built from many copies of the same proteins.

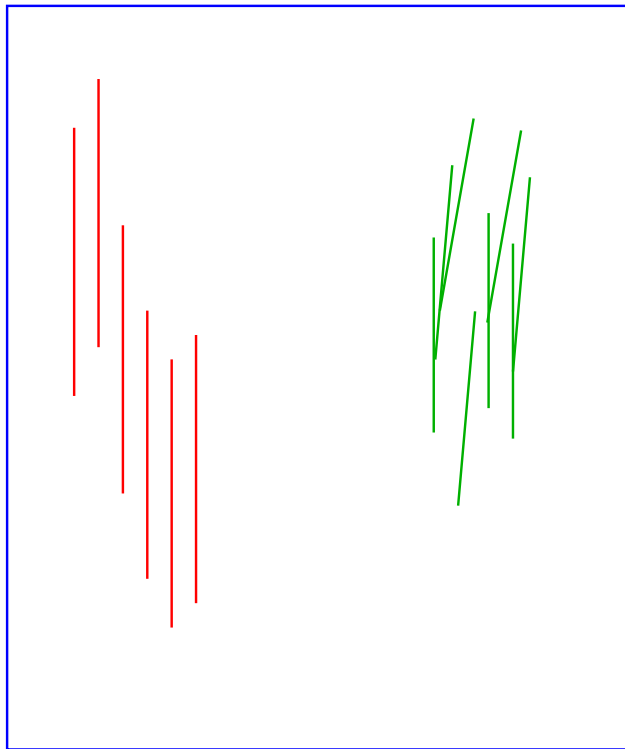
Our aim is to understand what really fixes the capsid's size, to compare the ensemble of shapes and sizes to imaging experiments, and to extract coarse-grained elastic constants from protein simulations.

The project I want to start soon – **this is my definite opening**: how does the well-known *microscopic* handedness of proteins get propagated to the *macroscopic* handedness seen in *plants* (the screw twist of climbing vines) and *animals* (asymmetry of the heart etc. in vertebrates). That's nontrivial, since development uses some sort of diffusion, but that is independent of the molecule's handedness.

The mechanism involves long helical fibers – specifically microtubules. The animal side leads to modeling the motions of cilia, but I’m likely to focus on plants which are less understood. This research will lean on hydrodynamics and elastic theory.



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