ICQM Program on "Quantum crystals, liquids and gases" (June 6—June 10, 2001)

Schedule (Tentative):

	6, Mon	7, Tue	8, Wed	9, Thu	10, Fri
9:30-10:30	Jason Alicea	Hui Zhai	Yong-Baek Kim	Srinivas Raghu	Fa Wang
10:30-10:45	Break	Break	Break	Break	Break
10:45-11:45	Jason Alicea	Fa Wang	Yong-Baek Kim	Srinivas Raghu	Ying Ran
14:00-15:00	Shou-Cheng Zhang	Kai Sun		Chi Zhang	Hong Yao
15:00-17:00	Discussion	Discussion		Discussion	

Title/Abstract:

Jason Alicea:

A recipe for turning graphene into a robust topological insulator using adatoms

The 2007 discovery of quantized electrical conductance in HgTe quantum wells delivered the burgeoning field of topological insulators (TIs) its first experimental confirmation. Subsequently, many three-dimensional TIs have been identified among narrow-band-gap semiconductors with strong spin-orbit coupling (SOC), but to date HgTe remains the only known two-dimensional system in this class. Despite much effort, difficulty fabricating HgTe quantum wells and the cryogenic temperatures required to realize the TI phase have hampered their widespread use. In this talk I will discuss a recent proposal for generating a robust TI state in a more readily available two-dimensional system -- graphene. Specifically, I will describe how endowing graphene with a small concentration of indium or thallium adatoms can induce a TI phase with a substantial band-gap (which can even approach room temperature for thallium coverage as low as ~6%). Engineering such a robust topological phase in graphene could pave the way for a new generation of devices for spintronics, ultra-low-dissipation electronics, and decoherence-free quantum information processing.

The quest for Majorana fermions in solid state systems

Exchange statistics, which characterizes how wavefunctions evolve under particle interchange, is one of the most fundamental properties of nature and ultimately underlies most condensed matter phenomena. Interchanging ordinary bosons or fermions, for instance, leaves the wavefunction either unchanged or with an extra overall minus sign. The story becomes much richer in a class of superconducting states supporting exotic particles known as Majorana fermions. Interchanging Majorana fermions produces not only a phase, but can actually transform the wavefunction to a fundamentally different quantum state. Apart from revealing something very profound about nature, Majorana fermions also hold promise for implementing decoherence-free quantum information processing. This talk will survey various promising proposals for engineering states supporting Majorana fermions, using materials ranging from topological insulators to more conventional systems such as semiconductors and ordinary superconductors. I will also describe how 1D systems can be used to meaningfully exchange Majorana fermions, in spite of that fact that exchange statistics is usually viewed as ill-defined in 1D.

Shou-Cheng Zhang: Topological insulators and superconductors

Recently, a new class of topological states has been theoretically predicted and experimentally observed. The topological insulators have an insulating gap in the bulk, but have topologically protected edge or surface states due to the time reversal symmetry. Similarly, topological superconductors or superfluids have novel edge or surface states consisting of Majorana fermions. In this talk, I shall review the recent theoretical and experimental progress in the field, and focus on a number of outstanding issues, including the quantized anomalous Hall effect, quantized magneto-electric effect, the topological Mott insulators and the search for topological superconductors.

Hui Zhai: Spin-orbit coupled quantum gases

Recently, spin-orbit coupled boson condensate has been realized in NIST experiment, and there are many proposals to generate various types of spin-orbit coupling in cold atom setup. In this talk, I will discuss new physics due to spin-orbit coupling in quantum gases system. I will present our theoretical results about ground state and finite temperature properties of spin-orbit coupled interacting bosons. At zero temperature this system exhibits two different phases, the plane wave phase and the stripe phase. At finite temperature, melting of stripe order gives rise to a novel phase, that is, boson paired superfluid which supports fractionalized vortices. I shall present the phase diagram of this system in terms of temperature, interaction and anisotropy of spin-orbit coupling. I shall also briefly discuss BEC-BCS crossover of spin-orbit coupled Fermi gas across a Feshbach resonance.

References: 1. Chunji Wang, Chao Gao, Chao-Ming Jian and Hui Zhai, Phys. Rev. Lett. 105, 160403 (2010).
2. Chao-Ming Jian and Hui Zhai, to be published 3. Zeng-Qiang Yu and Hui Zhai, arXiv: 1105.2250

Fa Wang: Functional renormalization group studies of iron-based high Tc superconductors

I will briefly review the physics of iron-based superconductors and discuss our approach, the functional renormalization group method, to the pairing problem in these systems. This method, despite significant technical challenges, is in principle unbiased and suitable for the studies of electronic instabilities of Fermi liquids with weak to intermediate correlations. Applying this method we found that for iron-pnictides superconductors the dominant pairing instability is the s_{\pm} pairing, a pairing order parameter with sign change in momentum space but is a trivial representation of the space group. However we found that details of the pairing order parameter, e.g. whether there are gap nodes on Fermi surfaces, varies among different iron-pnictides. I will also discuss the remaining challenges in this field, e.g. the experimental detection of the predicted pairing order parameter.

Kai Sun: Emerging conformal symmetry and zero-energy edge modes in isostatic lattices

Rigidity transitions in elastic systems have been the focus of intensive studies. In the theoretical understanding of these transitions, the idea of isostaticity has been found to play an important role and captures the essential physics in many different systems, such as random packings, polymer networks, etc. In this talk, I will first provide a brief introduction to the idea of isostaticity and then present our recent studies on a new class of isostatic systems in two dimensions. One of the key features of these systems is the existence of a large number of zero-energy vibrational modes localized at the edges. In the phenomenological level, the emergence of these edge modes is a classical analogy to some topological states of matter studied in quantum systems. However, different from the quantum systems, these edge modes here are protected by an emerging conformal symmetry in the low-energy effective theory. At long distance, this emerging symmetry results in universal behaviors for all isostatic systems in this universality class. However, in the short distance limit, subleading corrections, known as the dangerous irrelevant terms, break the emerging conformal symmetry and leads to nonuniversal behaviors sensitive to microscopic details. This crossover will also be addressed.

Yong-Baek Kim: Topological Phases in Correlated Systems with Strong Spin-Orbit Coupling

It has recently been recognized that 5d transition metal oxides may provide a new avenue for the emergence of novel electronic phases. In these systems, the strength of the interaction, effective band-width, and spin-orbit coupling may be comparable. We discuss theory of possible topological insulators, spin liquids, and other related phases that could be realized in such systems. We also discuss potential candidate materials for these phases.

Srinivas Raghu: Superconductivity in the repulsive Hubbard model: an asymptotically exact weak coupling solution

We study the phase diagram of the Hubbard model in the limit where U, the onsite repulsive interaction, is much smaller than the bandwidth. We present an asymptotically exact expression for T$_c$, the superconducting transition temperature, in terms of the correlation functions of the non-interacting system which is valid for arbitrary densities so long as the interactions are sufficiently small. Our strategy for computing T$_c$ involves first integrating out all degrees of freedom having energy higher than an unphysical initial cutoff Ω_0. Then, the renormalization group (RG) flows of the resulting effective action are computed and T$_c$ is obtained by determining the scale below which the RG flows in the Cooper channel diverge. We prove that T$_c$ is independent of Ω_0.

Chi Zhang: Unusual Conductivity of a 2D Hole Wigner Crystal In Ultrahigh Magnetic Fields

In a new type of carbon-doped, high hole density ($p = 1.9\times10^{11}$ cm^{-2}), high mobility (*mu*> 1 x 10^6 cm^2/Vs) quantum wells, we discovered a reentrant insulating phase (PI) around filling factor nu= 1/5. Previous measurements reported the reentrant PI around nu= 1/3 FQHE state in dilute 2DHS [1] and around nu= 1/5 FQHE in dilute 2DES [2]. In a range of ultrahigh magnetic field B ~ 30 - 42 T, we systematically measured the magnetoconductance ($sigma_{xx}$) in a Corbino configuration, and two major findings emerge: 1) at 1/5, a PI prevails at T < 100 mK, and melts to become FQHE liquid > 100 mK; and, 2) in the flanks of 1/5, the sigma_{xx} shows a remarkable λ- shape as a function of 1/T. Above a critical T_c ~ 200 mK, sigma_{xx} increases exponentially with 1/T; and below T_c, sigma_{xx} decreases exponentially with 1/T. We interpret the λ- shape as the long-sought-after signature of a superfluid-insulator transition. Differential conductivity in the PI phases shows strong nonlinear response, indicating a pinned- to sliding- Wigner crystal transition driven by electrical field.

[1] M. B. Santos, Y. W. Suen, M. Shayegan, Y. P. Li, L. W. Engel and D. C. Tsui, *Physical Review Letter* **68**, 1188 (1992).
[2] T. Sajoto, Y. P. Li, L. W. Engel, D. C. Tsui and M. Shayegan, *Physical Review Letter* **70**, 2321 (1993).

Fa Wang: Schwinger boson spin liquid states on honeycomb lattice: projective symmetry group analysis and critical field theory

Motivated by the numerical evidence of a gapped spin liquid in the honeycomb Hubbard model [Meng et al. Nature 464, 847 (2010)], we analyse possible Z_2 spin liquids with gapped bosonic spinons coupled to Z_2 gauge field on honeycomb lattice within the Schwinger boson formalism. By the projective symmetry group method we find that there are only two relevant Z_2 spin liquids on honeycomb lattice with different (zero or π) gauge flux in the elemental hexagon. The zero-flux state seems to be a good candidate for the numerically observed spin liquid. It can acquire collinear AFM Neel order via a continuous O(4) transition. In the critical field theory of this transition the coupling of bosonic spinons to the Higgs field contains cubic powers of spatial derivatives, therefore does not break honeycomb lattice symmetry and allows for a continuous transition to a commensurate collinear Neel order. We will also discuss several observable features of this spin liquid.

Ying Ran: Z2 spin liquid and chiral anti-ferromagnetic phase on honeycomb lattice.
Following the previous talk, I will discuss the same phase diagram found by quantum monte carlo on honeycomb lattice[Meng et al. Nature 464, 847 (2010)]. We use a different method: Schwinger-fermion approach, and propose one particular state, sublattice pairing state, as the spin liquid state found in the phase diagram. In our approach, both the Mott transition and the magnetic phase transition are studied. We prediction of a novel hidden-phase: chiral anti-ferromagnetic phase in the same phase diagram. Surprisingly, we show that sublattice pairing state is identical to the zero-flux state discussed by Fa Wang. This is the first time that a duality between Schwinger-fermion and Schwinger-boson representations is obtained.

Hong Yao: TBA