Proposal: Aspen Center for Physics Workshop on Quantum Simulation/Computation with Cold Atoms

Organizers: Lincoln Carr, Ignacio Cirac, Erich Mueller, David Weiss

Primary Contact: Lincoln Carr [lcarr@mines.edu, (303)273-3759]
Diversity: Erich Mueller [em256@cornell.edu, (607)255-1568]
Other Organizers: Ignacio Cirac [ignacio.cirac@mpq.mpg.de], David Weiss [dsweiss@phys.psu.edu]

We would like to bring together researchers from several fields to explore how cold atom experiments can be used to solve "hard problems" in quantum mechanics. One thrust is the use of cold atoms for quantum information processing, in particular quantum computing. A second thrust is the simulation of many-body quantum models, like Hubbard models, particularly in strongly correlated regimes. In both cases one needs to engineer a specified, possibly time-dependent Hamiltonian, prepare a well-characterized initial state via cooling and dynamical manipulation of the Hamiltonian parameters, and read out the results. Researchers with many different backgrounds are needed not only to come to grips with the technical problems posed by carrying out such experiments, but also to pinpoint important issues in quantum information processing and many-body physics. Combining the ideas of the quantum information community and the many-body physics community will lead to more rapid progress in experimentally implementing these types of models. For example, state-initialization schemes devised for quantum computation may be the most practical way to produce low-entropy states for studying phase transitions of atoms on optical lattices.

Interest in this area is high, driven to a large extent by the prospects of using cold atoms to faithfully represent important condensed matter models. Cold atoms can be used to address long-standing problems such as whether or not the two-dimensional repulsive-U Hubbard model leads to a d-wave superfluid state. The recent KITP workshop on “Strongly Correlated Phases in Condensed Matter and Degenerate Atomic Systems,” which was largely aimed at this area, was packed with top-notch researchers.

Experiments are sufficiently advanced that actual implementations of model Hamiltonians are not far off. Experimental groups have demonstrated quantum degenerate fermionic atoms in optical lattices (Esslinger, Ketterle). Superfluidity has been observed in Fermi gases, along with pseudogap phenomena (Grimm, Hulet, Jin, Ketterle, Salomon, Thomas). Experimentalists have demonstrated the ability to control the dimensionality and interaction strength of these atomic systems (Dalibard, Esslinger, Phillips, Weiss). Basic quantum information processing protocols have already been demonstrated (Philips, Porto, Spielman, Weiss).

In fact, several large scale, collaborative experimental and theoretical efforts are underway to study these problems. For example, just recently the Air Force Office of Scientific Research awarded a “Multidisciplinary University Research Initiative” on “Quantum Simulations of Condensed Matter Systems Using Ultra-Cold Atomic Gases.” A related DARPA competition on a similar topic resulted in three large interdisciplinary groups being awarded significant grants. The cold atom community has traditionally been extremely open and collaborative. We hope that by bringing together large groups like these, we can help maintain this dynamic. Moreover, the proposed experiments are so technically difficult that progress will require that we pool the intellectual resources of the community. Since these groups share many common goals, such gatherings are also essential to avoiding gross duplication of effort.

A key component of the workshop will be to involve leading researchers in numerical simulation of quantum many-body systems. Such simulations provide a benchmark for the atomic system, and are essential for evaluating the feasibility of various proposals. Moreover, recent de-
developments in time-dependent Density Matrix Renormalization Group Methods in 1D and their 2D generalization (Cirac, Schollwoeck, Troyer, Vidal, White) have led to profound insight into the foundations of quantum mechanics, practical applications to quantum information processing, and the ability to study the dynamics of strongly correlated systems – exactly what is needed in cold atom experiments.

The ideal dates for this workshop would be Monday, June 16 through Thursday, July 3, 2008. These dates avoid the following major conferences: the 39th Annual Meeting of the Division of Atomic, Molecular, and Optical Physics (May 27-31); Theory of Quantum Gases and Quantum Coherence (June 3-7); 21st Congress of the International Commission for Optics (July 7-10); the European Science Open Forum (July 18-22); International Conference on Atomic Physics (ICAP) (July 27-Aug 1) and preceding Summer School on ultracold atoms (July 21-25); the 25th Low Temperature Physics Conference (August 6-13); and the Gordon Research Conference on Quantum Information Science (Aug 31 - Sep 5). Alternatively, August 4 - 22 would allow us to increase international participation by being adjacent to ICAP. Our third choice would be June 30 - July 18. The two conferences we absolutely cannot overlap with are DAMOP at the end of May, and ICAP and its associated summer school in the last two weeks of July, since all the cold atom experimentalists will be at, and in some cases (e.g., Ketterle) actually running these meetings. There would be an overlap (but not conflict) of interest between several participants of this conference and those of a Graphene workshop also to be proposed for Aspen (as Allan Macdonald informed us), due to connections in the physics of strongly correlated systems and 2D lattices. All four organizers will attend the full proposed three weeks of the workshop.

The following list is indicative of the researchers who we expect to apply to attend this workshop. Females are marked with an (f), organizers with an (o). Those with whom we have explicitly verified availability at the proposed times, and have stated they would like to attend, are marked with an asterisk before their names. We have received highly enthusiastic responses from those with whom we have discussed the possibility of this workshop, including people on the following list. People from all three communities described below are very excited about this.

