LANL Quantum Workshop

December 10, 2008
Los Alamos Research Park Building, Room 203
URL: http://quantum.lanl.gov
LA-UR: 08-07789

The LANL Quantum Initiative and CNLS are sponsoring this Laboratory-wide workshop on Quantum Science and Technology. The purpose of the workshop is to update all those interested in quantum research at the Laboratory on recent accomplishments, to discuss future directions, and to initiate new collaborations. We hope that all research relevant to quantum entanglement and quantum coherence conducted in and around the Laboratory will be represented.
The day-long program will consist of 9 talks, along with a poster session which will run over an extended lunch break to provide ample time for discussion. Poster presenters will be able to present a 2 minute "advertisement" for their poster in an oral session immediately before the posters.

Program

9:00 - 9:10	*Welcome* Malcolm Boshier (Quantum Initiative/P-21)
9:10 - 9:45	*Quantum states in heavy-fermion systems* J. D. Thompson (MPA-10)
9:45 - 10:20	*Simulation of open quantum systems* Michael Zwolak (T-4)
10:20 - 10:55	*Cold atom prospects for studying complex quantum matters* Eddy Timmermans (T-CNLS)
10:55 - 11:00	Break
11:00 - 11:45	“Two-minute” poster summary presentations
11:45 - 1:30	Poster session and lunch
1:30 - 2:05	*Development of a Silicon physical qubit and single logical qubit design* Malcolm Carroll (Sandia)
2:05 - 2:40	*A counter-example to additivity: Using entanglement to boost communication capacity* Matthew Hastings (T-4)
2:40 - 3:15	*Mechanics of the quantum vacuum* Diego Dalvit (T-4)
3:15 - 3:30	Break
3:30 - 4:05	*Quantum control of atomic spins* Ivan Deutsch (UNM)
4:05 - 4:40	*Experimental realization of dynamic “arbitrary” 2D potential for the manipulation of Bose condensed atoms with a scanning laser beam* Changhyun Ryu (P-21)
4:40 - 5:15	*Atomic, molecular, optical and quantum physics with radioactive atoms (ions) for basic and applied research* Xinxin Zhao (C-NR)

Oral Session 1

1. Quantum states in heavy-fermion systems*

J. D. Thompson (MPA-10)

The macroscopic quantum state of superconductivity that is found in many conventional metals and alloys is well-understood theoretically to arise from a phonon-mediated attractive interaction among electrons. Introduction of tiny amounts of magnetic impurities into these conventional superconductors breaks time-reversal symmetry of the quantum state and rapidly suppresses superconductivity. The discovery of superconductivity in heavy-fermion metals, composed of a periodic array of 'magnetic impurities', has raised the possibility that magnetism, not phonons, provides the glue that forms Cooper pairs. Most often superconductivity in these strongly correlated systems emerges as their magnetic transition is tuned toward zero-temperature, suggesting more specifically that fluctuations associated with magnetic quantum criticality are important. In the absence of either a theory of magnetically mediated superconductivity or magnetic quantum-critical phase transitions, the task for experiment has been to provide a basis that would guide the development of appropriate theory. The heavy-fermion materials $CeCoIn_5$ and $CeRhIn_5$ have proven especially fertile in revealing the complexity of this challenge. As will be discussed, recent experiments, many in MPA-10, on these prototypical materials have discovered previously unappreciated symbioses among magnetism, quantum criticality and unconventional superconductivity which strongly suggest, but not prove, that fluctuations near a quantum-phase transition provide the pairing interaction in these unconventional superconductors.

*in collaboration with E. D. Bauer, N. J. Curro, H-O. Lee, R. Movshovich, T. Park, F. Ronning, J. L. Sarrao, V. A. Sidorov and R. Urbano

2. Simulation of open quantum systems

Michael Zwolak (T-4)

Understanding dissipative and decohering processes is fundamental to the study of non-equilibrium systems and quantum computing, and such processes can even induce quantum phase transitions. A typical construction is to have a system connected to a continuum environment, which acts as the source of dissipation or decoherence, or as a reservoir of particles. If the connection is strong or the environment has long-range correlations in time, the system dynamics are not easily separated from the dynamics of the environment. To study this situation numerically, one option is to simulate both the system and environment. This is a viable option so long as an efficient finite representation of the environment can be constructed. I will discuss both applications and the construction of finite representations of environments for use in computational simulations.

3. Cold atom prospects for studying complex quantum matters

Eddy Timmermans (T-CNLS)

Oral Session 2

4. Development of a Silicon physical qubit and single logical qubit design

Malcolm Carroll (Sandia)

An overview will be given of both experimental and theoretical development of a single error corrected logical qubit using silicon based hardware. The physical qubit research centers on demonstrating a basic qubit fabricated in an accumulation mode silicon metal oxide semiconductor (MOS) structure. The experimental component of the logical qubit focuses on the classical-quantum circuit interface and its impact on error correction. The logical qubit effort includes both hardware development, such as cryogenic complementary metal oxide semiconductor (CMOS), and a theoretical component, which examines a quantum error correction circuit architecture. The theoretical analysis accounts for more realistic constraints suggested by the physical qubit research while providing insight and feed-back about choices of lay-out, transport and error code choice. We note that some insight drawn from constraints of working in a cryostat may be more generally useful to other quantum computing architectures using cryogenics. In summary, the goal of this combined engineering effort is to more completely understand the design of a single solid-state logical qubit and work towards development of the required silicon qubit hardware elements (e.g., single qubit and read-out) with which to build it.

5. A counter-example to additivity: using entanglement to boost communication capacity

Matthew Hastings (T-4)

Suppose Alice is using a noisy quantum channel to send classical information to Bob. For example, she might send single photons over a fiber optic line. How should she do this? In particular, should she use entanglement or should she send unentangled input states? The additivity conjecture in quantum information theory states that it is never useful for her to use entanglement. In fact, there are several related additivity conjectures, depending on the use of entanglement for different tasks. I will present a counterexample to one of these conjectures, the minimum output entropy conjecture, implying that all of these conjectures are false and that in some circumstances Alice can increase the communication capacity by using entangled states.

6. Mechanics of the quantum vacuum

Diego Dalvit (T-4)

In this talk I will review recent progress in Casimir physics, with special emphasis on ideas to tailor quantum vacuum forces for applications in nanotechnology, including reduced stiction in nanomachines and contactless force transmission. I will describe recent theoretical and experimental work on nano-engineered Casimir forces with metamaterials, metals and semiconductors. I will report on work done in collaboration with Peter Milonni (T-4), Felipe da Rosa (T-4), Toni Taylor (MST-DO), John O'Hara (MPA-CINT), Roberto Onofrio (Dartmouth), Steve Lamoreaux (Yale), and Steven Johnson (MIT).

Oral Session 3

7. Quantum control of atomic spins

Ivan Deutsch (UNM)

Spins in atoms are natural carriers of quantum information given their long coherence times, and the ability to control them with rf, microwave, and optical fields. In this talk I will review a variety of theoretical protocols that we have developed, and in collaboration with Prof. Poul Jessen, University of Arizona, implemented in the laboratory. Examples include state preparation in a large dimensional Hilbert space and quantum-state reconstruction via continuous measurement. The tools we are developing should allow for full unitary control of a qudit of dimension d = 16 in the ground-electronic hyperfine manifold of cesium. These are designed through a constructive procedure that sidesteps the known exponentially complexity in optimal control theory for numerical searches of the requisite control waveforms. The protocol can also be made robust through composite pulse techniques applied to sequences of SU(2) rotations. With these tools we consider novel error protection and correcting protocols for qubits embedded in qudits.

8. Experimental realization of dynamic "arbitrary" 2D potential for the manipulation of Bose condensed atoms with a scanning laser beam

Changhyun Ryu (P-21)

There has been a lot of interest in developing a dynamic "arbitrary" 2D potential to manipulate Bose condensed atoms. The main motivation comes from the possibility of creating many interesting trapping potentials including a torus trap to study persistent current, novel lattice structure, and compact atom interferometer with Bose condensed atoms. In this talk, I'll describe the novel way of making a dynamic "arbitrary" 2D potential with a scanning laser beam. If the scanning time is much shorter than trapping periods of atoms, we can create an arbitrary time-averaged potential and I'll show several examples of nontrivial trapping geometries we created including a torus trap for Bose condensed atoms. With this technique, we can also manipulate atoms in real time and I'll show a couple of examples of this dynamic manipulation. Finally, I'll conclude my talk discussing the future experiments we are going to pursue.

9. Atomic, molecular, optical and quantum physics with radioactive atoms (ions) for basic and applied research

Xinxin Zhao (C-NR)

I'll review the recent highlights of the two projects "Beta decay of ^{82}Rb in an optical tweezer" and "Search of the temporal variation of the fine structure constant with laser cooled Yb^{+}/Yb^{2+} ions". Laser cooling and trapping of (radioactive) atoms/ions has great potential in precision measurements for testing fundamental physics such as electric dipole moment (EDM), parity violating β-asymmetry and the temporal variation of the interaction coupling constants. Following the success of the first trapping of radioactive atoms in a YAG laser optical dipole trap [1], we have completed the polarization study of the trapped atoms using both Faraday rotation polarimetry and resolved Zeeman spectroscopy techniques [2]. For the Yb ion trapping project, we have studied the collision population transfer of the metastable state of Yb^{+} [3] and demonstrated the trapping Yb^{2+} ions. These advancements are important steps towards a new generation of precision measurement. I'll also discuss briefly two ideas we are proposing: (1) Frequency comb spectrometer for real time optical detection of nuclear material and chemical agents for threat reduction; (2) Nuclear clock and precision optical spectroscopy of ^{229}Th nuclei. These projects and ideas advance and take advantage of LANL's capabilities in atomic, molecular, optical, quantum and nuclear physics as well as isotope production and actinide chemistry for cutting edge basic and applied research important to the evolving mission of LANL.

[1] D. Feldbaum, et al., Phys. Rev. A **76**, 051402R (2007). [2] F. Fang, et al., to be submitted to PRA. [3] M. Shauer, et al., in preparation.

Poster Presentations

1. Laser communication using a partially coherent beam propagating through the turbulent atmosphere: Quantum effects

Gennady Berman (T-4), Boris Chernobrod, Alan Bishop, Alexander Chumak, and Vyacheslav Gorshkov

The photon density operator function is used to describe the propagation of single photon pulses through a turbulent atmosphere. The effects of statistical properties of the photon source and the effects of a random phase screen on the variance of photon counting are studied. A procedure for reducing the total noise is discussed. The physical mechanisms responsible for this reduction are explained:

1. A setup for a PCB propagating in the atmosphere.
2. Approach based on Wigner function.
3. Results for scintillation index and wandering.
   (a) Classical case.
   (b) Quantum limit.

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2. Comparison between continuous wave and pulsed laser EQKD

Pat Rice (P-21) and Israel Owens

In this poster, we provide a complete description and comparison of the secret bit rate for continuous-wave and pulsed laser EQKD systems. In particular, we highlight the relevant Poissonian and thermal photon statistics that affect the secret bit rate and use practical system parameters and configurations to show regimes where one expects optimal performance for each case.

3. Closed timelike curves enable perfect state distinguishability

Jim Harrington (P-21)

The security of prepare-and-measure quantum key distribution schemes rests on the no-cloning theorem; nonorthogonal states cannot be perfectly distinguished due to the linearity of quantum mechanics. However, if closed timelike curves (CTCs) exist (which are allowed by the theory of general relativity), then there are self-consistent solutions of CTC-assisted interactions which enable non-linear evolutions of other qubits. We show how to construct circuits involving CTC qubits that can perfectly distinguish any set of distinct quantum states, thus breaking prepare-and-measure quantum key distribution. We also point out other radical changes to quantum information theory, such as the invalidation of Holevo's theorem.

4. Quantum Darwinism for mixed-state environment

Haitao Quan (T-4)

We examine quantum Darwinism when a system is in the presence of a mixed environment, and we find a general relation between the mutual information for the mixed-state environment and the change of the entropy of the fraction of the environment. We then look at a particular solvable model, and we numerically exam the time evolution of the ``mutual information" for large environment. Finally we discuss about the exact expressions for all entropies and the mutual information at special time.

5. Quantum state reconstruction and random evolution

Carlos A. Riofrio (UNM), Seth T. Merkel, Steven T. Flammia, and Ivan H. Deutsch

In order to perform quantum state reconstruction, the set of measured observables must be informationally complete. In this poster, we explore the performance of the reconstruction algorithm developed by Silberfarb et al. (PRL 95, 030402 (2005)) under the assumption that the quantum system undergoes random evolution. We show that in that case, although the measurements do not span the space of all density matrices, we are able to reconstruct the set of all pure states and almost-all mixed states with very high fidelities. We find that this is only possible after the inclusion of the physical constraint of positivity. Using as an example the quantum states stored in the ground-electronic hyperfine manifold (F=3) of an ensemble of ^{133}Cs atoms controlled by radio-frequency magnetic fields, we give a possible physical realization of this protocol provided that the dynamics exhibits a classically chaotic phase space. For this purpose, we chose the well studied quantum kicked top dynamics.

6. Quantum wavepacket dynamics with trajectories

Brian K. Kendrick (T-1)

A time-dependent quantum wave packet method is presented which is based on solving the hydrodynamic equations of motion associated with the de Broglie-Bohm formulation of quantum mechanics. The hydrodynamic equations are solved using a meshless method based upon a moving least squares approach. An Arbitrary Lagrangian-Eulerian (ALE) frame of reference and a regridding algorithm which adds and deletes computational points are used to maintain a uniform and nearly constant interparticle spacing. Averaged fields are used to maintain unitary time evolution and the numerical instabilities associated with the formation of nodes in the reflected portion of the wave packet are avoided by adding artificial viscosity to the equations of motion. For systems with many degrees of freedom, a vibrational decoupling scheme can be used for which the computational cost scales linearly with respect to the dimensionality of the problem. The computational issues associated with this methodology will be discussed in the context of several applications: (1) tunneling through an Eckart barrier; (2) a one-dimensional model chemical reaction that is known to exhibit a quantum resonance; and (3) an *N*-dimensional model chemical reaction.

7. Quantum simulated annealing

Howard Barnum (CCS-3)

I describe a quantum algorithm that solves combinatorial optimization problems by quantum simulation of a classical simulated annealing process. For each transition matrix ("random walk") of the classical simulated annealing process, the algorithm uses instead a quantum-coherent version of it: a similarity-transformed version of Szegedy's quantization of the walk. The zero-eigenphase state of each walk is a quantum-coherent version of the equilibrium state of the corresponding random walk. By successively projecting (or nearly so) onto the zero-eigenphase states of the quantized walks, as the temperature of the corresponding classical walk is reduced, the algorithm makes the computer state track the coherent version of the equilibrium state at each temperature. The approximate projections are implemented by quantum phase estimation. At the end, one has a "quantum sample" of the ground space of the classical combinatorial problem, so that measurement in the standard basis gives a classical sample from the minimizing configurations of the problem. The cost scales as the inverse square root of the minimum spectral gap of the classical transition matrices, rather than the inverse gap as in classical simulated annealing.

The techniques used have applications beyond combinatorial optimization. The measurement (or decoherence) based technique we use can simulate adiabatic quantum evolution, enabling it to prepare ground states of quantum systems with rigorously provable performance, with respect to the gap, comparable to that expected, according to heuristic arguments and folklore, from adiabatic evolution.

Joint work with Rolando Somma (Perimeter), Sergio Boixo (Caltech) and Manny Knill (NIST Boulder).

8. Entanglement, bifurcations and the generation of random states in the quantum chaotic dynamics of kicked coupled tops

Vaibhav Madhok (UNM)

We study the dynamical generation of entanglement as a signature of chaos in a system of periodically kicked coupled-tops, where chaos and entanglement arise from the same physical mechanism.

The long-time averaged entanglement as a function of the position of an initially localized wave packet very closely correlates with the classical phase space surface of section it is nearly uniform in the chaotic sea, and reproduces detailed structure of the regular islands.

The uniform value in the chaotic sea in explained by the random state conjecture. As classically chaotic dynamics take localized distributions in phase space to random distributions quantized version take localized coherent states to pseudo-random states in Hilbert space. Such random states are highly entangled, with an average value near that of maximally entangled state. For a map with global chaos, we derive that value based on new analytic results for the entropy of random states. For a mixed phase space, we u se the Percival conjecture to identify a "chaotic subspace" of the Hilbert space. The typical entanglement, averaged over the unitarily invariant Haar measure in this subspace, agrees with the long time averaged entanglement for initial states in the chaotic sea. We also study the entanglement and the Husimi entropy of eigenstates of the system as a function of the coupling parameter. In addition, we examine behavior in the entanglement of eigenstates when the classical region supporting them undergoes a bifurcation. We study the Husimi entropy of the eigenstates as they make a transition from the "regular subspace" to the "chaotic subspace" in Hilbert space as the system becomes more chaotic.

9. Quantum limited metrology with |β0> + |0β> states

Vaibhav Madhok (UNM)

We show how to achieve Heisenberg-limited sensitivity using states of the form,|β0> + |0β> where |β> is a coherent state, in a two arm interferometer. We describe appropriate measurements to achieve the above limit and discuss a scheme for making such states and measurements. We compare these states with the "NOON" states and with other methods for achieving the Heisenberg-limited sensitivity.

10. Spin squeezing in a double-pass optical-feedback geometry

Collin Trail (UNM), Ivan Deutsch

Squeezed collective atomic spin states can be generated using the Faraday effect, by passing light through an atomic sample twice, imprinting the spin component along the direction of the propagation of light on to the light on the first pass, and rotating the atoms proportionally to this spin component on the second pass, thus creating an effective nonlinearity (M. Takeuchi et. al., 2005, Phys. Rev. Lett. **94**, 023003). The squeezing produced is reduced by loss of light still entangled to the atoms. We show how this scheme can be improved by a quantum eraser effect, where measuring the light properly reduces its entanglement to our atomic sample. Furthermore, we present estimates for the reduction in squeezing due to spontaneous emission, by approximating the distribution of the collective variables by a gaussian.

11. How the group index modulates the electromagnetic field noise associated with a particular cavity mode

Doug Bradshaw (CCS-3)

Optical resonators are often used because of their spectral properties. For example, vacuum field energy in an optical cavity is compressed spectrally, damped for some frequencies and amplified for others. However, optical resonators are not fundamentally frequency filters but wavelength filters. The mapping from wavelength to frequency is controlled by the dispersion relation. Specifically, the mapping between changes in wavelength to changes in frequency is modulated by the group index. By controlling the group index it is possible to alter fundamental cavity properties (including, importantly, the quantum noise associated with a single cavity mode) over many orders of magnitude. In common practice, the mapping between changes in wavelength and changes in frequency for a given cavity finesse is altered by changing the cavity length. In this poster we explain that the important quantity is not length alone but length multiplied by the group index. Thus, alterations in length may be replaced by alterations in the group index. The fact that the group index can take values that are impossible for the cavity length to reach (l<=0), suggests that by controlling the group index we can enter experimental regimes that are impossible to enter by controlling length alone.

12. Practical quantum metrology with Bose-Einstein condensates

Alexandre B. Tacla (UNM), Sergio Boixo, Animesh Datta, Anil Shaji, Matthew J. Davis, Carlton M. Caves

We analyze in detail the recently proposed experiment [Boixo et al., Phys. Rev. Lett. **101**, 040403 (2008)] for achieving better than $1/n$ scaling in a quantum metrology protocol using a two mode Bose- Einstein condensate of n atoms. There were several simplifying assumptions in the original proposal that made it easy to see how a scaling approaching $1/n^{3/2}$ may be obtained. We look at these assumptions in detail to see when they may be justified. We present numerical results that confirm our theoretical predictions for the effect of the spreading of the BEC wave function with increasing n on the scaling. Numerical integration of the coupled Gross-Pitaevskii equations for the two mode BEC also shows that the assumption that the two modes share the same spatial wave function is justified for a length of time that is sufficient to run the metrology scheme.

13. Quantum-enhanced measurement using trapped ions

Warren Lybarger (P-21) and John Chiaverini

The application of algorithms and techniques from the realm of quantum information processing to the problem of metrology can enable better precision than is possible with traditional measurement protocols using similar resources. We describe plans for the use of trapped ion quantum processors to surpass the shot-noise limit to precision for measurements of various quantities of interest. In particular, the motional states of ions trapped in a 3D harmonic well may be put into superposition states (Schroedinger-cat-type states) that are more sensitive to displacements than classical-like coherent states. These states may be created using operations similar to those employed for trapped-ion quantum computing gates. Also, superpositions of internal atomic states may be used to more quickly achieve a prescribed precision in the measurement of external fields through use of a bit-by-bit phase estimation algorithm via conditional coherent operations applied to an individual ion. There is also the possibility to use nonlinear interactions among many-body probe systems to surpass the standard quantum limit for measurement; trapped-ion arrays may be exploited to achieve this kind of enhanced sensitivity to external fields of interest.

14. Atomic magnetometer for MRI and NMR detection

Igor Savukov (P-21)

We have built an atomic magnetometer at Los Alamos and applied it to detection of NMR and MRI. The atomic magnetometer has sensitivity similar to that of a SQUID, but it is non-cryogenic and has some other advantages. In situ MRI is obtained with an atomic magnetometer for the first time. Many applications of atomic magnetometers will be described.

15. ^{229}Th for quantum information, solid state atomic clocks and physics beyond the Standard Model

Saidur Rahaman, David Viera, Xinxin Zhao and Justin Torgerson (P-23 and C-NR, LANL), Eric Hudson (Dept. of Physics, UCLA)

It has been inferred from nuclear spectroscopic studies that ^{229}Th must possess a low-lying nuclear isomer state. The inferred energy given by Rich and Helmer was 3.5 eV ±1.0 eV. Recently, researchers at LLNL have done an improved measurement of the isomer energy deduced from the difference in two gamma transitions originating from the same excited state where one leads to the isomer and the other the ground state. The inferred isomer energy is 7.6 ±0.5 eV and they estimate the isomer half-life to be ~5 hours (natural linewidth ~55 µHz and a Q~10^{20}). The extremely low-energy and narrow linewidth of this isomer opens up exciting possibilities at the interfaces of atomic and nuclear physics. For example, because it is a nuclear transition, the frequency is extraordinary insensitive to external perturbations and allows for the first time the possibility of a solid state clock whose stability is guaranteed by Nature. Because of the extremely long lifetime and high isolation, the isomeric state is also of interest for storage of quantum information. The 7.6 eV (164 nm) transition is within the range of state-of-the-art tunable high harmonic laser sources. We have recently begun a search for the exact wavelength of this transition and have plans to drive the transition directly.

16. Trapping and spectroscopy of singly- and doubly-charged Ytterbium Ions

Jeremy Danielson, David Feldbaum, Saidur Rahaman, Martin Schauer, Baozhou Sun, Xinxin Zhao and Justin Torgerson (P-23 and C-NR)

Forbidden optical transitions in Ytterbium ions have been shown to possess both high sensitivity to possible time variation of the Fine Structure Constant and low sensitivity to external field perturbations. These properties allow for the possibility of tests of Physics Beyond the Standard Model as well as a new generation of optical frequency standards which should be able to achieve a fractional frequency uncertainty of 10^{18} or better. Many of the properties that are of interest for optical frequency standards are also of interest for quantum information and quantum computing. Of specific interest in this regard are the $^1S_0 - {}^3P_0$ transition in Yb^{2+} and the $^2S_{1/2} - {}^2D_{3/2}$ electric quadrupole transition in Yb^+. We describe recent progress in trapping Yb^{2+} and report on initial spectroscopic work on Yb^+ and Yb^{2+}. In addition, we discuss work on collisionally-induced, forbidden transitions into metastable states in Yb^+.

17. Time-averaged optical potential for dynamic manipulation of BEC atoms

Kevin Henderson (P-21), Changhyun Ryu, and Malcolm Boshier

We report an experimental realization of a time-averaged arbitrary optical dipole potential for Bose-Einstein condensate atoms. This experimental setup allows for dynamic generation of a two dimensional potential for direct manipulation of Bose-Einstein atoms. Arbitrary potentials can be generated and transformed with negligible heating.

18. Coherent control of plasmons on metal nanostructures

Dzmitry Yarotski (MPA-CINT), Anatoly Efimov, Ilya Grigorenko, and Antoinette Taylor.

Reliable control over plasmon generation and propagation is a key to development of new types of miniaturized photonic devices, photonic interfaces to nano-devices, enhanced sensors, and surface nano-lithography. Here, we explore the use of temporally shaped ultrafast laser pulses to efficiently concentrate plasmon fields at a specific time and site on nano-structured metal surfaces. Our approach combines observation of temporal and spatial evolution of plasmon fields with the development of a predictive theoretical framework that will enable their nanoscale control and optimization for specific applications.

19. Atoms on chips

G. Biedermann (Sandia), K. Fortier, M. Blain, D. Stick, T. Loyd, P. Schwindt, J. Hudgens

Much like laser cooling in the 1990's, atom chip technology today is rapidly gaining popularity as a convenient and powerful approach to achieving precise control over an atom's motion and internal state. While great success has been achieved in magnetically manipulating the atoms, integrating optical elements onto the atom chip is an active area of research. Premier applications for these "optoatomic circuits" can be foreseen in both quantum information science[1] and in quantum sensors[2].

At Sandia, our efforts (in collaboration with researchers at the University of New Mexico and Stanford University) are focused on integrating micro-optical cavities with atom chips for quantum sensing and information processing applications. Our atom chips contain patterned Al conductors forming magnetic traps and guides underneath an integrated mirror surface. Separately, small mode-volume, open access micro-optical cavities in a Si substrate have been developed. We are currently focusing on the monolithic integration of the magnetic trapping chips and the optical micro-cavities. New measurements of the finesse of the micro-cavities show improved performance.

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[2]. Y.-J. Wang, D. Z. Anderson, V. M. Bright, E. A. Cornell, Qu. Diot, T. Kishimoto, M. Prentiss, R. A. Saravanan, S. R. Segal and S. Wu, Phys. Rev. Lett. **94**, 090405 (2005). T. Schumm, S. Hofferberth, L. M. Andersson, S. Wildermuth, S. Groth, I. Bar-Joseph, J. Schmiedmayer, P. Kruger, Nature Physics, **1**, 57 (2005).

20. Odd-frequency pairing in binary boson-fermion cold atom mixtures

R. Kalas, A.V. Balatsky, D. Mozyrsky

We study fermionic superfluidity in a boson-single-species-fermion cold atom mixture. We argue that apart from the standard p-wave fermion pairing mediated by the phonon field of the boson gas, the system also exhibits s-wave pairing with the anomalous correlator being an odd function of time or frequency. We show that such a superfluid phase can have a much higher transition temperature than the p-wave and may exist for sufficiently strong couplings between fermions and bosons. These conditions for odd-frequency pairing are favorable close to the value of the coupling at which the mixture phase-separates. We evaluate the critical temperatures for this system and discuss the experimental realization of this novel superfluid in ultracold atomic gases.

21. Quantum nucleation and macroscopic quantum tunneling in cold-atom boson-fermion mixtures

Dmitry Solenov (T-4) and Dima Mozyrsky

We present the results on kinetics of phase separation transition in boson-fermion cold atom mixtures. We demonstrate that for low fermion-boson mass ratio the transition is governed by experimentally observable quantum nucleation mechanism. The crossover to macroscopic quantum tunneling regime is analyzed. Based on a microscopic description of interacting cold atom boson-fermion mixtures we derive an effective action for the critical droplet and obtain an asymptotic expression for the nucleation rate in the vicinity of the phase transition and near the spinodal instability of the mixed phase. We show that dissipation due to excitations in fermion subsystem play a dominant role close to the transition point.

22. Quantum phase transitions in a spin-1 Bose-Einstein condensate

B. Damski (T-4) and W.H. Zurek

This poster summarizes our research on dynamics of phase transitions in a spin-1 Bose-Einstein condensate. We show how (i) spin vortices can be created during a symmetry breaking transition in this system; (ii) magnetization oscillates in the system driven to the critical point; (iii) a quantum phase transition can be induced in space by imposing a gradient field on the condensate. We also describe a novel way for measurement of critical exponents of the condensate based on the scaling of various quantities during a non-equilibrium quench.

23. Two-qubit quantum logic gates via optical Feshbach resonances in alkaline-earth-like atoms

Iris Reichenbach (UNM), Paul Julienne and Ivan H. Deutsch

The ability to implement quantum information processing in neutral atoms hinges critically on the ability to coherently control both the internal states and the interactions between two such atoms. We show that alkaline-earth-like atoms are uniquely suited to the task of quantum computing, due to their rich but controllable internal structure, including the nuclear spin, and their very narrow $^1S_0$ -> $^3P_1$ intercombination transition, which makes the application of optical Feshbach resonances possible. Optical Feshbach resonances allow for fine tuning of the interaction strength over a wide range, even making it possible to completely turn off the interaction, thus improving the coherence time. Theoretical modeling of the optical Feshbach resonance on the example of ^{171}Yb shows their potential in the implementation of two qubit gates through nuclear spin exchange.

24. Control of atomic wave functions in optical lattices

Brian Mischuck (UNM), Ivan Deutsch, Poul Jessen

The coherent transport of atoms in optical lattices is essential for quantum computation and quantum simulations involving controlled collisions between the atoms. Such coherence is typically limited by inhomogeneities and background fields. By applying the techniques of quantum control, we study protocols for robustly evolving the motional wave function in the ground band using applied external fields, and well-designed lattices. We examine explicit constructions for synthesizing specific unitary maps.

25. Quantum control of hyperfine spins with coherent electromagnetic fields

Seth Merkel (UNM), Gavin Brennen, Poul Jesssen, Ivan Deutsch

With long coherence times and well characterized control fields from the "quantum optics toolbox", cold neutral atoms provide a useful platform in which to explore methods and techniques for quantum information processing and quantum control. In this poster we study the use of coherent electromagnetic fields to control ultracold neutral alkali atoms in their electronic ground state. In cesium-133, the two hyperfine manifolds comprise a 16 dimensional state space that we can manipulate with rf/microwave magnetic fields. These fields lead to evolutions that are controllable in the Lie algebraic sense and have a relatively simple geometric structure. We look at three protocols for quantum control in this poster: state preparation (mapping a fiducial state to an arbitrary target state), generating unitary maps from state preparations, and robust state preparations using composite pulse techniques from NMR.

26. Casimir force and metamaterials

Felipe da Rosa (T-4), Peter Milonni, Diego Dalvit

We extend our previous work on the generalization of the Casimir-Lifshitz theory to treat anisotropic magnetodielectric media, focusing on the forces between metals and magnetodielectric metamaterials and on the possibility of inferring magnetic effects by measurements of these forces. We present results for metamaterials including structures with uniaxial and biaxial magnetodielectric anisotropies, as well as for structures with isolated metallic or dielectric properties that we describe in terms of filling factors. The elimination or reduction of Casimir ``stiction" by appropriate engineering of metallic-based metamaterials, or the indirect detection of magnetic contributions, appear from the examples considered to be very challenging, as small background Drude contributions to the permittivity act to enhance attraction over repulsion, as does magnetic dissipation. Also, in dielectric-based metamaterials the magnetic properties of polaritonic crystals appear to be too weak for repulsion to overcome attraction.