

Using Molecular spectroscopy to search for the e -EDM

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In our laboratory we are using precise molecular spectroscopy to look for discrete symmetry breaking associated with fundamental particles. In particular we are searching for the Electric Dipole Moment of the electron (e -EDM). The possibility of the electron having some asymmetry in its charge distribution with a resulting EDM breaks time reversal symmetry. The e -EDM has a long history. It was first proposed by Ramsey and Purcell in 1950 and it has been a subject of successively more precise searches since then. Most high-energy particle theories predict a tiny but finite value for the e -EDM. We have chosen to pursue this search using the free radical PbF. I will discuss the properties of PbF which are advantageous for this search, our progress in understanding this molecule to high precision, ~ 100 Hz in the ground state, and our plans to carry out a molecular-beam experiment to search for the e -EDM.

Feshbach Optimized Photoassociation spectroscopy of excited electronic states of Rb₂

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Our immediate goals are to measure the complete vibrational spectrum of singly-excited molecular electronic potential curves of Rubidium using Feshbach optimized photoassociation (FOPA). While traditional spectroscopy identifies the lowest vibrational molecular states and photoassociation of ultracold atoms has proven very powerful in determining the highest-lying vibrational levels, often there is a substantial gap between these two regions limiting our knowledge of these important molecular interactions. Feshbach resonances have been used to enhance photoassociation signal by altering the initial wave function, increasing the overlap with the excited state wavefunction in this intermediate region. We are currently exploring the purely triplet $0g^-$ state connected with the $2S_{1/2}+2P_{1/2}$ separated atom limit of 85Rb . Our initial calculations of PA rates found from closed-coupled scattering calculations indicate that FOPA should be able to completely determine the vibrational spectrum of the $0g^-$ state.

Quantum phases of bosons in optical lattice geometries

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In this talk I will overview quantum phases of bosons, with emphasis on dipolar bosons, confined within single-, bi-, and multi-layer geometries. The results presented are based on Quantum Monte Carlo simulations based on the Worm algorithm and its extension, developed to deal with multi-layers/multi-components systems. I will discuss phases and phase transitions displayed by such systems --- with emphasis on solids and supersolids ---, and the experimental conditions required to observe such phases.

21st Century Rydberg Atom Physics

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Rydberg atom physics is experiencing a renaissance because the long range interactions that occur between Rydberg atoms can be used to entangle them. With ultracold atomic samples and coherent spectroscopy, Rydberg atoms are a promising element for developing entanglement based devices such as quantum gates and single photon sources. We will give an overview of our efforts in this field to quantitatively understand Rydberg atom interactions, explore exotic states of matter, use Rydberg atoms as standards, and create useful quantum hybrid systems.

Rearranging the Exponential Wall

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The resources required for an exact solution of the quantum N-body problem are widely believed to scale exponentially with N, typically doubling for every particle added. With current numerical resources, this problem hits an “exponential wall” around N=10 (within a factor of 2). Even the advent of quantum computers is not expected to solve this problem, since recent studies have predicted that exact solutions of N-body wave functions for fermions or bosons are unlikely to have efficient algorithms on quantum computers. This exponential wall has prompted the creation of many approximate methods to avoid this exponential scaling. In this talk, I will present a method which performs an exact rearrangement of this exponential wall using analytic building blocks with N as a parameter, i.e. the method now scales as N^0 , shifting the exponential complexity to the order in the perturbation theory. Group theory and graphical techniques do the “heavy lifting” to allow a direct transformation from microscopic two-body interactions to macroscopic motions of large-N systems. This approach thus allows the study of arbitrarily large systems of identical particles through low order in our perturbation series.

Time-Dependent Quantum Reactive Scattering in Three Dimensions Using Hyperspherical (APH) Coordinates. Theory and Results

Gregory A. Parker, Jeff Crawford and Zachary Eldredge

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We will present a novel time-dependent hyperspherical coordinate method for studying the dynamics of triatomic systems. The use of wave packets provides information over a distribution of scattering energies and one can also visualize the wave packet as it enters the interaction region and then returns to the asymptotic region where it is analyzed. This ability to visualize the wave packet as it propagates in time offers an intuitive, physically meaningful picture of the dynamics. Our results for $H + H_2$ and $F + H_2$ show that this method is more accurate over a wide energy range than other time-dependent methods.

Using adiabatically adjusting, principal axes hyperspherical (APH) coordinates increases the computational efficiency, since the triatomic PES becomes symmetric, reducing the amount of coordinate space required to represent the evolving wave packet. Rearrangement processes are important in the areas of combustion chemistry, atmospheric chemistry, three-body recombination, collision induced dissociation, photo-dissociation and photo-association.

Generation and Control of Quantum States of Light

Alberto M. Marino

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The field of quantum information holds the promise of harnessing quantum resources to provide secure communications, perform complex calculations, and enhance the sensitivity of measurements. Among those resources, one of the most important is entanglement, which is characterized by correlations stronger than allowed classically. Due to its fundamental role in quantum information science, the generation and control of entangled states of light are active research areas. In this talk I will show that non-degenerate four-wave mixing (4WM) in rubidium vapor has applications in both of these areas. The use of this process makes it possible to generate highly entangled beams of light known as twin beams with some distinct properties. First, the generated quantum states contain multiple spatial modes, which leads to spatial quantum correlations. Second, the entangled twin beams are close to an atomic resonance, which makes it possible to obtain an efficient interaction with an atomic system. I will finish by giving an overview of future research directions.

Nature of anti-correlations in Gaussian electromagnetic fields

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The HBT intensity interferometer was invented by astronomers Hanbury Brown and Twiss, which gives a much more accurate measurement of angular size of distant stars. Unlike the Michelson stellar interferometer, the HBT interferometer measures the second-order intensity-intensity correlation of thermal light with two independent photodetectors at different places. The joint-photodetection gives the intensity correlation $\langle I(x_1)I(x_2) \rangle$, with the visibility (defined by the maximum and minimum of the measures as $\frac{\max - \min}{\max + \min}$) up to maximum 33%.

The HBT intensity interferometer is now greatly improved by a new method discovered by Shih's experimental group. They define the intensity I_{\pm} (I_{\pm}) as the intensity greater (smaller) than the average intensity \bar{I} . In their experimental setting, a novel coincidence circuit is introduced, so that instead of directly measuring $\langle I(x_1)I(x_2) \rangle$, they can now measure the four correlations: $G_{\pm\pm} = \langle I_{\pm}(x_1)I_{\pm}(x_2) \rangle$ and $G_{\pm\mp}$, $G_{\mp\pm}$, $G_{\mp\mp}$. The measurements can give the intensity-intensity correlation $G_{\pm\pm}$ with visibility more than 50%, as well as the anti-correlations $G_{\pm\mp}$ and $G_{\mp\pm}$ with 100% visibility.

We have developed a theoretical method to calculate the correlations $G_{\pm\pm}$, etc. In quantum optics, the light fields at two photodetectors can be denoted by the two field operators $a(x_1)$ and $b(x_2)$. The average intensity is then given by $\bar{I} = \langle a^\dagger a \rangle = \langle b^\dagger b \rangle$. We define the correlation functions $G_{\pm\pm}$, $G_{\pm\mp}$, $G_{\mp\pm}$ and $G_{\mp\mp}$ via relations like $G_{\pm\mp} = \langle : [a^\dagger a b^\dagger b \theta(a^\dagger a - \bar{I}) \theta(\bar{I} - b^\dagger b)] : \rangle$, here the step function $\theta(a^\dagger a - \bar{I})$ means we only need the field with the instantaneous intensity $a^\dagger a$ greater than \bar{I} , and here $:$: denotes normal ordering of operators. These correlations are quantum and need to be calculated using the P -representation of quantum optics. We will present theoretical calculation of all the four correlations and show their comparison with experiments of shih et. al.

Phonon mediated electromagnetically induced absorption in hybrid opto-electro mechanical systems

Kenan Qu and G. S. Agarwal
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The single cavity optomechanical systems have been extensively investigated for their response to quantized and classical fields. The existence of the electromagnetically induced transparency in such systems has given a new perspective to such systems as they can be used as optical memory elements. The mechanical oscillator acts as memory element because this has a very long relaxation time. Recently the interest is shifting to more complex mechanical systems involving either several mechanical elements or even combination of different types of resonators. Here we present new features associated with hybrid double resonator systems. We establish the existence of an absorption window within the EIT window. Such an absorption window can be used to create a photon router. We also show how photons at optical frequencies can be converted to microwave frequencies. It turns out that the complex behavior of such hybrid systems can be understood in terms of the dynamics of three coupled oscillators (rather than two) under different conditions on the relaxation parameters, frequencies and coupling strengths. This model enables us to understand number of interference effects, Fano line shapes etc. This way of understanding opens up application of similar ideas in the context of metamaterials and plasmonic structures.

EIT Analogs using Orthogonally Polarized Modes of a Single Whispering-Gallery Microresonator

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The throughput of a single fiber-coupled whispering-gallery microresonator, such as a fused-silica microsphere, can exhibit behavior analogous to electromagnetically induced transparency and absorption (EIT, EIA). These effects enable slow and fast light, respectively, in the form of pulse delay or advancement. Two different methods are used here to realize this behavior; in both methods, the key feature is the use of two co-resonant orthogonally polarized whispering-gallery modes of very different quality factor (Q). The first method relies on intracavity cross-polarization coupling when a single mode is driven, and the second on a simple superposition of orthogonal throughputs when the two (uncoupled) modes are simultaneously driven. Using the second method produces a pulse delay approximately equal to the pulse width. This surprising result indicates that it is not mode coupling that is responsible for slow light, but rather simple mode superposition.

A Cost Effective Method for the Production of Silica Hollow Bottle Resonators for Chemical Sensing

Razvan-Ionut Stoian and A. T. Rosenberger

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Silica hollow bottle resonators are interesting research objects that can be used in chemical sensing. A simple method for the production of these resonators using available off-the-shelf laboratory items will be presented. Precisely, a multistage process that includes the computer-mediated etching of a capillary down to 5-10 μm average wall thickness using hydrofluoric acid, and the making of silica hollow bottle resonators from the etched capillary using a semi-automated procedure, will be emphasized. Data pertaining to sensing experiments in the near infrared domain (1560 nm) using the internal evanescent field of a typical whispering gallery mode excited by external evanescent field coupling between a tapered fiber and the hollow bottle resonator will also be discussed.

Sodium spinor Bose-Einstein condensates and their applications in quantum metrology

Lichao Zhao, Jie Jiang, Micah Webb, and Yingmei Liu

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An atomic Bose-Einstein condensate (BEC) is a state where all atoms have a single collective wavefunction for their spatial degrees of freedom. The key benefit of spinor BECs is the additional spin degree of freedom. Together with Feshbach resonances and optical lattices, spinor BECs constitute a fascinating collective quantum system offering an unprecedented degree of control over such parameters as spin, density, temperature, and the dimensionality of the system. Spin-squeezing and entanglement are predicted to arise naturally in spinor BECs from either spin-exchange collisions or elastic collisions controlled by spin-dependent potentials. In addition, collective coupling of spinor BECs to a light field introduced by a quantum non-demolition measurement can also create spin-squeezed states. In this talk, we present the design and construction of a novel apparatus to generate spin-squeezing with sodium spinor BECs in optical lattices. We will also discuss spinor BEC's immediate applications in quantum metrology, including magnetometry and atomic clocks.

THE OFF-RESONANT RATCHET: A STUDY OF THE CROSSOVER BETWEEN CLASSICAL AND QUANTUM DYNAMICS

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We experimentally investigated several aspects of an off-resonant atomic ratchet by exposing a Bose-Einstein condensate to short spatially- and temporally-periodic trains of pulses. We measured the mean momentum as a function of a scaling variable which is associated with an effective Planck constant as well as pulse parameters characterizing the kicking strength and kicking number. The experimental results show how the crossover between the classical and quantum dynamical behavior of the ratchet can be described using the scaling variable and that the ratchet momentum is determined by a universal scaling law. We also verified a current inversion predicted by theory.