Combining Single Atoms and Quantum Gases

Artur Widera

Recent advances in the preparation and detection of ultracold neutral atoms have opened the way to study and control quantum many-body systems on the level of single atoms. I will outline our project to immerse single neutral Cesium atoms into a Rubidium Bose-Einstein condensate, where we have developed tools for independent control and detection of single atoms and the quantum gas, such as a species-selective conveyor belt for the individual Cs atoms. Focusing on the single atoms, we have studied the classical dynamics of Cs atoms driven by near-resonant molasses in such a one-dimensional optical lattice. We observe a transition from classical to markedly non-classical diffusion, showing Lévy-type statistics in the averaged atom position distribution as well as in the distribution of individual step sizes as the lattice depth increases. Immersing single atoms into our quantum gas, our system is particularly suited for studying impurity physics in a strongly interacting regime, relevant for the simulation of Fröhlich-type polarons emerging in condensed matter systems. I will discuss the prospects and relevance of this type of solid state simulations.

Dipolar physics with ultracold magnetic erbium atoms

Simon Baier

Strongly influenced by their large magnetic moment and exotic electronic configuration, rare-earth atoms deliver an ideal system for exploring intriguing phenomena in ultracold quantum physics. Here, we report on our recent results with ultracold fermionic and bosonic quantum gases of dipolar erbium atoms. Universal dipolar scattering allows us to cool even identical fermions, leading to the first degenerate Fermi gas of erbium atoms. We explore the impact of the anisotropic and long-range character of the dipole-dipole-interaction both at the few- and many-body level. By driving the dipolar Fermi gas out of equilibrium, we can investigate how it collisional relaxes into a novel equilibrium state. We find a very strong dependence of the number of involved collisions on the dipole orientation. At the many-body level, we prove the long-standing prediction of a deformed Fermi surface in a dipolar gas. In a different set of experiments we focus on bosonic erbium atoms in a 3D optical lattice. Probing the Superfluid-to-Mott-insulator transition we observe the impact of the dipole-dipole interaction on the phase transition point, showing a dependence on the orientation of the dipoles.

Quantum Optics of Chiral Spin Networks

Tomas Ramos

We study the driven-dissipative dynamics of a network of spin-1/2 systems coupled to one or more chiral 1D bosonic waveguides within the framework of a Markovian master equation. We determine how the interplay between a coherent drive and collective decay processes can lead to the formation of pure multipartite entangled steady states. The key ingredient for the emergence of these many-body dark states is an asymmetric coupling of the spins to left and right propagating guided modes. Such systems are motived by experimental possibilities with internal states of atoms coupled to optical fibers, or motional states of trapped atoms coupled to a spin-orbit coupled Bose-Einstein condensate.

Bose polarons in systems of ultracold atoms

Eugene Demler

Tba

Optical diode based on the chirality of guided photons

Jürgen Volz

Nanophotonic components confine light at the wavelength scale and enable the control of the flow of light in an integrated optical environment. Such strong confinement leads to an inherent link between the local polarization of the light and its propagation direction [1-3]. We employ this effect to demonstrate low-loss nonreciprocal transmission of light at the single-photon level through a silica nanofiber in two different experimental schemes. We either use an ensemble of spin- polarized atoms weakly coupled to the nanofiber-guided mode [2] or a single spin-polarized atom strongly coupled to the nanofiber via a whispering-gallery-mode resonator [1]. We observe a strong imbalance between the transmissions in forward and reverse direction of 8 dB and 13 dB for the atomic ensemble and the resonator-enhanced scheme, respectively. At the same time, the forward transmissions still exceeds 70%. The resulting optical isolators exemplify a new class of nanophotonic devices based on chiral interaction of light and matter, where the state of individual quantum emitters defines the directional behavior.

[1] C. Junge et al., Phys. Rev. Lett. 110, 213604 (2013).
[2] R. Mitsch et al., arXiv:1406.0896 (2014).
[3] J. Petersen et al., Science 346, 67 (2014).

Quantum technologies as tools to deepen our understanding of quantum theory and relativity

Ivette Fuentes

Quantum information and quantum metrology can be used to study gravitational effects such as gravitational waves and the universality of the equivalence principle. On one hand, the possibility of carrying out experiments to probe gravity using quantum systems opens an avenue to deepen our understanding of the overlap of these theories. On the other hand, incorporating relativity in quantum technologies promises the development of a new generation of relativistic quantum applications of relevance in Earth-based and space-based setups. In this talk, I will introduce a framework for the application of quantum information and quantum metrology techniques to relativistic quantum fields. I will show how, using this framework, we have been able to develop an accelerometer and a gravitational wave detector that exploit both quantum and relativistic effects. I will discuss some of my future research plans in relativistic quantum metrology including ideas to estimate with high precision spacetime parameters such as the Earth's Schwarzchild radius, develop a new generation of gravimeters and study the effects of motion and gravity on quantum clocks.

Gaussian and non-Gaussian phase-fluctuations between two 1D quasi-condensates in and out of equilibrium

Thomas Schweigler

We show experimentally and theoretically how tunnel-coupling between two 1D quasicondensates can lead (depending on its strength) to Gaussian or non-Gaussian phase fluctuations for the thermal equilibrium state. Moreover, we show result for a quench from finite to vanishing tunnel-coupling. Starting from a non-Gaussian initial state, a Gaussian fixed point of the dynamics is approached.

Quantum information processing with 3D integrated photonics

Fabio Sciarrino

Integrated photonic circuits have a strong potential to perform quantum information processing [1, 2]. Indeed, the ability to manipulate quantum states of light by integrated devices may open new perspectives both for fundamental tests of quantum mechanics and for novel technological applications [3]. By exploiting waveguides fabricated by femtosecond laser waveguide, inegrated circuits with three dimensional geometry can be designed to carry out several quantum information processing tasks. Our aim has been to develop and implement quantum simulation by exploiting 3-dimensional integrated photonic circuits. As first we implemented an integrated beam splitter able to support polarization-encoded qubits [5]. As following step we addressed the implementation of discrete quantum walk: we investigated how the particle statistics, either bosonic or fermionic, influences a two-particle discrete quantum walk both in ordered and disordered systems [5]. As alternative approach we implemented continuous quantum walk to investigate the multi-particle case and observe Fano interference in a non-interacting two-particle Fano-Anderson model by considering propagation of two-photon states in engineered photonic lattices [6]. Analogously, inspired by recent observations in biological energy transport phenomena, we demonstrated how a quantum walker can efficiently reach the output of a maze by partially suppressing the presence of interference. In particular, we investigated experimentally these hybrid transport phenomena, by mapping the maze problem in an integrated waveguide array, probed by coherent light, hence successfully testing our theoretical results [7]. Finally we will discuss the perspectives of optical quantum simulation: the implementation of the boson sampling to demonstrate the computational capability of quantum systems [8,9] and the development of integrated architecture with three-dimensional geometries [10].

[1] T. D. Ladd, et al, “Quantum computers”, Nature 464, 45 (2010).
[2] J. L. O’Brien, A. Furusawa, and J. Vuckovic, “Photonic quantum technologies”, Nature Photonics 3, 687 (2009).
[3] A. Politi, J. Matthews, M. Thompson, and J.O’Brien, “Integrated quantum photonics”, Selected Topics in Quantum Electronics, IEEE Journal of QE 1673, 15 (2009).
[4] L. Sansoni, F. Sciarrino, G. Vallone, P. Mataloni, A. Crespi, R. Ramponi, R. Osellame, “Polarization entangled state measurement on a chip”, Phys. Rev. Lett. 105, 200503 (2010).
[5] L. Sansoni, F. Sciarrino, G. Vallone, P. Mataloni, A. Crespi, R. Ramponi, R. Osellame, “Two-particle bosonic-fermionic quantum walk via 3D integrated photonics”, Phys. Rev. Lett. 108, 010502 (2012); A. Crespi, R. Osellame, R. Ramponi, V. Giovannetti, R. Fazio, L. Sansoni, F. De Nicola, F. Sciarrino, and P. Mataloni, “Anderson localization of entangled photons in an integrated quantum walk”, Nature Photonics 7, 322 (2013).
[6] A. Crespi, L. Sansoni, G. Della Valle, A. Ciamei, R. Ramponi, F. Sciarrino, P. Mataloni, S. Longhi, R. Osellame, “Fermionic statistics suppresses Fano resonances”, [arXiv:1409.8081].

[7] F. Caruso, A. Crespi, A. G. Ciriolo, F. Sciarrino, R. Osellame, "Fast Escape from Quantum Mazes in Integrated Photonics", [arXiv:1501.06438].
[8] A. Crespi, R. Osellame, R. Ramponi, D. J. Brod, E. F. Galvao, N. Spagnolo, C. Vitelli, E. Maiorino, P. Mataloni, and F. Sciarrino, "Experimental boson sampling in arbitrary integrated photonic circuits", Nature Photonics 7, 545 (2013).
[9] N. Spagnolo, C. Vitelli, M. Bentivegna, D. J. Brod, A. Crespi, F. Flamini, S. Giacomini, G. Milani, R. Ramponi, P. Mataloni, R. Osellame, E. F. Galvao, F. Sciarrino, "Efficient experimental validation of photonic boson sampling", Nature Photonics 8, 615 (2014).
[10] N. Spagnolo, C. Vitelli, L. Aparo, P. Mataloni, F. Sciarrino, A. Crespi, R. Ramponi, and R. Osellame, "Three-photon bosonic coalescence in an integrated tritter", Nature Communications 4, 1606 (2013).

Taking trapped strontium ions to a higher level

Gerard Higgins

Trapped Rydberg ions are a novel approach to quantum information processing [1]. By combining the high degree of control of trapped ion systems with long-range dipolar interactions of Rydberg ions [2], fast entanglement gates $\sim 1\mu$s may be realised in large ion crystals [3]. We are working towards exciting strontium ions, trapped in a linear Paul trap, to Rydberg states 26<n<60 using a two-photon excitation scheme with 243nm and 304-309nm laser light. We report on excitation using the UV lasers into higher levels, such as the intermediate states (6P1/2 and 6P3/2) with 243nm laser light. We also present the overlapping of both Rydberg-excitation laser beams using a hydrogen-loaded photonic crystal fiber [4] and the focussing of both beams down to $\sim 10\mu$m onto trapped ions.

[1] M. Müller, et al., New J. Phys. 10, 093009 (2008)
[2] D. Jaksch, et al., Phys. Rev. Lett. 85, 2208 (2000)
[3] F. Schmidt-Kaler, et al., New J. Phys. 13, 075014 (2011)
[4] Y. Colombe, et al., Opt. Express, 22, 19783 (2014)