Q 36: Quantum gases: Effects of interactions

Time: Thursday 10:30–12:15 Location: UDL HS2002

Group Report Q 36.1 Thu 10:30 UDL HS2002

BEC with loss – a paradigm for an open many-body system —
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Modern atom-optical experiments allow for an unprecedented control of microscopic degrees of freedom, not just in the initialization but also in the coherent and incoherent evolution of quantum states. We focus on the dynamics of ultra-cold bosons in an optical lattice with controlled and localized dissipation [1-4]. In the weakly interacting, or semiclassical regime, a quantum version of stochastic resonance is seen [1]. For suitable initial states, strong dissipation can stabilize a Bose-Einstein condensate, such that it remains coherent even in the presence of strong interactions between its constituents [2]. Using an exact unraveling of the underlying master equation for small systems and a perturbative approach for large ones, we predict, in particular, the formation of stable and coherent soliton-like structures [3,4].

[1] D. Witthaut, F. Trimborn, S. Wimberger, PRL **101**, 200402 (2008)
[2] D. Witthaut, F. Trimborn, H. Hennig, G. Kordas, T. Geisel, S. Wimberger, PRA **83**, 063608 (2011)
[3] G. Kordas, S. Wimberger, D. Witthaut, EPL **100**, 30007 (2012)
[4] G. Kordas, S. Wimberger, D. Witthaut, PRA **87**, 043618 (2013)

Q 36.2 Thu 11:00 UDL HS2002

Quantum chaos in ultracold collisions of erbium —
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In the 1950's the Nobel Laureate Eugene Wigner designed a revolutionary statistical theory, based on random matrices, to describe complex systems. Originally created for nuclear matter, Random Matrix Theory (RMT) has today a vast domain of applications from solid-state disordered systems and quantum chromodynamics to number theory and wireless communication [1]. Remarkably, the Bohigas-Giannoni-Schmit (BGS) conjecture ties RMT to classical and quantum chaos [2]. Inspired by [3], we show that even ultracold quantum gases, whose high tractability has been hymned for decades, can escape a deterministic logic and show chaotic behavior in the sense of the BGS conjecture. In particular, we perform high-resolution trap-loss spectroscopy of Fano-Feshbach resonances with two bosonic and one fermionic isotopes of erbium. We observe an unprecedented high density of resonances which allows a statistical analysis of the position of resonances according to the toolset provided by RMT. From a bottom-up approach unique to ultracold atoms, we elucidate the native source of chaotic scattering in the anisotropy of the interactions.

[1] H. A. Weidenmüller et al., Rev. Mod. Phys. 81, 539 (2009)
[2] O. Bohigas et al., Phys. Rev. Lett. 52, 1 (1984)
[3] M. Mayle et al., Phys. Rev. A 87, 012709 (2013)

Q 36.3 Thu 11:15 UDL HS2002

Interaction properties of the the $^3P_0$ meta stable state of ^{173}Yb —
•Christian Hofrichter[1,2], Francesco Scazza[1,2], Moritz Höfer[1,2], Pieter C. de Groot[1,2], Christian Schweizer[1,2], Emily Davis[1,2], Immanuel Bloch[1,2], and Simon Fölling[1,2] — [1]MPI für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany — [2]Ludwig-Maximilians-Universität München, Schellingstraße 4, 80799 München, Germany

Atoms with Alkaline-earth-like electronic structure such as Ytterbium have more complex electronic level structures compared to the more common alkali atoms. Specifically, they include a metastable excited state with an associated 'clock transition' as well as a strong decoupling between the nuclear and the electronic spin in the ground state.

Metastable states in such atoms are being used for the implementation of optical atomic clocks, and have been proposed as additional internal degrees of freedom for the study of complex many-body systems such as Kondo lattice physics. The phase diagram of such many-body systems is strongly characterized by the collisional properties of the involved atomic states.

Here we report on the investigation of the $^3P_0$ - $^1S_0$ (metastable to ground state) and $^3P_0$ - $^3P_0$ - interactions of fermionic ^{173}Yb. We measure the elastic and inelastic scattering properties in degenerate ensembles in optical lattices, with control over both the electronic and nuclear spin degree of freedom.

Q 36.4 Thu 11:30 UDL HS2002

Understanding Feshbach resonances of ^{6}Li and ^{133}Cs —
•Juris Ulmanis[1], Rico Pires[1], Marc Repp[1], Eva D. Kuhnle[1], Matthias Weidemüller[1], Tobias Tiecke[2], Chris Greene[3], Brandon Ruzic[4], John Bohn[4], and Eberhard Tiemann[5] — [1]Physikalisches Institut, Im Neuenheimer Feld 226, 69120 Heidelberg — [2]Department of Physics, Harvard University, Cambridge, Massachusetts, 02138, USA — [3]Department of Physics, Purdue University, West Lafayette, Indiana, 47907-2036, USA — [4]JILA, University of Colorado and National Institute of Standards and Technology, Boulder, Colorado 80309-0440, USA — [5]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

The recently measured interspecies Feshbach resonances in the Fermi-Bose mixture of Li-Cs [M. Repp *et at.*, Phys. Rev. A 87, 010701(R) (2013)] provides an excellent system for exploring different topics in few- and many-body physics. It is a promising candidate for the creation of deeply bound polar molecules and polarons. For the investigation of these phenomena, precise knowledge of the scattering properties and molecular structure is necessary. In this talk we give a brief overview and quantitative comparison of three different theoretical models for description of Feshbach resonances, namely, coupled channels calculation, asymptotic bound state model and the multichannel quantum defect theory. Each model reproduces the previously observed collisional behaviour and allows to make important predictions for further experiments in the Li-Cs system.

Q 36.5 Thu 11:45 UDL HS2002

Ultracold Chemistry and its Reaction Kinetics —
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The experimental progress in cooling, controlling and producing ultracold particles led us to the possibility to establish molecular bindings of particles even at ultracold temperatures. This process is referred to as ultracold chemistry. A quantum field theoretical description, e.g. in the context of the formation of a molecular Bose Einstein condensate (BEC), was proposed in [1]. By generalizing the proposed model and investigating the predicted dynamics with the help of the time-dependent variational principle (TDVP), we find that phenomena like entanglement and decoherence play an important role in this framework. In particular, we identify an example of an ultracold reaction which displays a rich structure of phenomena, and which can be tested experimentally.

[1] D. Heinzen, R. Wynar, P. Drummond, and K. Kheruntsyan, Physical review letters 84, 5029 (2000).

Q 36.6 Thu 12:00 UDL HS2002

Beyond the Laboratory: Bose-Einstein Condensation in Stars —
•Christine Gruber[1] and Axel Pelster[2] — [1]Department of Physics, Freie Universität Berlin, Germany — [2]Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany

We investigate the possible occurrence of Bose-Einstein condensates (BECs) in astrophysical contexts, i.e. in compact objects such as white dwarfs and neutron stars. Conditions in such environments allow for the formation of BECs due to a favorable combination of temperature and density, and thus it is of interest to investigate the condensation of bosonic particles under the influence of gravitational interactions. Here we extend the corresponding zero-temperature Hartree-Fock theory of the literature by including finite-temperature effects. Solving the resulting Hartree-Fock self-consistency equations within the Thomas-Fermi and the semiclassical approximation leads to the radial density profiles of both the condensed and the thermal bosons. Furthermore, macroscopic astrophysical quantitites like the equation of state, the total mass, and the maximum star mass are derived. The theory has been applied to the case of helium white dwarfs and neutron stars, yielding reasonable predictions in the latter case, where the superfluidity emerges due to effectively bosonic neutron pairs which form a BEC.