OSCAR[1] Reports–

an SFB/TR 185 quarterly magazine

Editorial by Dieter Meschede

The OSCAR project – in short taming atomic and photonic matter by manipulating their reservoirs or by topological properties - has now entered its second year. The second retreat has received much interest, and first results of our new scientific program are rolling in. With this series of reports on OSCAR results we intend to better disseminate our advancing knowledge within OSCAR in order to share new concepts and stimulate new ideas. We strongly recommend to read the focused summaries[2] provided here and address your OSCAR colleagues at all levels, from the PI to the postdoc to the PhD to the master student. Enjoy the new OSCAR Reports!

I did enjoy looking in more detail into the OSCAR results covered here. An unbiased selection happened to find publications from A, B, and C areas. I was very pleased to learn that at this early stage they all and explicitly do contribute very well to the central scientific aims of OSCAR. Therefore, reading our articles and addressing OSCAR topics in future publications will help to further shape our joint efforts by preparing the ground for growing cooperations.

With my best wishes for all OSCAR projects, Dieter Meschede

Fig.1 OSCAR Retreat 2 at Marienburg (Bullay, Mosel valley, Germany). About 60 researchers of the OSCAR teams from Bonn and Kaiserslautern met for three days to discuss the progress of their individual projects, to find out about the status of OSCAR, and to get to know each other.

[1] stands for **O**pen **S**ystem **C**ontrol of **A**tomic and Photonic Matte**R;** funded by the Deutsche Forschungsgemeinschaft since July 01, 2016

[2] All OSCAR publications can be found at https://www.oscar.uni-bonn.de/publications/sfb-publications

Single Atoms Trace out the Laws of Diffusion (Area A)

Tracer Atoms in an Ultracold Dilute Gas
M. Hohmann, F. Kindermann, T. Lausch, D. Mayer, F. Schmidt, E. Lutz, A. Widera
Phys. Rev. Lett. **118**, 263401 (2017)

Brownian motion connects diffusion, which describes stochastic motion of particles interacting with a large reservoir in our macroscopic world, with the notion of microscopic particles. In his famous *annus mirabilis* of 1905 Einstein[3] not only puts forward this model but also makes a crucial prediction that for realistic parameter ranges experimenter should be able to observe Brownian motion directly at micrometer scales over seconds with their microscopes. Einstein's invitation was about 20 years later accepted by Perrin and rewarded with the nobel prize.

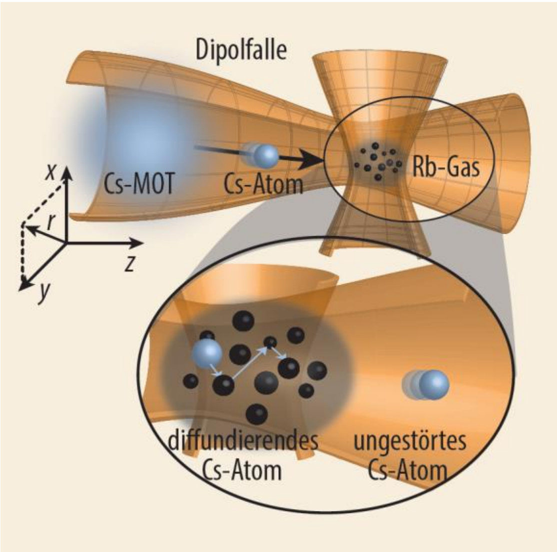

Fig. 2 Single Caesium atoms are directed at a cloud of cold Rb atoms.Some atoms pass the cloud ballistically, others scatter of the Rb reservoir and start to diffuse within the cloud.

Following Einstein's footsteps, the article by M. Hohmann et al. studies a new regime of diffusion by tracing the motion of light instead of heavy objects—namely, individual Cs atoms —interacting with a reservoir of ultracold Rb atoms. A clever arrangement of parameters (atoms travelling at the speed of few mm/s for few tens of milliseconds) has allowed new insight: The Kaiserslautern team has succeeded to monitor the dynamic evolution of the diffusion process by almost instantaneously freezing the motion of the single Cs atom tracers before recording their final position through fluorescence microscopy.

The classic diffusion problem à la Einstein is modeled by the stochastic Langevin equation with a constant friction coefficient. It was found that for the present system – where the masses and thus also velocities of the reservoir's particles and the diffusing particle are of similar order – this approach needs to be extended with a velocity-dependent friction coefficient yielding good agreement of theory and experiment.

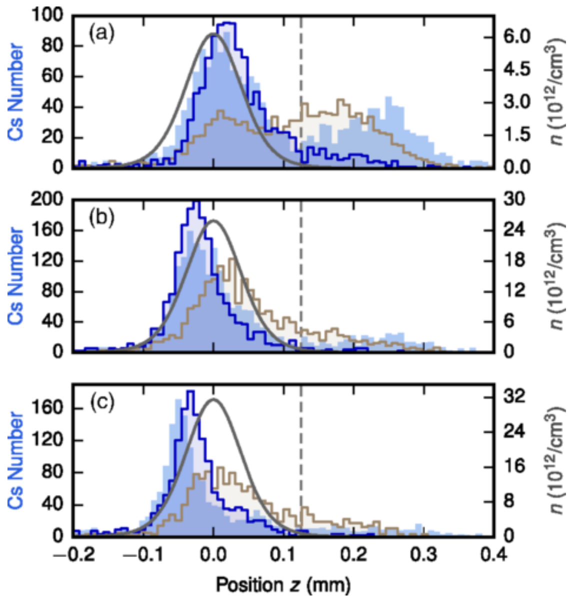

Fig. 3 Spatial distribution of Cs atoms (orange) after a fixed diffusion time. On the left side the dashed line gives the simulation following a modified Langevin theory (blue) reflects well the thermalized fraction of Cs-tracer atoms very well. On the right we find ballistic atoms.

We may consider Einstein's 1905 conjecture as a very simple level of open system control, which was certainly not very sophisticated but - at the time - provided deep insight into the microscopic structure of nature. The experiment by Hohmann et al. takes a first step along the lines put forward in OSCAR area A: well controlled single atomic particles interacting with a tailored and unusual reservoir.

[3] A. Einstein, Ann. Phys. 322, 549 (1905)

Drive Fields and Dissipation Compete in a Strongly Interacting Rydberg Gas (Area B)

Bistability Versus Metastability in Driven Dissipative Rydberg Gases
F. Letscher, O. Thomas, T. Niederprüm, M. Fleischhauer, and H. Ott
Phys. Rev. X **7**, 021020 (2017)

Promoting atoms from their ground state to a Rydberg state induces strong interactions between atoms characterized by the so called Rydberg blockade (the probability of exciting another Rydberg atom within the blockade radius is strongly suppressed) or anti blockade regime (the probability of exciting further Rydberg atoms is strongly enhanced by the presence of a first Rydberg atom).

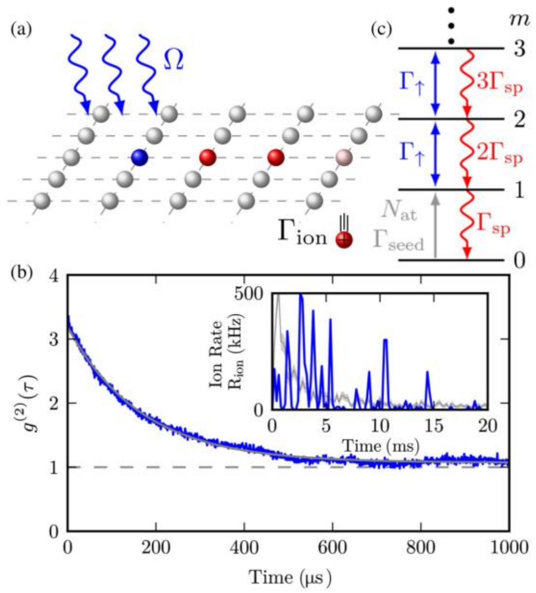

Fig. 4 A Mott insulator many atom system is exposed to a UV light field driving Rydberg excitations (a). The system is probed by the ion current originating from weak photo ionization which reflects the temporal excitation dynamics (b). The steady state of the system is governed by excitation processes including Rydberg antiblockade ((c), the lowest lying excitation probability Γ_{Seed} is smaller than $\Gamma_\uparrow$) and dissipation by spontaneous emission.

The article by Letscher et al. addresses the question what phase transitions can occur in a reasonably dense Rydberg gas when exposed to a continuous drive by suitable laser fields under anti-blockade conditions. As shown in Fig. 4 the excitations dynamics competes with dissipation by deexcitation caused by the finite life-time of the Rydberg states.

The strong interactions within the Rydberg non-equilibrium state are calling for potentially interesting many body quantum states exhibiting long range order. This situation would be equivalent to a driven phase transition indicated by some bistable behaviour of the system as a function of, e.g., the driving strength.

In the experiment the temporal $g^{(2)}(\tau)$ correlation function of the ionization current was extracted as a function of driving strengths and the detuning governing the antiblockade effect. A rate equation model is used to extract information from the temporal fluctuations of the system dominated by the $g^{(2)}$ relaxation times τ_{cl} (see Fig. 4, 5). According to this model, the relaxation of a Rydberg cluster–a group of correlated excited atoms is proportional to the cluster size (the number of correlated excitations) times the Rydberg state life-time, $\tau_{cl} \sim m\, \tau_{sp}$.

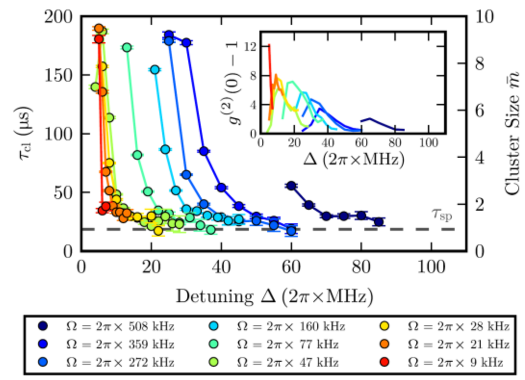

Fig. 5 Experimental results of the Rydberg cluster relaxation times as a function of driving strengths and detuning with associated cluster sizes m *(right axis)*

The cluster life-times significantly exceed the spontaneous life-times creating some metastability but do not diverge which would be expected for a truly bistable behaviour. Thus a picture emerges where on average about a percent of the cold atom system is promoted into excited states with large fluctuations associated with the continuous birth and death of small Rydberg clusters.

Topological Edge States in Position and Momentum Space (Area C)

Spectral imaging of topological edge states in plasmonic waveguide arrays
F. Bleckmann, Z. Cherpakova, S. Linden, and A. Alberti
Phys. Rev. B **96**, 045417 (2017)

Topological insulator materials show astonishing properties such as currents propagating along the edges while the bulk remains insulating as, for instance, in the quantum Hall effect. These properties apply at the single particle level and are characterized by quantum numbers such as the winding or Chern number. The energy spectrum of a topological insulator exhibits gaps inside which edge states appear that are topologically protected.

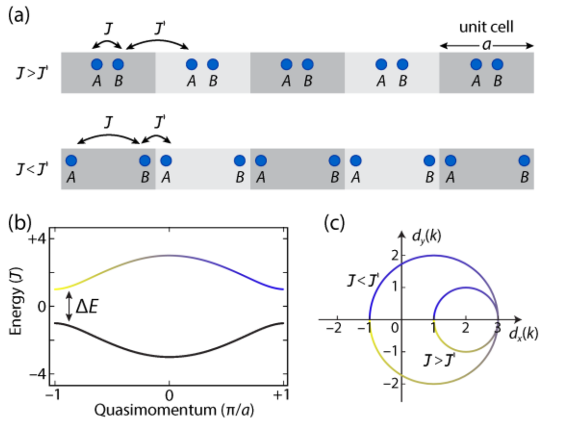

Fig.6 The SSH model considers a one-dimensional periodic system with two lattice sites per unit cell (a). Local dynamics is described by two different hopping rates J (inside) and J' (between the cells). Note that the two-site unit cell is composed of two levels equivalent to a pseudo spin-½ system.

One of the simplest models of a topological insulator is the SSH-model[4] Theoretical analysis shows that the SSH dispersion relation consist of two bands with a gap $\Delta E = 2|J\text{-}J'|$. Every quasi momentum k of the bands is associated with a specific pseudo spinor in the xy-plane (Fig. 6). Sweeping the quasi momentum across the entire Brillouin zone lets the spinor carry out a full rotation around the point (J,0,0) in the Bloch-sphere representation. Now, for J' > J the origin is enclosed, for J' < J not, leading to different quantized winding numbers 1 and 0, respectively. These two situations are associated with two distinct kinds of dimerization of the simulated polymer chain.

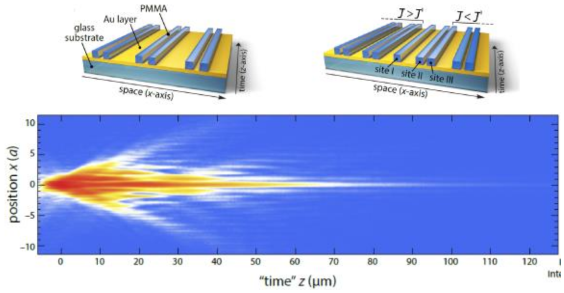

Fig. 7 Insertion of light field at the boundary of topologically distinct systems (site I, upper right) creates a topologically protected edge state visible by leakage radiation.

Single particle motion in periodic potentials can be experimentally modelled with waveguide arrays where propagation in the *z*-direction maps the system onto the time-dependent Schrödinger equation. For plasmonic waveguide arrays the evolution can be probed by leakage radiation microscopy, which detects light coherently scattered out of the system. Imaging of the leakage radiation provides information about the spatial distribution of the photon field at different times as well as a record of the Fourier transform of the propagating photon field. in the back focal plane of the objective lens which can be understood as a direct representation of the momentum-resolved energy spectrum. This spectrum (Fig. 8) contains the dispersion relation of photons propagating in the bulk (far from edges), as well as about the mid gap topologically protected states in the proximity of edges.

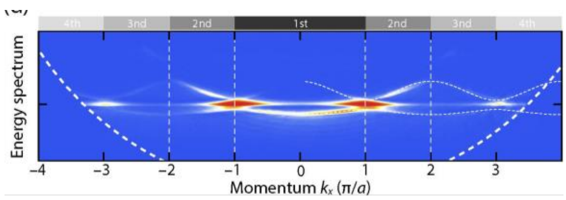

Fig. 8 Fourier image of the leakage radiation field showing the topologically protected states at mid bandgap position.

[4] W. P. Su, J. R. Schrieffer, A. J. Heeger, Phys. Rev. Lett. **42**, 1698 (1979)