41. EAS -Tagung "Extreme Atomic Systems"

27 – 31 January 2020, Riezlern/Kleinwalsertal

– list of abstracts –

Rajat Agrawal, mpipks Dresden

Scattering an atom from a Rydberg composite

Here we analyze the collision of a slow atom with a 2D Rydberg composite [1] (changes the electron density of the composite). We will discuss the collision for different geometries like the atomic lattice of Rydberg composites is perpendicular and parallel to the trajectory of an atom. We will also discuss the lattice of the Rydberg composite which has just a single ground state atom (trilobite limit).

[1] Andrew L. Hunter, arXiv:1909.01097v1 (2019)

Lazaro Alonso Silva, mpipks Dresden

On photon-electron spectra, synthetic hamiltonians and machine learning

In this talk we will discuss the idea of an ensemble of synthetic Hamiltonians as a tool to purify photon-electron spectra coming from the interaction of noisy pulses with a potential whose first energy levels are similar to the meta-stable helium. Here, the goal will be to trained a neural network with sufficient noisy spectra from different noisy pulses and synthetic Hamiltonians with their pure counterpart (Fourier-limited pulse), such that the trained network will be able to purify a new spectrum, which in this case could come from experiment.

Jackson Angonga, University of Illinois

Towards quantum simulation using Rydberg-excited atoms in optical tweezer arrays

Trapped neutral atoms in optical tweezers present a versatile platform for quantum simulation, metrology and quantum information processing. We present a scheme where a synthetic dimension can be added to a one-dimensional array of individually trapped 39^K atoms by exciting them to Rydberg states. A synthetic lattice of coupled internal states is created by coupling multiple Rydberg levels using microwave fields. Enhanced dipole moments associated with atoms in Rydberg states lead to strong dipole-dipole interactions. These interactions and control of synthetic lattice parameters open up avenues for studying a wide range of quantum many-body phenomena. The near arbitrary ability to engineer a generic tight-binding Hamiltonian in the synthetic dimension allows new capabilities for the exploration of interaction effects in topological and disordered systems. One particular, novel phenomenon i.e. the formation of stable quantum strings have been predicted to occur in such synthetic systems.

Henry Banks, University College London

Understanding XFEL interactions with atomic and molecular systems through pathway analysis

We investigate the interaction of molecular nitrogen and xenon with x-ray free-electron laser pulses using rate equations and Monte-Carlo calculations. By analyzing the transition pathways, we can identify the formation of short-lived intermediate states with interesting physical properties, such as multiple-core-hole states. Furthermore, we identify pulse parameters that favor the production of these interesting states. We observe how the dominant pathways are determined by the pulse parameters and investigate how the pulse shape can affect the pathway populations.

H. I. B. Banks, D. A. Little, J. Tennyson and A. Emmanouilidou, Phys. Chem. Chem. Phys. 19 19794-806 (2017)

H. I. B. Banks, A. Hadjipittas and A. Emmanouilidou, arXiv:1908.08728v1 [physics.atom-ph]

Eric Brunner, Albert-Ludwigs-University Freiburg
Partial Distinguishability and Coherence in Many-Body Systems

Many-body interference in the dynamics of identical particles is controlled by their mutual indistinguishability. This can be tuned by addressing suitable "label" degrees of freedom. Through a systematic analysis of coherence in the dynamical modes, limited by entanglement between dynamical and label degrees of freedom, we define a hierarchy of indistinguishability measures. Identifying robust signatures of many-body interference in randomized correlation measurements allows us to uncover the coherence structure of a given input state, and, therefore, to assess the degree of indistinguishability. This paves the way for an experimental quantification of partial distinguishability in general non-interacting many-body systems.

Berislav Buca, University of Oxford
Non-stationary quantum many-body dynamics

The assumption that quantum systems relax to a stationary (time-independent) state in the long-time limit underpins statistical physics and much of our intuitive understanding of scientific phenomena. For isolated systems this follows from the eigenstate thermalization hypothesis. When an environment is present the expectation is that all of phase space is explored, eventually leading to stationarity. We will discuss simple algebraic conditions that lead to a quantum many-body system never reaching a stationary state, not even a non-equilibrium one. This unusual state of matter characterized by persistent oscillations has been recently called a time crystal. We show that it's existence can be either related to the symmetry properties of the an isolated system, or can be, counter-intuitively, induced through the dissipation itself.

References:
B Buca, J Tindall, D Jaksch. Nat. Comms. 10 (1), 1730 (2019)
M Medenjak, B Buca, D Jaksch. arXiv:1905.08266 (2019)
B Buca, D Jaksch. arXiv:1905.12880 (2019) (accepted in Phys. Rev. Lett.)
J Tindall, B Buca, J R Coulthard, D Jaksch. Phys. Rev. Lett. 123, 030603 (2019)
J Tindall, C Sanchez Munoz, B Buca, D Jaksch. arXiv:1907.12837 (2019)

Andreas Buchleitner, Albert-Ludwigs-University Freiburg
Transporting atoms between finite reservoirs

Cold atom experiments get ever closer to simulating proper solid state scenarios, such as time-resolved transport across a lattice-like potential landscape. Inspired by experiments at ETH, we develop an open system treatment to describe many-particle transport between finite-size reservoirs, and analyse the emerging time scales.

David Busto, Lund University
High-spectral resolution attosecond photoelectron spectroscopy

The development of attosecond light sources has opened a new window through which we can study electronic processes, such as photoionization, on their natural timescale. Attosecond electron dynamics can be investigated via transient absorption spectroscopy or photoelectron spectroscopy. Absorption measurements provide information of the light-matter interaction while photoelectron measurements are sensitive to both light-matter interaction and propagation effects of the electron on the ionic potential. While attosecond photoelectron spectroscopy is powerfull technique to study both direct and resonant ionization processes, it can suffers from a lack of spectral resolution. One approach to improve the spectral resolution is to use attosecond pulse trains, corresponding to a comb of narrow harmonics in the frequency domain, instead of isolated attosecond pulses. Despite the femtosecond duration of the entire pulse train, it is possible to measure photoionization dynamics with attosecond precision using the interferometric technique RABBIT (reconstruction of attosecond beating by interference of two-photon transitions)[1, 2]. The RABBIT scheme is based on the interference of two photoionization paths: absorption of one harmonic plus one infrared (IR) photon or absorption of the following harmonic plus stimulated emission of an IR photon. The interference of the two-photon transitions results in the creation of photoelectron peaks called sidebands whose

intensity oscillates as a function of the delay between the attosecond pulse train and IR pulse, providing both amplitude and phase information of the emitted photoelectron wavepackets. However, because the amplitude and phase measurements are performed in the sidebands, they are affected by the spectral width of the short IR pulses [3]. As a result, when probing narrow spectral features such as Fano resonances, the amplitude and phase measured in the two-photon sidebands are strongly smoothed out compared to what would be expected from Fano's theory [4, 5]. In our work we show that it is possible to significantly increase the spectral resolution of the RABBIT technique by using longer probe pulses with a reduced spectral bandwidth of 10 nm. This allows us to characterize the autoionized electron wavepackets in the time-frequency domain with unprecedented spectral resolution and investigate decoherence effects in our measurements.

[1] P. M. Paul et al., Science 292, 1689 (2001).
[2] M. Isinger et al., Science 358, 893 (2017).
[3] À . Jiménez-Galán et al., Phys. Rev. A 93, 023429 (2016).
[4] V. Gruson et al., Science 354, 734 (2016).
[5] D. Busto et al., J. Phys. B: At. Mol. Opt. Phys. 51, 044002 (2018).

Edoardo Carnio, Albert-Ludwigs-University Freiburg
Coherent control of two-photon absorption via entangled photons

We investigate the optimal shape of light pulses, treated either as classical fields or photons, that drive the two-photon absorption in the matter degrees of freedom. We show that the Schmidt decomposition can reveal both the shape of the modes, and the correlations between them, that maximally drive the transition. We then generalize the optimization problem to realistic driving pulses, e.g., Gaussian wave packets emitted in spontaneous parametric down-conversion.

Jonathan Dubois, mpipks Dresden
High harmonic generation and nonsequential double ionization with circularly polarized pulses

This poster addresses high harmonic generation (HHG) and nonsequential double ionization (NSDI) from atoms subjected to intense circular polarized laser pulses. After the electron is ionized by the laser, the initial momentum of the electron is very low. Following the conventional scenario given by the so-called three-step model, the electron then drifts away from the core without returning to it, therefore predicting that HHG and NSDI cannot be observed for nearly circular polarization. Instead, we identify a recollision channel referred to as 'envelope-driven recollisions' in which the electron ionizes early after the laser field is turned on, and therefore the sideways drift of the electron is potentially compensated by its initial nearly-zero momentum. We demonstrate that this recollision channel builds up HHG spectra and the enhancement in double ionization probability curves, even for circularly polarized pulses. Our results open up the exploitation of elliptically polarized light and in particular, highlight the instrumental role played by the pulse envelope, as a potential tool for the enhancement and control of high harmonic generation.

Agapi Emmanouilidou, University College London
Frustrated double ionization in strongly driven molecules

We present the possible pathways for forming high Rydberg states during the break-up of two-electron multi-centre molecules. We demonstrate control of the different pathways of Rydberg formation with orthogonally polarised laser fields as well as with counter-propagating circular fields.

1.Emmanouilidou, A., Lazarou, C., Staudte, A., Eichmann, U. (2012). Routes to formation of highly excited neutral atoms in the breakup of strongly driven H-2. PHYSICAL REVIEW A, 85 (1) 011402. doi:10.1103/PhysRevA.85.011402

2. Chen, A., Kling, M.F., Emmanouilidou, A. (2017). Controlling electron-electron correlation in frustrated double ionization of triatomic molecules with orthogonally polarized two-color laser fields. Physical Review A, 96 (3) 033404 (5 pages). doi:10.1103/PhysRevA.96.033404

3. G. P. Katsoulis, R. Sarkar, and A. Emmanouilidou, Enhancing frustrated double ionisation with no electronic correlation in triatomic molecules using counter-rotating two-color circular laser fields, arXiv.1908.06262

Daniel Finkelstein-Shapiro, Lund University

Translating atomic physics to molecules and nanoparticles in water: a cavity QED example

The weak coupling of atomic systems with their environment render them ideal for observing and testing quantum phenomena that require coherence, such as dressing of orbitals by light, entanglement and interference. These effects are at the root of important technological applications (quantum computing, cooling) and theoretical explorations have suggested that they could also be profitable for other applications including solar cells, if only they could be reproduced in molecular or extended systems.
I will discuss the problematic of reproducing quantum optics effects in chemical systems in solution, by focusing on molecules attached to plasmonic nanoparticles. These constitute a candidate realization for cavity quantum electrodynamics with a high degree of complexity given by the number of orbitals involved as well as the strong coupling to a dissipative environment. Theoretically, I will describe the limits under which we can still use atomic-like Hamiltonians – including Dicke and Fano Hamiltonians - and what to do when these break down. Experimentally, I will present measurements using ultrafast electronic multidimensional spectroscopy that reveal the loss of coherence and energy to the environment and underline the opportunities, challenges and pitfalls of using these chemical systems as if they were atomic ones.

Andrew Forembski, Dublin City University

Towards a multi-GPU heterogeneous Lanczos time propagator of atomic systems in ultra-short and strong laser fields.

The Physics aspect- The evolving technological breakthroughs of intense ultra-short laser sources (HOHG/FEL) have led to the realization of experimental schemes that allow for the study (and control) of electromagnetically-driven processes at time-scales which correspond to those of characteristic atomic times such as: the Hydrogen ground state 'orbital' period, ionization and auto-ionization - formation and -decay times, the spin-orbit procession period etc. Slowly, but irreversibly, simple theoretical interpretations become obsolete as, the validity of their approximations begins to break down. Particularly with non-linear/ultra-short interactions the use of a first principle approach offers a unique advantage, not only in relation with the theoretical goal of a comprehensive description, but also at the level of the interpretation (and often the design) of experimental data/schemes. Our motivation is to develop a computational method which takes into account the most modern technological advancements in the computing industry, namely the use of heterogeneous platforms. With a key goal being, to test the method in the double ionization of noble gases. While for helium there exist a vast number of theoretical works, much fewer investigations are available for other targets, which makes the current project highly timely. Description of the computational approach- A common method of solving the TDSE involves an expansion on the eigenstate basis. This results in the TDSE taking the form of a differential matrix equation:

$$\dot{c}(t) = -i\mathcal{H}(t)c(t), \tag{1}$$

where H is a (time-dependent) symmetric matrix consisting of eigenenergies and dipole matrices and $c(t)$ is a vector of the corresponding time dependent coefficients. There exist several methods for time propagating the TDSE, finite-difference integration schemes can show good runtime performance but lag behind in accuracy when compared to finite element schemes. The accepted state-of-the-art finite element numerical time propagator is based on the Lanczos algorithm [1, 2]. First introduced by Park and Light in [3], this method has seen widespread use in solving TDSE's for use-cases where accuracy is of great importance. Formally the explicit numerical solution of Eq. (1) requires calculating the exponent of the matrix $\mathcal{H}$ which if performed directly would incur a massive computational cost (left-hand side of Eq. (2)). Hence in practice one turns to matrix reductions and/or transformations in order to greatly reduce the number of required numerical operations.

$$c(t+\Delta t) = e^{-i\mathcal{H}(t)\Delta t}c(t) \quad \rightarrow \quad c(t+\Delta t) = Qe^{-i\Lambda_h \Delta t}Q^\dagger c(t). \tag{2}$$

The latter part of Eq. (2) presents an eigendecomposition-based approach, where h is a vector of eigenvalues of the matrixH . Not all eigenvalues are required in order to solve this system to a sufficient level of accuracy. The Lanczos algorithm provides a subset of the most distinct eigenvalues via expansion on a Krylov subspace. This reduction in the spectral (eigenvalue) range of the problem reduces the size of the vector h thus greatly reducing the number of expensive exponent calculations that are required. Graphics Processing Units (GPUs) are highly parallel processors that can provide state-of-the-art performance for numerical matrix and vector operations. The aim of this project is to develop a multi- GPU Lanczos based solver to greatly improve the speed of this method without a loss in accuracy.

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[3] Tae Jun Park and JC Light. Unitary quantum time evolution by iterative lanczos reduction. The Journal of chemical physics, 85(10):5870–5876, 1986.

Kieran Adam Fraser, mpipks Dresden

Quantum nonlinear optics in driven fermi gases

Hybrid systems of photons and neutral atomic gases have emerged as ideal playgrounds for nonlinear quantum optics, a rapidly-growing field offering great technological promise, while also involving complex and novel many-body phenomena. Characterized by effective interactions between photons even at very low light intensities, this realm of optics offers new possibilities for quantum technologies, as optical nonlinearities at the single-photon level would facilitate quantum information processing with light, the latter being simultaneously an ideal information carrier. We study the effective photon-photon scattering in a laser-driven Fermi gas interfaced with a multimode optical waveguide using a path-integral approach. Using this, we can identify possible bound states and determine the scattering phase shift for the photon-photon scattering.

Stefanie Gräfe, University of Jena

Plasmonic hybrid systems in external light fields: can we achieve sub-nanometer lateral resolution using near-field techniques?

What is the ultimate spatial resolution that can be achieved with near-field methods? In current experiments, for example based on tip-amplified Raman scattering (TERS), there is increasing evidence for an extremely high spatial resolution on the nanometer or even sub-nanometer scale. In this talk, I will present some of these experiments of our collaboration partner, Prof. Volker Deckert from Jena, as well as the first results of our calculations.
For the theoretical description of such plasmonic hybrid systems in external light fields, it is necessary to describe both the electromagnetic interaction and the more chemical effects equally. Our calculations show pronounced changes of the Raman spectrum under non-resonant and resonant conditions and support the possibility of sub-nanometer spatial resolution.

Jiri Hofbrucker, Helmholtz Institute Jena

Cooper minimum in multi-photon ionziation

In one-photon ionization, the photon energy for which the dominant ionization channel vanishes is called the Cooper minimum. This concept is extended to nonlinear ionization of atoms. We study this in the two-photon ionization process. In our talk it will be shown that the nonlinear Cooper minimum leads to strong variation in practically all observable quantities of the two-photon ionization process. For example, by tuning the incident photon energy to the nonlinear Cooper minimum, it is possible to enhance the polarization transfer from the incident light to the photoion. The ion polarization can be observed either directly, or in the case of inner-shell ionization, via polarization of subsequent fluorescence and Auger decay particles. The nonlinear Cooper minimum also leads to the maximum elliptical dichroism in photoelectron angular distributions. As all the mentioned quan-

tities are normalized quantities, they are less sensitive to experimental uncertainties. It is theorized that detection of the energy position of the nonlinear Cooper minimum via one of the mentioned methods could lead to comparison of experimental measurements and theoretical calculations at hitherto unreachable accuracy.

Andrew L. Hunter, mpipks Dresden
Energy level statistics in Rydberg Composites

Rydberg Composites are a new class of Rydberg matter consisting of a single Rydberg atom interfaced with a dense environment of neutral ground state atoms organized in a lattice (cite). The properties of the Rydberg composite are directly linked to the discrete symmetry of the occupied sites in the lattice with characteristic but unusual footprints of quantum chaos in the energy level statistics of the composite. We have developed techniques to identify these effects and present a systematic study of broken lattice symmetry and the transition to full chaos as atoms are removed from the lattice. We also describe how these statistics change with decreasing lattice constant with a transition to a continuous environment when the Rydberg electron can no longer resolve the lattice spacing.

Christian Johansen, mpipks Dresden
Superradiant multimode Floquet polaritons

Optically trapped driven ultracold atoms in cavities present a highly tunable system for exploring many-body physics. Using near-planar cavities the transversal modes (TMs) are typical distanced by several hundreds megahertz. As such the atoms will dominantly interact only with the resonant TM of the cavity. This interaction between atoms and the cavity gives rise to the well known superradiant instability. New confocal experimental setup have shown that when multiple modes becomes relevant then the nature of the unstable mode changes. In this project we theoretically investigate a system where the pump laser's phase is periodically modulated. This modulation puts higher-order transversal modes closer to resonance in a way that is easily implemented in current near-planar cavity setups Using non-equilibrium field theory we find that this modulation affects both the threshold of the instability and the unstable modes nature.

Georgios Petros Katsoulis, University College London
Slingshot non-sequential double ionization as a gate to anti-correlated two electron escape

Non-sequential double ionization (NSDI) of atoms driven by intense laser fields is a fundamental process which has attracted considerable theoretical and experimental interest. Using a three-dimensional semiclassical model, we study double ionization of He driven by near-single-cycle laser pulses at low intensities at 400 nm. We present a new mechanism for NSDI, named Slingshot NSDI. In this mechanism, we have recollision-induced excitation with one electron escaping fast after recollision and the other electron escaping with a time delay via a Coulomb slingshot motion. In addition, we identify differences in two-electron probability distributions of the Slingshot NSDI and the other NSDI pathways. Those differences are accessible by experiments, and thus can be used to observe Slingshot NSDI.

References

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[2] G.P. Katsoulis, and A. Emmanouilidou, 'Fingerprints of slingshot non-sequential double ionization on two-electron probability distributions', Sci. Rep. 9, 18855 (2019)

Dominik Lentrodt, MPI for Nuclear Physics Heidelberg
Ab initio few-mode theory for open quantum systems

The concept of a few modes of the electromagnetic field interacting with matter is a paradigm in the field of light-matter interactions. For example, the single mode Jaynes-Cummings model and its many generalisations, such as the many-body Dicke model, have been indispensable tools in studying open light-matter quantum dynamics. In particular in cavity and circuit QED, where strong light-matter coupling is routinely achieved in experiment, such models have been tremendously successful. Recently, however, various experimental platforms have emerged where multi-mode effects, complex environments and the openness of the system constitute an essential part of the physics. Consequently, the applicability of few-mode models has been debated in these extreme regimes of light-matter interaction. In this talk, I will present "ab initio few-mode theory", which allows to include new physics into few-mode models without abandoning their conceptual and computational simplicity. I will outline practical implications for various fields featuring extreme light-matter interactions, including multi-mode strong coupling and ultra-strong coupling physics as well as the emerging platform of nuclear many-body cavity QED and X-ray quantum optics.

Severin Meister, MPI for Nuclear Physics Heidelberg
Analyzing angular distributions of light induces states in Helium, using XUV and NIR elds

In a two color experiment at FLASH2 we used an XUV pulse to electronically excite Helium, which is subsequently ionized by a moderately strong NIR pulse. While for a delayed NIR pulse the photoelectrons just reveal bound 2p states of Helium, XUV and NIR pulses in temporal overlap lead to the emergence of light induced states (LIS). These states can be interpreted as direct two photon excitation, where the dipole selection rule does not hold anymore. The experiment was performed with a Reaction microscope (REMI), where both charged fragments (e^-, He^+) can be detected in coincidence and their associated momenta reconstructed. Electron angular distributions and their NIR intensity dependence are analyzed for parallel and perpendicular orientation of the two light fields linear polarization.

Sara Mikaelsson, Lund University
Controlling the photoelectric effect in the time domain

One of the most fundamental and fastest processes in nature is the photoelectric effect, where an electron is emitted from matter after absorption of a high-energy photon. Such photoionization dynamics on the attosecond timescale are traditionally studied using an extreme ultraviolet field (XUV) for ionization and an infrared laser field for amplitude- or phase- modulation of the emitted electron wavepackets. Common techniques include streaking, appropriate in the regime where a single XUV attosecond pulse is used, and RABBIT, used with a long XUV pulse train. In this work we investigate photoionization of helium with instead a short sequence of either two or three attosecond pulses, in the presence of a weak infrared laser field, and we demonstrate control of photoelectron emission through electron wavepacket interference. This control, made possible by the extreme temporal confinement of the light-matter interaction, opens up new possibilities of manipulation of ultrafast processes with a tailored sequence of attosecond pulses.

Robert Müller, PTB Braunschweig
Isotope shift spectroscopy as an indicator for physics beyond the standard model

In order to identify discrepancies between experimental and theoretical that can be atttributed to physics beyond the standard model, quantities need to be considered, that can be very precisely measured and calculated. It has been shown in the recent years that the isotope shift ratio of two transitions could be such a quantity. Displayed as a function of the number of nucleons this ratio resembles the so-called King plot. In first order of the electron-nucleus mass ratio, this function is strictly linear. The precision achieved by modern experimental and theoretical methods, however, makes this approximation inapplicable and higher order effects need to be taken into account. These effects can be seen as nonlinearities in the King plot. Similar nonlinearities may be caused by new particles that are not part of the standard model. In our talk we discuss important higher order effects on the isotope shift in highly charged ions and how we can use isotope shift spectroscopy to put restrict the properties of supposed new particles.

Mama Kabir Njoya Mforifoum, Albert-Ludwigs-University Freiburg
Interference of two composite particles

The dynamics of systems of identical particles is characterized by many-body interference. However, the interfering particles (bosons or fermions) can be composite objects, raising the question of the conditions under which bound states of several particles behave as ideal elementary bosons or fermions. Here we take a look at the dynamics of two bound pairs on a 1D lattice and observe their Hong-Ou-Mandel interference on an impurity. We investigate also to which extent the composite nature of the bound pairs affects their dynamics.

Natalia S. Oreshkina, MPI for Nuclear Physics Heidelberg
Skyrme-type nuclear interaction for high-presicion atomic calculations

We demonstrate a new approach for calculating the finite nuclear size correction to the fine structure and bound-electron g factor for a series of highly charged hydrogen-like ions. Firstly, self-consistent mean-field calculations based on the Skyrme-type nuclear interaction are employed in order to produce a nuclear charge distribution. In the second step, the obtained nuclear charge density is used to construct the potential of an extended nucleus for the Dirac equation. The ambiguity in the choice of a Skyrme parametrization is supressed by fine-tuning of only one parameter of the Skyrme force by reproducing the experimental values of nuclear radii. The homogeneously charged sphere approximation, the two-parameter Fermi distribution and experimental nuclear charge distributions are used for comparison with our approach, and the uncertainties of the presented calculations are estimated. In addition, suppression of the finite nuclear size effect for the weighted differences of g factors is demonstrated.

Christian Ott, MPI for Nuclear Physics Heidelberg
Nonlinear driving of resonant transitions in atoms with intense XUV light

With ultrafast XUV transient absorption spectroscopy, carried out in Fraunhofer-type transmission geometry by directly measuring the attenuated light, one is sensitive to both the linear and nonlinear XUV-optical dipole response of the electron dynamics in the local vicinity of an atom, enabling a direct view into the bound-state dynamics of excited electrons.
In this talk, we will present new results of direct XUV nonlinear effects in both helium and neon atoms. These include XUV-induced shifting of energy levels through the ac Stark effect, as well as non-trivial line-shape modifications of a correlated two-electron transition in helium. These results were experimentally obtained by using intense XUV pulses from the Free-Electron Laser (FEL) in Hamburg (FLASH), tuned to photon energies of 60 eV and 50 eV, respectively, for the helium and neon absorption targets. The pulse energy ranges up to multiple ten μJ with a photon fluence of several J/cm^2 in the interaction volume. Depending on the stochastic substructure of the FEL pulses, intensities up to 10^{15} W/cm^2 can be reached with these parameters.
New insights on strong-XUV-field light-matter interaction can thus be gained, demonstrating the feasibility of quantum control of specific transitions characteristic to each atom.

Lukas Pausch, Albert-Ludwigs-University Freiburg
Eigenstate versus spectral structure of interacting bosons on a lattice

Important structural features of a quantum system are encoded into the localisation properties of its energy eigenstates [1,2]. In the present investigation, we study the transition from regular to chaotic spectral and eigenvector structure in the Bose-Hubbard Hamiltonian. Using the framework of generalized fractal dimensions to characterize the eigenstates' localisation properties in Fock space, we show that the change of the latter with the ratio of tunneling to interaction strength correlates with a qualitative change of the energy level statistics: In the regime of fully developed spectral chaos each individual eigenstate delocalizes over the entire Fock basis. This is corroborated by a very narrow distribution of generalized fractal dimensions, which becomes ever sharper as the Hilbert space dimension is increased.

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Anton Peshkov, University of Braunschweig
Excitation of atomic transitions with twisted light

In this work we study the excitation of electric-dipole-forbidden transitions in a single trapped atom using twisted Bessel light when the atom is assumed to be well localized on the beam axis. A transition rate for absorption is derived for the general case when the light propagation direction does not coincide with the atomic quantization axis defi
ned by an applied static magnetic field. The main emphasis was on calculating the excitation rates for the $S_1^2/2(F=0) \rightarrow F_7^2/2(F=3)$ electric octupole (E3) transition in the 171^1Yb^+ ion. The hyperfine transitions driven by the linearly, radially, and azimuthally polarized Bessel beams are analyzed
and compared with the corresponding plane-wave results. The work shows that the excitation rate for twisted light
can be signicantly enhanced under certain orientations of the
magnetic field, making this excitation scheme very promising for atomic clocks.

Thomas Pfeifer, MPI for Nuclear Physics Heidelberg
The optical response of a continuum threshold, in weak and strong fields

Maria Novella Piancastelli, Uppsala University
Molecular movie: where are we?

The possibility of making the so-called " molecular movie" is the Holy Grail of everybody performing pump-probe experiments to follow a photoexcitation-decay process or even a photochemical reaction. Various techniques have been used to reach this goal, including e.g. electron scattering, imaging, photoelectron diffraction, valence photoelectron spectroscopy, and transient absorption spectroscopy. These methods have been used following optical laser photoexcitation as pump, and either HHG sources or free-electron laser sources as probe.
The author has been involved in experiments with valence photoelectron spectroscopy at FERMI-LDM, which can give a very accurate description of a photoexcitation-relaxation process on the few-femtosecond timescale.
Since other complementary and/or alternative approaches exist, it will be interesting to plan a general discussion to compare advantages and drawbacks of the various nowadays available tools.

Kevin Prince, Elettra Sincrotrone Trieste
Recent experiments with fully coherent Free-Electron Laser light

Recent experiments with fully coherent Free-Electron Laser light The seeded Free-Electron Laser (FEL) FERMI produces light in the extreme ultraviolet to soft x-ray wavelength regions. Unlike FELs based on Self Amplified Spontaneous Emission, whose light is transverse coherent but not longitudinally coherent, FERMI generates fully coherent light. This permits a number of experiments with short wavelength light that are not possible at other FELs. One application is the use of bichromatic light (fundamental plus second harmonic), whose relative phase can be controlled precisely, to determine photoemission delays (also known as Wigner delays.) By measuring Photoelectron Angular Distributions at several photon energies as a function of phase, we have developed a method to determine the angle-resolved group delays of the emitted photoelectrons, which are measured on the attosecond scale. Another application is the study of a novel excited ionic state decay mechanism, single-photon Laser Enabled Auger Decay [1-3].
It is also possible to user single-colour, double pulses with phase control to obtain information about atomic and molecular systems, and examples will be shown.
1. B. Cooper and V. Averbukh, Phys. Rev. Lett. 111 (2013) 083004.
2. D. Iablonskyi et al, Phys. Rev. Lett. 119 (2017) 073203.
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Adam Prior, Dublin City University

Radial and Angular Distributions of Photoionized Quantum Dot

Quantum Dots (QDs), also referred to as artificial atoms, are semiconductor nano-structures with the ability to trap electrons in a controllable confining potential. Various models for the confining potential of a spherical QD exist, and our choice of potential to describe the single-electron QD states is by a Hamiltonian, hq, a central Gaussian potential well of the form:

$$h_q(\mathbf{r}) = -\frac{\nabla_r^2}{2\mu_e} + V_Q(r), \qquad V_Q = -V_0 e^{-(r/R_Q)^2},$$

$R_Q \sim$ QD's size, where the V_0 parameter controls the potential depth. Our results show that varying the size of the QD directly effects the QD states and energies. Of particular interest is the dynamics of electrons trapped in these structures upon interaction with an intense and ultrashort laser pulse. QDs, like atoms, possess a bound and continuum spectrum of states so the dynamics of excitation and photoionization can be studied numerically via the solution of the timedependent Schrödinger equation (TDSE). This project currently focuses on studying the dynamics of a two-electron QD, or 'artificial helium', in an intense, ultra-short, THz laser field (of duration 150 fs and intensity $\sim 10^6$ W/cm2). Focused on here is double-ionization of the quantum dot, i.e excitation of two electrons into the continuum states. Within the model of this QD, the correlation between electrons is also taken into account and thus included in the double ionization study. Another property shared with atoms is the existence of more than one double ionization mechanism, namely the direct and sequential double ionization mechanisms. With atoms, these different mechanisms can be accessed by varying the photon energy to reach the energies required. However with QDs, we can vary the size of the dot to access these mechanisms and study the ionization dynamics in the direct and sequential regimes. To solve this problem, specially designed atomic structure methods and numerical approaches have been developed and tested thoroughly over the years in our group [1], which have been successfully adapted to the case of QDs [2,3]. The time dependent Schrödinger equation is formulated as below,

$$i\frac{\partial}{\partial t}\psi(\mathbf{r}_1, \mathbf{r}_2; t) = \left(h_q(\mathbf{r}_1) + h_q(\mathbf{r}_2) + \frac{1}{4\pi\epsilon}\frac{1}{|\mathbf{r_2} - \mathbf{r_1}|} - \mathbf{A}(t) \cdot (\mathbf{p_1} + \mathbf{p_2}) \right) \psi(\mathbf{r}_1, \mathbf{r}_2; t),$$

where is the material's dielectric constant. The QD's one-electron spectrum is calculated by expanding the radial wavefunction on a local polynomial B-Spline basis, and these radial functions are used to expand the two-electron field free eigenstates on a set of (correlated) configurations to calculate the two-electron QD spectrum. The time dependent Schrödinger equation can be solved by expansion of the time-dependent wavefunction on the set of two-electron eigenstates with time-dependent coefficients. These wavefunctions are used to calculate observables which in our case are the radial and angular distributions of the doubly ionized QD.

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Michael Karl Rosner, MPI for Nuclear Physics Heidelberg

Production and preparation of highly charged ions for re-trapping in ultra-cold environments

Certain Highly charged ions (HCIs) exhibit enhanced sensitivity to fundamental interactions due to the specifics of their level structure, enabling improvement in atomic clocks and frequency metrology. This allows more precise tests of fundamental physics than achievable with atoms or singly charged ions, e. g. in the search for a possible time variation of the fine-structure constant α. Their narrow optical transitions make them suitable targets for quantum metrology, as recently demonstrated for Ar^{13+}. An electron beam ion trap (EBIT) is used to produce ions in the desired charge states. However, the high temperature within EBITs requires a transfer of the HCIs into a cooling trap to perform high-resolution spectroscopy. This work presents a setup comprising an EBIT and a beamline suitable for transfer, bunching, precooling and deceleration of extracted HCIs. In the EBIT, an electron beam is electrically accelerated and magnetically compressed to sequentially ionize neutral atoms injected into the trap center to generate HCIs. The ion optics, diagnostic elements and a

decelerating/pre-cooling unit of the beamline prepare them for re-trapping. Time-of-flight measurements were performed to determine the charge state distribution of the extracted ions. Furthermore, a retarding field analyzer allowed the determination of their mean kinetic energy as well as their energy spread, which has been subsequently reduced in the pre-cooling unit.

Jan M Rost, mpipks Dresden
Purifying electron spectra from noisy pulses with machine learning using synthetic Hamilton matrices

We construct a fully connected feedforward artificial neural network to extract a purified electron spectrum corresponding to ionization with a Fourier limited light pulse from a noisy spectrum created by a short, noisy pulse. The network is trained by theoretical spectra obtained from a large number of synthetically generated random Hamilton matrices coupled to short pulses and noise. Therefore, application to a wide variety of problems is possible. Concrete first examples presented will include helium and H2+ for processes dominated by non-linear two- and three-photon absorption in the XUV, where we demonstrate that indeed, the noise free spectrum can be uncovered with good accuracy. The results show that noise is very helpful if one can deal with it.

Patrick Rupprecht, MPI for Nuclear Physics Heidelberg
Electron-vibrational coupling dynamics in SF_6

Visible and infrared vibrational spectroscopy, probing non-localized electronic molecular states, is commonly used in chemistry and biology. In combination with core-level spectroscopy, studies of coherently coupled electronic and vibrational dynamics with site and element specificity are possible. In my talk, I will report on the investigation of sulfur hexafluoride (SF_6) using attosecond transient absorption spectroscopy driven by mJ-level, few-cycle 15 fs FWHM pulses centered at 1550 nm in the short-wave infrared (SWIR) spectral region. The excited $6a_{1g}$, $2t_{2g}$ and $4e_g$ molecular states related to the sulfur $L_{2,3}$ absorption edge were probed. First, altering the absorption spectrum in the 160 eV to 200 eV soft X-ray (SXR) region under the presence of a strong SWIR field was demonstrated. Furthermore, varying the delay between the SXR and SWIR pulses resulted in an oscillatory behavior of the resonance lines' intensities, with a leading SWIR pulse. The extracted oscillation period of (773 ± 16) cm^{-1} matches the Raman-active symmetric breathing mode $\nu_1 = 775$ cm^{-1}. This result implies sensitivity to nonresonant impulsive stimulated Raman scattering via probing electronic transitions to states localized near the sulfur atom.

Ulf Saalmann, mpipks Dresden
Is there a Coulomb-laser-coupling time?

Krzysztof Sacha, Jagiellonian University
Time Quasi-Crystals

Ordinary space crystals from because the space translation symmetry is spontaneously broken in condensed matter systems. It is also known that periodically driven many-body systems can spontaneously self-reorganize their periodic motion and form new crystalline structures in time which are dubbed discrete time crystals [1]. We show that periodically driven systems can also spontaneously form time quasi-crystals [2]. That is, patterns in time that lack translation symmetry but still reveal long range order. Such phenomenon can be realized in ultra-cold atoms experiments [3].

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Frans Schotsch, MPI for Nuclear Physics Heidelberg
TrapRemi – A Reaction Microscope Inside a Zajfman Trap

Reaction Microscopes (REMIs) are routinely used to study atomic or molecular processes like ionization, charge transfer, dissociation, structural rearrangements, and many more by means of angular resolved and kinematically complete measurements. In almost all cases the reaction of interest is induced by collisions of various kinds of projectile beams with neutral gas targets inside the REMI. In order to extend the range of applications towards ionic atomic and in particular charged molecular targets we combined two well-known technologies: a REMI and a Zajfman-trap. In this talk, I will show the development of this experiment, from the basic idea to a first proof-of-principle measurement.

Bernd Schütte, MBI Berlin
XUV spectral compression by four-wave mixing

The spectral compression and broadening of visible and infrared light pulses has many applications ranging from precision spectroscopy to the generation of few-cycle laser pulses used e.g. in attosecond science. In the XUV regime, a corresponding technique has not been available so far, but would be desirable for applications including EUV lithography, coherent diffractive imaging and the compression of ultrashort XUV pulses. Here we show spectral compression of XUV pulses by three orders of magnitude making use of a four-wave mixing (FWM) technique. We exploit the fact that the slope of the refractive index is much larger in between two atomic resonances than it is far away from a resonance. The off-resonance nature of our FWM process results in little absorption and allows us to use high atomic densities, making high conversion efficiencies possible. The same concept may be used in the future to spectrally broaden and temporally compress XUV pulses emitted from comparably narrowband XUV sources such as seeded free-electron lasers.

Nico Strauß, Albert-Ludwigs-University Freiburg
Quantum friction and internal atomic dynamics

The CasimirPolder force between atoms or molecules is of quantum mechani- cal origin and forms the basis of quantum friction, which is predicted to occur when two objects move at distance on the order of a few tens of nanometers relative to each other. In this presentation, we consider the eects of this force on the energy levels of atoms and their velocity dependence as well as that of the resulting transition frequencies [1]. We investigated how this frequency de- pendence can be observed in the experiments of M. Ducloy and M. Fichet [2] by measuring the changes in the re ection coecients of a modulated laser beam incident on the boundary between a dielectric and a gas moving atoms.
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Felix Thiel, Humboldt University Berlin
Quantization of the mean decay time for non-Hermitian quantum systems

We consider a quantum system with a general Hermitian Hamiltonian $\hat{H}$ and one decay channel, through which probability dissipates to the environment with rate Γ. When the system is initially prepared exactly in the decay state, the mean decay time $\langle T \rangle$ is quantized and equal to $w/(2\Gamma)$. w is the number of distinct energy levels, i.e. eigenvalues of $\hat{H}$, that have overlap with the decay state, and is also the winding number of a transform of the resolvent in the complex plane. Apart from the integer w, $\langle T \rangle$ is completely independent of the system's dynamics. We compute the complete decay time distribution in the strong and weak dissipation limit and show how its decay modes are obtained from an effective charge theory in general. We discuss our findings in the two-level atom in an electric field and in a disordered tight-binding model.

Vasily Tulsky, University of Rostock

Applications of the phase-of-the-phase spectroscopy to two-color bi-circular fields

The talk consists of two main parts. // A. Originally proposed for two-color linearly polarized fields [1-2], phase-of-the-phase (PoP) spectroscopy has shown to be a useful tool to distinguish in photoelectron spectra (PES) between physical effects of different origin. Extended to the two-color bi-circular case, PoP appeared to provide sharp features in PES that are sensitive to the laser intensity [3], thus making it a potential handy intensity calibration technique. // B. A study of PES from complex targets may be hampered by the presence of laser-incoherent contributions to the total signal: electrons can originate from thermal emission (initially incoherent) or undergo multiple scattering on the parent cluster (and losing their coherence by this) before being registered. We propose an example for an application of the PoP to the latter case, modelling argon atoms in helium droplets. It appears that the PoP is capable to reveal the remaining laser-coherent features in the spectrum even when it is buried under the dominating signal from multiply scattered electrons [4]. //

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Sebastian Ulbricht, PTB Braunschweig

Gravitational Effects on Laser Stabilization Cavities

Matthias Wollenhaupt, Carl von Ossietzky University Oldenburg

XUV spectral compression by four-wave mixing

Three-dimensional free electron wave packets with arbitrary rotational symmetry are generated by multiphoton ionization of atoms with polarization-tailored laser fields and manipulated with the optical phases including the CEP and relative phases. In the experiment we combine advanced supercontinuum pulse shaping with high-resolution photoelectron tomography. We use a 4f polarization pulse shaper to sculpture bichromatic fields from a CEP-stable over-octave spanning white light supercontinuum by spectral amplitude and phase modulation [1]. The experimental results show that multiphoton ionization of potassium atoms with a single-color sequence of counterrotating circularly polarized (CRCP) femtosecond laser pulses produces vortex-shaped photoelectron momentum distributions [2] with even-numbered rotational symmetry (c4, c6 and c8). In contrast, bichromatic CEP-stable polarization-tailored counter- and corotating (COCP) femtosecond laser pulses generate c7 rotationally symmetric and asymmetric momentum distributions [3]. To elucidate the physical mechanisms, we investigate the interplay between the symmetry properties of the driving field and the resulting electron wave packets by varying the optical field parameters. Applications dynamic holography of Rydberg electron wave packet dynamics are discussed.

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Vladimir Yerokhin, Peter the Great St. Petersburg Polytechnic University

Tests of bound-state QED in Lamb shift and g factor of few-electron ions

Precision measurements of atomic transition frequencies and bound-electron g factors combined with sophisticated ab initio QED calculations provide stringent tests of QED theory of bound states, deliver improved determinations of fundamental constants (the Rydberg constant, the electron mass), and put constrains on the new physics beyond the Standard Model. In my talk I will examine recent advances of theoretical calculations of QED effects in Lamb shift and the bound-electron g factor and analyse the comparison of theory with latest experiments. A review of different (rigorous and approximate) methods of calculations of QED effects will be given, with emphasis on new developments in this field.

Klaudia Zaremba-Kopczyk, University of Warsaw

Interactions and collisions in the ultracold Fermi-Fermi mixture of chromium and lithium

Mass-imbalanced strongly-interacting Fermi-Fermi mixtures of ultracold atoms have been predicted to oer much richer physics as compared to the mass-balanced case due to the introduction of mass-ratio dependent exchange interaction between constituent atoms. For the mass ratio below the critical value 13.6, peculiar few-body features, such as the formation of exotic non-E
movian trimer states, should be observed and enable to access novel exotic phases on both sides of the BEC-BCS crossover. Among the atomic species that have already been brought to Fermi degeneracy, a good candidate for the experiments with mass-imbalanced fermionic mixtures is the 53Cr+6Li combination. Here we investigate interactions and collisions in the ultracold 53Cr+6Li mixture. We employ the multireference con
guration interaction method, MRCI, and coupled cluster method restricted to single, double, and noniterative triple excitations, CCSD(T), to calculate the interaction potential energy curves for the CrLi molecule both in ground and excited states. Next, we use accurate ground-state potential energy curves to investigate magnetically tunable Feshbach resonances in the considered mixture. We also analyze the prospects for photoassociation of chromium and lithium atoms into CrLi molecules, and prospects for application of CrLi molecules in precision measurements.