# A 18: Attosecond physics I

Time: Tuesday 14:00–16:00 Location: V47.03

**Invited Talk** A 18.1 Tue 14:00 V47.03

**Ultrafast Quantum Photonics** — •Alfred Leitenstorfer — Department of Physics and Center for Applied Photonics, University of Konstanz, Konstanz, Germany

This talk provides an overview of our efforts to investigate condensed-matter systems and light down to the molecular level of single electrons and photons, with direct access to the electric field amplitude and sub-cycle precision. First, ultrabroadband femtosecond fiber lasers are introduced as an enabling technology for ultrafast quantum photonics [1]. In the following, femtosecond experiments on single semiconductor quantum dots are featured [2]. Via broadband enhancement of light-matter coupling e.g. with plasmonic nanoantennas [3], we are aiming at a precise control of the photon number of ultrashort pulses. The third part discusses the field of multi-terahertz physics where new regimes for quantum optics [4] and a nonlinear access to low-energy excitations of complex matter [5] are currently arising.

[1] G. Krauss et al., Nature Photon. 4, 33 (2010)
[2] F. Sotier et al., Nature Phys. 5, 352 (2009)
[3] T. Hanke et al., Phys. Rev. Lett. 103, 257404 (2009)
[4] G. Günter et al., Nature 458, 178 (2009)
[5] T. Kampfrath et al., Nature Photon. 5, 31 (2011)

**Invited Talk** A 18.2 Tue 14:30 V47.03

**Attosecond dynamics in laser-driver metal clusters** — Johannes Passig[1], Sergey Zherebtsov[2], Robert Irsig[1], Slawomir Skruszewicz[1], Josef Tiggesbäumker[1], Matthias Kling[2], Karl-Heinz Meiwes-Broer[1], and •Thomas Fennel[1] — [1]University of Rostock, 18051 Rostock, Germany — [2]Max Planck Institute of Quantum Optics, 85748 Garching, Germany

Clusters in intense laser pulses are valuable systems to illuminate strong-field many-particle physics in the attosecond domain [1]. The understanding of key processes like collective excitations, ultrafast plasma creation, and electron rescattering in clusters may open up new routes for the analysis and control of nanosystems with light [2].

The extreme resonant field enhancement in clusters allows the acceleration of electrons to energies of a few hundred times the ponderpomotive potential in a single rescattering process [3]. In pump-probe experiments on silver cluster we found that the emission direction of electrons can be precisely controlled by the relative phase of a two-color laser field up to the keV energy range. A molecular dynamics analysis reveals that the asymmetric acceleration results from the attosecond timing of the induced polarization fields, demonstrating the opportunity of precise and highly efficient control of sub-cycle electron dynamics in resonant plasmonic many-particle systems.

[1] Th. Fennel et al., Rev. Mod. Phys. 82:1793 (2010)
[2] J. Köhn, Phys. Chem. Chem. Phys. 13:8747-8754 (2011)
[3] Th. Fennel et al., Phys. Rev. Lett. 98:143401 (2007)

A 18.3 Tue 15:00 V47.03

**Two-dimensional spectroscopy methods to explore attosecond electron dynamics** — Christian Ott, Philipp Raith, Andreas Kaldun, Kristina Meyer, Martin Laux, Yizhu Zhang, and •Thomas Pfeifer — Max-Planck Institut für Kernphysik, Heidelberg

Traditional two-dimensional (2D) spectroscopy methods are based on time-delayed mutually-coherent pulse sequences, allowing to map out correlations among different vibrational or electronic transition frequencies. This allows the measurement of population and (de-) coherence information of a system's density matrix and the coupling of quantum states, recently leading to the observation of coherent energy flow in macromolecular photosynthetic light-harvesting complexes, even at room temperature [1]. However, these powerful 2D-spectroscopy methods have thus far been limited to the femtosecond time scale.

Here, we present experimental results demonstrating novel concepts of 2D spectroscopy that are applicable to the attosecond strong-field domain and the exploration of one- and two-electron dynamics. The carrier-envelope phase (CEP) is used as a dynamical parameter, opening a second dimension to gain access to electron dynamics and to separately identify spectrally overlapping quantum paths within one and the same few-cycle strong-field laser pulse. We also used laser-dressed soft-x-ray transient-absorption spectroscopy to create experimental 2D spectrograms, from which we read the quantum-interference pathways of two-electron excited states and their dynamics embedded in an ionization continuum.

[1] Panitchayangkoon *et al.* PNAS **107**, 12766 (2010)

A 18.4 Tue 15:15 V47.03

**Correlated motion of two electrons on a 1 fs time-scale** — •Christian Ott, Andreas Kaldun, Philipp Raith, Kristina Meyer, Martin Laux, Yizhu Zhang, Steffen Hagstotz, Thomas Ding, Robert Heck, and Thomas Pfeifer — Max-Planck Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg

The concerted motion of two or more electrons is at the heart of almost any chemical reaction, as molecular bonding typically involves electron correlation dynamics. We experimentally observed and analyzed the time-resolved behavior of both electrons in helium, the prototype of the three-body Coulomb problem, via the technique of transient-absorption spectroscopy, combined with attosecond-pulsed soft-x-ray light produced via high harmonic generation using few-cycle ($\sim$ 7 fs) moderately intense (up to $5 \cdot 10^{12}$ W/cm$^2$) near-visible (VIS) laser pulses. Using broadband soft-x-ray light in the 60 to 70 eV energy range, we simultaneously excite up to 7 doubly-excited states of the $sp_{2,n+}$ ($^1P^o$) series. A temporally resolved coupling among the states with the VIS laser pulses at various field intensities (from the perturbative to the strong-coupling regime) was observed. In particular, we discuss VIS-intensity-dependent changes (up to complete inversion) of the Fano line shape which is characteristic of these intrinsically entangled two-electron states. A laser-induced coupling among various states allows the measurement of a two-electron quantum beating on a 1 fs timescale as theoretically predicted [1].

[1] L. Argenti and E. Lindroth, Phys. Rev. Lett. **105**, 053002 (2010).

A 18.5 Tue 15:30 V47.03

**Attosecond control of electrons emitted from a nanoscale metal tip** — •Michael Krüger, Markus Schenk, Michael Förster, Sebastian Thomas, Lothar Maisenbacher, and Peter Hommelhoff — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching bei München, Germany

By focusing low-power few-cycle Ti:sa pulses tightly onto sharp tungsten tips it is possible to reach a strong-field photoemission regime, a prerequisite for performing attosecond science. We have recently observed strong-field effects such as peak suppression and peak shifting [1] and rescattering [2] in this system. Here we use carrier-envelope phase (CEP) stabilized pulses and measure photoelectron spectra for varying CEP. We observe a CEP dependent current modulation that increases in amplitude to about 100% for high-energy electrons. Furthermore, we observe a clear change in the peak visibility of the high-energy plateau part of the spectrum when the phase is changed by $\pi$. The presence (absence) of spectral interference indicates that high-energy electrons are emitted within two time windows (one window) of sub-optical-cycle duration. Quantum mechanical theory models confirm this notion and show that photoelectrons from the metal tip can be steered with attosecond precision by changing the CEP, in analogy to atomic gases. We discuss results deepening the understanding of the processes involved.

[1] M. Schenk, M. Krüger, P. Hommelhoff, *PRL* **105**, 257601 (2010)
[2] see contribution of M. Schenk et al. at this conference
[3] M. Krüger, M. Schenk, P. Hommelhoff, *Nature* **475**, 79 (2011)

A 18.6 Tue 15:45 V47.03

**Attosecond plasma wave dynamics in laser-driven cluster nanoplasmas** — •Christian Peltz[1], Charles Varin[2], Thomas Brabec[2], and Thomas Fennel[1] — [1]Institute of Physics, University of Rostock, Germany — [2]Department of Physics and Centre for Photonics Research, University of Ottawa, Canada

Molecular dynamics (MD) and particle-in-cell (PIC) methods have been used with great success for modeling intense laser-plasma interaction, though both have certain important limitations. Electrostatic MD works well for small nanoplasmas, where the dipole approximation and the neglect of field propagation are justified. PIC codes average over the fine-grained atomic structure and thus neglect collisions and plasma microfields which is only justified at relativistic intensi-

ties or in weakly coupled plasmas and makes the treatment of large plasma volumes possible. We introduce a novel microscopic particle-in-cell (MicPIC) method that overcomes the above limitations with a $P^3M$-type force decomposition. In MicPIC, long-range electromagnetic interactions are described on a PIC level, on which particles are represented by wide Gaussian distributions on a relatively coarse numerical grid. When two particles come close, the PIC field is replaced by the analytic electrostatic field to resolve microscopic (Mic) interactions. As a first application, we study the resonant excitation of metal-like clusters (Mie plasmon and laser in resonance) where we found plasma waves in surprisingly small clusters at moderate laser intensities ($< 10^{14}\,\mathrm{W/cm^2}$). A detailed analysis of the wave dynamics and its impacct on absorption and ionization will be presented[submitted].