A 16: XUV/X-ray spectroscopy III

Time: Tuesday 14:30–16:30 Location: N 2

Invited Talk A 16.1 Tue 14:30 N 2

High-power XUV frequency combs — •Christoph M. Heyl[1,2], Gil Porat[1], Stephen Schoun[1], Craig Benko[1], Nadine Dörre[1,3], Kristan L. Corwin[1,4], and Jun Ye[1] — [1]JILA, NIST and the University of Colorado, 440 UCB, Boulder, CO 80309-0440, USA — [2]Department of Physics, Lund University, P. O. Box 118, SE-221 00 Lund, Sweden — [3]University of Vienna, Faculty of Physics, VCQ & QuNaBioS, Boltzmanngasse 5, A-1090 Vienna, Austria — [4]Department of Physics, Kansas State University, Manhattan, Kansas, USA

Frequency combs are nowadays routinely used for precision spectroscopy in the visible and near-IR spectral region. In contrast, the extreme ultraviolet (XUV) spectral region presents a barely explored area for precision spectroscopy studies with promising targets such as ground state transitions in helium, highly charged ions and possibly even nuclei. While XUV combs can reach sub-Hz coherence levels [1], the bottleneck is the limited power available in the XUV.

Here we discuss recent steps towards high-power XUV comb generation. These include down-scaling of efficient high-order harmonic conversion schemes [2] to adapt for intra-cavity operation as well as the exploration of intra-cavity plasma dynamics and their suppression. Our recent effort allowed us to generate high harmonics with average power levels in the mW range, setting a new record for XUV combs and more generally, for high-harmonic-based XUV sources.

[1] C. Benko, et al., Nature Photonics 8, 530 (2014).
[2] C. M. Heyl, et al., Optica 3, 75 (2016).

A 16.2 Tue 15:00 N 2

Towards XUV metrology with Highly Charged Ions using a HHG frequency comb — •Janko Nauta[1], Andrii Borodin[1], Julian Stark[1], Peter Micke[1,2], Lisa Schmöger[1,2], Maria Schwarz[1,2], José Crespo López Urrutia[1], and Thomas Pfeifer[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Highly charged ions (HCI) are atomic systems with only a few tightly bound electrons and offer many advantages over neutral and singly charged ions for probing fundamental physics. For example, HCI are intrinsically sensitive to a possible variation of the fine-structure constant α. Moreover, they have been recently proposed as candidates for novel frequency standards, because their low polarizability makes them insensitive to black body radiation and laser-induced shifts [1].

To this end, our project aims at studying trapped HCI, cooled down to mK temperatures [2], with ultra-high precision in the extreme ultraviolet (XUV) regime. We will use high harmonic generation (HHG) to coherently transfer the modes of an infrared frequency comb to the XUV, and then plan to perform direct frequency comb spectroscopy. To amplify the femtosecond pulses we are developing an enhancement cavity, with a focus waist size smaller than 15 μm in order to reach intensities of 10^{14} W/cm^2, enabling for intra-cavity HHG. The experimental approach and first results of the new enhancement cavity will be presented.

[1] A. Derevianko *et al.*, Phys. Rev. Lett. **109**, 180801 (2012)
[2] L. Schmöger *et al.*, Science **347**, 6227 (2015)

A 16.3 Tue 15:15 N 2

Electron correlation meets high-harmonic generation in He: Identifying plateaus beyond $3.17\,U_\mathrm{p}$ in the simulation — •Julius Rapp, Martins Brics, and Dieter Bauer — Institute of Physics, University of Rostock, 18051 Rostock, Germany

The harmonic radiation generated by an atom with ionization potential I_p^{n+} subjected to a laser field of ponderomotive energy U_p is classically expected to reproduce the cutoff energies of $3.17\,U_\mathrm{p} + I_\mathrm{p}^{n+}$ considering a single active electron (SAE) at each ionic charge number n. Beyond the SAE, electron correlation may give rise to new phenomena such as nonsequential double recombination [1] where—in simple man's picture—double ionization is followed by the simultaneous recombination of two electrons. Apart from those subtle yet qualitative additions, electron correlation may influence the ionization probabilities to such an extent that the contributions from different ionic charge states to the harmonic yield are significantly modified.

We present high-harmonic spectra of helium obtained by the numerical propagation of renormalized natural orbitals (RNOs) in 3D. Indeed, time-dependent RNO theory (TDRNOT) [2] applied to helium in full dimensionality produces harmonic-radiation plateaus which can not be explained in the SAE picture (confirming the prediction from 1D simulations [2]). We finally illustrate the disentanglement of different possible explanations by extended simple-man's modeling and time-frequency analyses.

[1] P. Koval, F. Wilken, D. Bauer, C. H. Keitel, *PRL* **98**, 043904 (2007)
[2] M. Brics, J. Rapp, D. Bauer, *PRA* **93**, 013404 (2016)

A 16.4 Tue 15:30 N 2

Optical and EUV spectroscopy of complex open $4d$-shell $Sn^{7+..14+}$ ions — •Hendrik Bekker[1], Francesco Torretti[2,5], Alexander Windberger[1,2], Alexander Ryabtsev[3,4], Stepan Dobrodey[1], Wim Ubachs[2,5], Ronnie Hoekstra[2,6], Anastasia Borschevsky[8], Emily V. Kahl[7], Julian C. Berengut[7], José R. Crespo López-Urrutia[1], and Oscar O. Versolato[2] — [1]Max-Planck-Institut für Kernphysik, Heidelberg — [2]Advanced Research Center for Nanolithography, Amsterdam — [3]Institute of Spectroscopy, Russian Academy of Sciences, Troitsk — [4]EUV Labs, Ltd., Troitsk — [5]Department of Physics and Astronomy, and LaserLaB, VU, Amsterdam — [6]Zernike Institute for Advanced Materials, University of Groningen — [7]School of Physics, University of New South Wales, Sydney — [8]The Van Swinderen Institute, University of Groningen

We present the analysis of the level structure of $Sn^{7+..14+}$ ions with their many-valence-electron open [Kr]$4d^m$ shell (m=7-0). These are essential in bright extreme-ultraviolet (EUV) plasma-light sources for next-generation nanolithography, but their complex electronic structure is an open challenge for both theory and experiment. We combine charge-state-resolved optical and EUV spectroscopy in an electron beam ion trap with state-of-the-art calculations using configuration-interaction many-body perturbation theory. Line identifications were performed employing semi-empirical calculations using the orthogonal parameters technique and COWAN code calculations. The results represent the most complete data available to date and suggest that some EUV line identifications in previous work need to be revisited.

A 16.5 Tue 15:45 N 2

High-precision X-ray spectroscopy of highly-charged ions at storage rings using silicon microcalorimeters — •Pascal Andree Scholz[1], Victor Andrianov[2], Artur Echler[3,4], Peter Egelhof[3,4], Oleg Kiselev[3], Saskia Kraft-Bermuth[1], and Damian Muell[1] — [1]Justus-Liebig-Universität, Giessen, Germany — [2]Lomonosov Moscow State University, Moscow, Russia — [3]GSI Helmholtz Center, Darmstadt, Germany — [4]Johannes-Gutenberg Universität, Mainz, Germany

High-precision X-ray spectroscopy of highly-charged heavy ions provides a sensitive test of quantum electrodynamics in very strong Coulomb fields. Silicon microcalorimeters, which detect the X-ray energy as heat rather than by charge production, have already demonstrated their potential to improve the precision of such experiments due to their excellent energy resolution for X-ray energies around 100 keV. Microcalorimeter arrays based on silicon thermistors and tin absorbers have already been successfully applied at the Experimental Storage Ring (ESR) of the GSI Helmholtz Center for Heavy Ion Research. Based on these experiments, a larger detector array with three times the active detector area in a new cryogen-free cryostat equipped with a pulse tube cooler is currently in preparation. Recently, a new compact detector design was applied in a test experiment at the ESR. In this presentation, we will introduce the detection principle, present the ESR test experiment following results, and discuss potential future applications.

A 16.6 Tue 16:00 N 2

The 3.5 keV X-ray line: a dark matter decay line or an unknown plasma line? — •Stepan Dobrodey[1], Chintan Shah[1], Sven Bernitt[1,2], René Steinbrügge[1], Liyi Gu[3], Jelle Kaastra[3], and José Ramón Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Friedrich-Schiller-Universität Jena, Jena, Germany — [3]SRON Netherlands Institute for Space Research, Utrecht, Netherlands

Speculations about a possible dark matter origin of an observed unidentified X-ray line feature at 3.5 keV from galaxy clusters have sparked an incredible interest in the scientific community and given rise to a tide of publications attempting to explain the possible cause for this line [1,2]. Motivated by this, we have measured the K-shell X-ray spectra of highly ionized bare sulfur ions following charge exchange with gaseous molecules in an electron beam ion trap, as a source of or contributor to this X-ray line. We produced S^{16+} and S^{15+} ions and let them capture electrons in collision with those molecules with the electron beam turned off while recording X-ray spectra. We observed a charge-exchange-induced X-ray feature at the Lyman series limit (3.47 ± 0.06 keV). The inferred X-ray energy is in full agreement with the reported astrophysical observations and supports the proposed novel scenario by Gu [2,3].

[1] E. Bulbul et al., ApJ, 13, 789 (2014)
[2] L. Gu et al., A&A, L11, 584 (2015)
[3] C. Shah et al., ApJ, in press (2016)

A 16.7 Tue 16:15 N 2

Nuclear excitation by electron capture in optical-laser-generated plasmas — •Jonas Gunst, Yuanbin Wu, Christoph H. Keitel, and Adriana Pálffy — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

In the process of nuclear excitation by electron capture (NEEC), the energy gained when a free electron is recombining into a bound state of an ion is simultaneously transfered to the atomic nucleus which is thereby excited. Recently, we have shown that this process can play the leading role among the nuclear excitation channels in cold, high-density plasmas created by an x-ray free-electron laser (XFEL), even higher than direct nuclear excitation channel using the XFEL beam on resonance [1,2]. However, the actual nuclear excitation rates are still small, strongly constrained by the attainable plasma conditions.

In contrast to XFELs, optical petawatt (PW) lasers are able to create plasmas over a broad parameter region. Exploring the potential of these lasers for NEEC raises several interesting questions: Is it possible to find a point on the accessible density-temperature landscape where NEEC is maximized? How does the NEEC rate depend on the laser parameters? What are the benefits/drawbacks of using optical PW lasers instead of XFELs? In this contribution, we are going to discuss these questions at the example of ^{93m}Mo isomer triggering.

[1] J. Gunst, Yu. A. Litvinov, C. H. Keitel, A. Pálffy, Phys. Rev. Lett. **112**, 082501 (2014).

[2] J. Gunst, Y. Wu, N. Kumar, C. H. Keitel and A. Pálffy, Phys. Plasmas **22**, 112706 (2015).