Towards an XUV frequency comb for precision spectroscopy of trapped highly charged ions

J.-H. Oelmann[*1], **J. Nauta**[†1], **A. Ackermann**[1], **L. Spieß**[1], **J. Stark**[1], **P. Micke**[1,2], **S. Kühn**[1], **J. R. Crespo López-Urrutia**[1], **T. Pfeifer**[1]

1. Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany
2. Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Highly charged ions (HCI) are atomic systems with a few tightly bound electrons. They offer many advantages over neutral and singly charged ions for probing fundamental physics and recently, they have been proposed as candidates for novel frequency standards [1]. Many optical transitions of HCI are located in the extreme ultraviolet (XUV). To study these transitions with high precision, a coherent ultra-narrow light source in this spectral region is required. For these reasons, we are developing an XUV frequency comb. High-harmonic generation (HHG) is used to transfer the coherence and stability of a near infrared frequency comb to the far ultraviolet [2-4]. Reaching intensity levels ($\sim 10^{14}\,\mathrm{W/cm^2}$) necessary for HHG, while operating at high repetition rates to achieve adequate comb-line spacing, is challenging. Therefore, the comb laser pulses are first amplified in a chirped-pulse fiber amplification setup and then resonantly overlapped in an astigmatism-compensated femtosecond enhancement cavity. To achieve high stability and low-noise performance, the cavity is placed on a rigid titanium structure with vibrational decoupling from the vacuum pumps. High-harmonics are generated in a target gas in the tight focus of the cavity. In other experiments, mirror degradation due to hydrocarbon aggregation is observed, which limits continuous operation time of XUV combs [4, 5]. To avoid this, we operate the cavity under ultra-high vacuum conditions. A differential pump setup will enable a high pressures of the HHG target gas without impairing the vacuum in the chamber, as shown in Fig. 1.

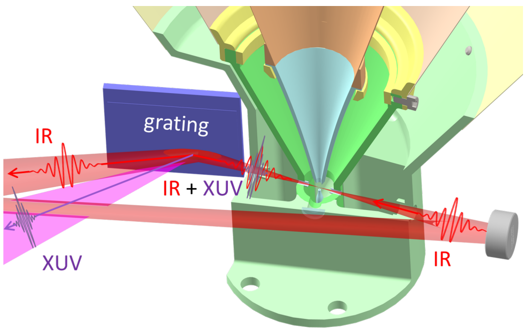

Fig. 1: Overview of the femtosecond enhancement cavity focus region. High-harmonics are generated in a gas jet in the cavity focus. The collinearly propagating XUV pulses are coupled out by a grating etched into a flat cavity mirror. A differential pump setup around the gas jet prevents gas from entering the main vacuum chamber to maintain ultra-high vacuum conditions.

The generated XUV light will be coupled out of the cavity by minus-first order diffraction of a small-period grating etched into a high-reflective cavity mirror directly behind the gas target [6]. Then, the light can be guided to trapped and sympathetically cooled HCI in a superconductive cryogenic linear Paul trap (CryPTEx II experiment at MPIK, based on [7]). By driving narrow transitions with individual comb lines, high-precision XUV spectroscopy of HCI will become possible for the first time [8].

References

[1] M.S. Safronova, V.A. Dzuba, V.V. Flambaum, U.I. Safronova, S.G. Porsev, and M.G. Kozlov, Phys. Rev. Lett. **113**, 030801 (2014).
[2] C. Gohle, T. Udem, M. Herrmann, J. Rauschenberger, R. Holzwarth, H.A. Schuessler, F. Krausz, and T.W. Hänsch, Nature **436**, 234 (2005).
[3] A. Cingöz, D.C. Yost, T.K. Allison, A. Ruehl, M.E. Fermann, I. Hartl, and J. Ye, Nature **482**, 68 (2012).
[4] C. Benko, T.K. Allison, A. Cingöz, L. Hua, F. Labaye, D.C. Yost, and J. Ye, Nat. Photon **8**, 530 (2014).
[5] A.K. Mills, T.J. Hammond, M.H.C. Lam, and D.J. Jones, Mol. Opt. Phys. **54**, 142001 (2012).
[6] D.C. Yost, T.R. Schibli, and J. Ye, Opt. Lett. **33**, 1099 (2008).
[7] L. Schmöger, O.O. Versolato, M. Schwarz, M. Kohnen, A. Windberger, B. Piest, S. Feuchtenbeiner, J. Pedregosa-Gutierrez, T. Leopold, P. Micke, A.K. Hansen, T.M. Baumann, M. Dewsen, J. Ullrich, P.O. Schmidt, and J.R. Crespo López-Urrutia, Science **347**, 1233 (2015).
[8] J. Nauta, A. Borodin, H.B. Ledwa, J. Stark, M. Schwarz, L. Schmöger, P. Micke, J.R. Crespo López-Urrutia, and Thomas Pfeifer, Nucl. Instrum. Meth. B **408**, 285 (2017).

*Corresponding author: oelmann@mpi-hd.mpg.de
†Corresponding author: nauta@mpi-hd.mpg.de