Bound states of a free electron: The role of the Kramers-Henneberger atom in the higher-order Kerr effect

Maria Richter[1], Serguei Patchkovskii[2], Felipe Morales[1], Olga Smirnova[1], and Misha Ivanov[1,3,4]

[1] Max-Born-Institute, Max-Born-Strasse 2A, D-12489 Berlin, Germany
[2] NRC of Canada, 100 Sussex Drive, Ottawa, Ontario K1A 0R6, Canada
[3] Dept of Physics, Humboldt University, Newtonstr. 15, D-12489 Berlin, Germany
[4] Department of Physics, Imperial College London, SW7 2AZ London, United Kingdom
mrichter@mbi-berlin.de

Even moderate laser fields with intensities of about 10^{13} W/cm^2, standard in many ultrafast experiments, suppress the potential barrier for ionization for *all excited states* in most atoms and molecules. By means of angle-resolved photoelectron spectra, we have shown [1] that in this regime the formation of *stable* 'laser-dressed' atoms, the so-called Kramers-Henneberger (KH) atoms [2] plays a crucial role and can be directly imaged. The response of the 'almost-free' states of this atom does not only play a key role in the experimental surprise of the unprecedented acceleration of neutral atoms [3] at the rate of 10^{15} m/sec^2 in intense infrared (IR) laser pulses, but it can also affect the complex process of filamentation of ultrashort IR femtosecond laser pulses in air [4].

We present a generalized model for the intensity-dependent response of atoms in strong IR laser fields, describing deviations in the nonlinear response at the frequency of the driving field from the standard model (linear Kerr effect + plasma defocusing) based on the formation of the *stable* KH states. According to our numerical simulations, shaping the driving laser pulse allows one to reveal signatures of the KH states in the Kerr response of a single atom.

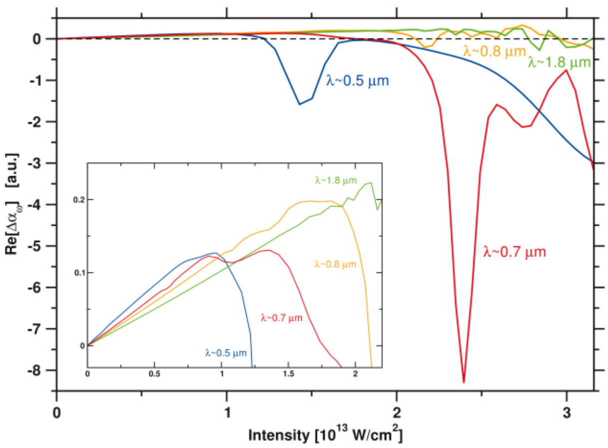

Fig. 1: Kerr response for long (4-40-4)-pulse. Plotted is the real part of the nonlinear contribution to the polarizability (with the low-field limit substracted) as a function of intensity for the 1D hydrogenic system and a central driving frequency of ω=0.0675 a.u. (red), ω=0.09 a.u. (blue), ω=0.055 a.u. (orange), ω=0.025 a.u. (green). The inset shows the low-intensity region. The horizontal black dashed line indicates $\mathrm{Re}[\Delta\alpha_\omega]=0$.

Fig.1 shows for a (4-40-4)-flat-top laser pulse (4 cycles turn-on/turn-off and 40 cycles flat-top) and different laser frequencies the response of the 1D model hydrogen atom at the driving frequency as a function of intensity. Our calculations reveal clear resonances, especially well pronounced for $\lambda\simeq 0.7$ μm at $I\approx 2.4\cdot 10^{13}$ W/cm^2. At first glance, considering the ponderomotive shift of the excited states of the model atom, it seems obvious that this drop is caused by a Freeman resonance. However, our Floquet analysis shows that this resonance can only be explained by population transfer into excited *KH states*.

References:
[1] F. Morales, M. Richter, S. Patchkovskii, and O. Smirnova, P. Natl. Acad. Sci. **108**, 16906 (2011).
[2] W. Henneberger, Phys. Rev. Lett. **21**, 838 (1968).
[3] U. Eichmann, T. Nubbemeyer, H. Rottke, and W. Sandner, Nature **461**, 1261 (2009).
[4] A. Braun, G. Korn, X. Liu, D. Du, J. Squier, and G. Mourou, Opt. Lett. **20**, 73 (1995)