

High-Lying Rydberg States from Strong Field Interaction

Seyedreza Larimian*, Sonia Erattupuzha*, Raffael Maurer*,
Christoph Lemell†, Stefan Nagele†, Shuhei Yoshida†, Joachim Burgdörfer†,
Andrius Baltuška*, Markus Kitzler*, Xinhua Xie*¹

* Photonics Institute, Vienna University of Technology, Gusshausstrasse 27, A-1040 Vienna, Austria

† Institute for Theoretical Physics, Vienna University of Technology, Wiedner Hauptstrasse 8-10, A-1040 Vienna, Austria

Synopsis We experimentally observed high-lying ($n > 238$) Rydberg states which are formed through recapture of electrons after strong field interaction in atoms and small molecules using electron and ion coincidence detection. The high-lying Rydberg states are identified through weak DC field-induced ionization.

In general, high-lying Rydberg states of atoms and molecules have quite low ionization potentials which may lead to over-barrier ionization in weak electric fields. Recent theoretical and experimental results indicate that such states play an important role in the interaction of atoms and molecules with strong laser fields [1, 2].

In this submission, we report direct observation of post-pulse detachment of electrons from high-lying Rydberg states which have previously been recaptured by the ionic core after strong field ionization in atoms and small molecules. In the experiments, we measured electrons and ions from the strong field ionization of atoms and molecules in coincidence using the reaction microscope technique [3, 4]. Measurements were performed with 795 nm, 25 fs laser pulses with peak laser intensity on the order of 1×10^{14} W/cm² (peak electric field 3×10^8 V/cm). Weak DC fields (from 0.1 V/cm up to 30 V/cm) are applied not only to accelerate charged particles to the detectors but also to induce field ionization of high-lying Rydberg states. Three types of atomic gases (argon, helium, and neon) and four types of molecular gases (hydrogen, ethylene, acetylene and 1,3-butadiene) were measured in the experiments.

After tunneling ionization of the gases in the strong laser field, a small fraction of electrons can be recaptured to form Rydberg states when the laser pulse is past. Later, electrons from very high-lying Rydberg states will be re-ionized by the very weak DC field through over-barrier or tunneling ionization. In the measurements, we observed such DC field induced ionization of high-lying Rydberg states for all measured targets except for 1,3-butadiene. This refers to an instability of highly excited 1,3-butadiene

resulting in molecular dissociation prior to re-ionization.

Measured photoelectron-photoion-coincidence (PEPICO) spectrum for argon is presented in Figure 1, in which we can clearly distinguish the signals originating from the strong field ionization and the weak DC field ionization.

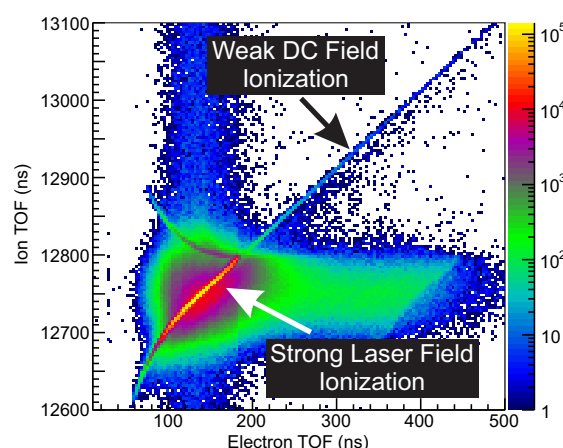


Figure 1. Measured PEPICO spectrum for argon.

We estimate the minimum primary quantum number n of the detected DC field-ionized Rydberg states from the ionization threshold ($-2\sqrt{F}$) for static field over-barrier ionization. For an electric field of 0.1 V/cm, we find that only Rydberg states with $n > 238$ is depopulated by the weak DC field.

References

- [1] T. Nubbemeyer *et al* 2008 *Phys. Rev. Lett.* **101** 233001
- [2] B. Wolter *et al* 2014 *Phys. Rev. A* **90** 063424
- [3] R. Dörner *et al* 2000 *Physics Reports* **330** 95
- [4] X. Xie *et al* 2012 *Phys. Rev. Lett.* **108** 193004

¹E-mail: xinhua.xie@tuwien.ac.at

