Optimizing High-order Harmonic Generation in Gases

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High-order harmonic generation (HHG) in gases is a well known process for obtaining spatially and temporally coherent extreme ultraviolet (XUV) radiation. The HHG process is intrinsically inefficient, with conversion efficiencies (CE) usually below 10^{-5}. At the same time, many applications of HHG, such as studies of nonlinear XUV processes or ionization processes with low cross-section, benefit from a high CE. This has lead to two complementary scaling directions, with both large scale facilities, with low repetition rate and high energy per pulse, and compact, high-repetition rate sources with low pulse energies, being built worldwide.

Recently, scaling laws were formulated, describing how the focusing geometry and the generating medium should be changed to reach a similar CE when the input pulse energy is scaled [1]. However, the scaling laws do not tell how the medium length and density should be chosen to optimize the CE, and both short gas jets with high density, and long gas cells with low density are used in experiments.

We propose a simple, scaling invariant analytic model [2], which predicts that efficient HHG is possible for a wide range of densities and medium lengths, if these follow a hyperbolic relation. The model is validated both in experiments, and using numerical simulations, for a wide range of generation parameters. A comparison of the model to experiments and simulations is shown in Fig. 1.

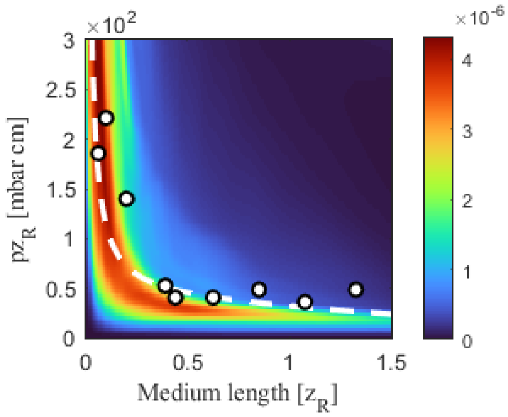

Figure 1: Simulation of CE of harmonic 23 in Ar (colorscale) as a function of medium length and pressure. The white dashed line shows the hyperbola of optimal CE predicted by the model, and white circles indicate experimental measurements.

References

[1] C. M. Heyl *et al.*, "Introduction to macroscopic power scaling principles for high-order harmonic generation," *J. Phys. B: At., Mol. Opt. Phys.* **50**, 013001 (2017)

[2] R. Weissenbilder *et al.*., "How to optimize high-order harmonic generation in gases," *Nat. Rev. Phys.* **4**, 713–722 (2022)