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Robust transverse structures in rescattered photoelectron wavepackets and their consequences

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Synopsis Initial-state symmetry has been under-appreciated in strong-field spectroscopies, where laser fields dominate the dynamics. We demonstrate numerically that the transverse photoelectron phase structure, arising from the initial-state symmetry, is robust in strong-field rescattering, and has pronounced effects on strong-field photoelectron spectra. Interpretation of rescattering experiments need to take these symmetry effects into account. In turn, robust transverse photoelectron phase structures may enable attosecond sub-Ångström super-resolution imaging with structured electron beams.

Symmetries, exact and approximate, as well as symmetry breaking underpin our understanding of perturbative spectroscopies, where field-free symmetries of initial and final states strongly constrain the range of possible outcomes. In contrast, in intense infrared laser fields, the overall dynamics is dominated by the field itself. The field symmetry determine many qualitative features of these processes, while the initial-state symmetry is often less important.

A recent study on molecular trans-butadiene[1] has shown that the rescattering probability in trans-butadiene is specific to the ionization channel and the molecular orientation, rather than a property of the driving field alone. These results may be interpreted as a signature of the transverse phase structure, imprinted on the recolliding electron wave packet (REWP) within each ionization channel.

In molecular systems, the initial-state symmetry effects are intertwined with contributions due to the asymmetry of the potential, orientation, and nuclear motion. This complexity makes the effects of the symmetry alone hard to isolate and model. Instead, we consider the simplest-possible example of the initial-state symmetry: a one-electron atom initially in an antisymmetric p state[2].

We demonstrate that the phase structure of the REWP due to the initial-state symmetry strongly affects strong-field rescattering (Fig 1). The effects are robust to the field misalignment with respect to the molecular symmetry element, and survive focal-spot intensity averaging. These effects need to be accounted for in the interpretation of strong-field recollision experiments both in the lower-energy (holographic) and the higher-energy (LIED) region.

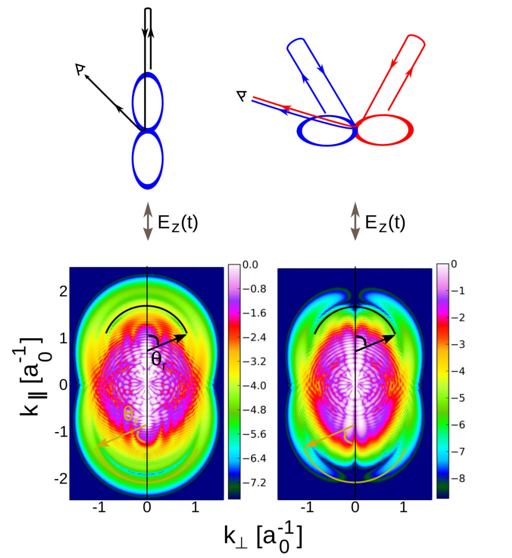

Figure 1. Strong-field photoelectron spectra (100 TW cm^{-2}, 800 nm, 13.5 fs) for the He$^+$ ion. Left column: symmetric initial state ($2p_z$). Right column: anti-symmetric initial state ($2p_x$). The $10U_p$ ($6U_p$) recollision-energy features shown with black (gold) lines.

References

[1] Schell F *et al* 2018 *Sci. Adv.* **4** 8148
[2] Bredtmann T and Patchkovskii S 2018 arxiv:1810.12672

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