Light Pulses with Self-Torque

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Abstract: We present a novel class of light pulses exhibiting self-torque, a previously unobserved property associated with a time-dependent angular momentum. Our quantum simulations and experimental measurements show that self-torque can be imprinted onto ultrafast pulses in the extreme-ultraviolet regime through high-order harmonic generation.

Light beams carrying orbital angular momentum (OAM) are well known due to their powerful capabilities for applications in many fields: optical communications, microscopy, quantum optics or microparticle manipulation [1]. Here we introduce a new class of light beams that possess a unique property associated with a temporal variation of their OAM: the self-torque of light [2]. Self-torque is found in other physical systems that can self-induce a temporal variation of their angular momentum but, until now, it was not even realized that light could possess self-torque. We define the self-torque of light as $\hbar\xi = \hbar d\ell(t)/dt$, $\hbar\ell(t)$ being the inherent OAM variation along a pulse.

In this work, we theoretically predict, and experimentally validate, that self-torque naturally arises in extreme-ultraviolet (EUV) beams generated through the extreme nonlinear process of high-harmonic generation (HHG), when driven by two time-delayed infrared (IR) pulses carrying different OAM (Fig. 1a). Recently, HHG has been used to imprint angular momenta onto ultrafast pulses in the EUV regime [3]. Here, the dynamical HHG process imprints a "continuous" temporal OAM variation into the EUV pulses, where all intermediate OAM states are present (Fig. 1b). We show that optical self-torque translates into an azimuthal frequency chirp, which allows us to quantify the EUV self-torque by an experimental measurement of the spatial HHG spectrum. The excellent agreement between our theory and experiments (Fig. 1c) confirms the creation of EUV self-torqued beams. We show that the amount of self-torque can be precisely controlled via the time delay and duration of the driving pulses. Our work not only presents and confirms an inherently new property of light beams, but also opens up a route for the study of systems with time-varying OAM. In addition, thanks to their ultrafast nature, EUV self-torqued beams can be extraordinary tools for laser-matter manipulation on attosecond time and nanometer spatial scales.

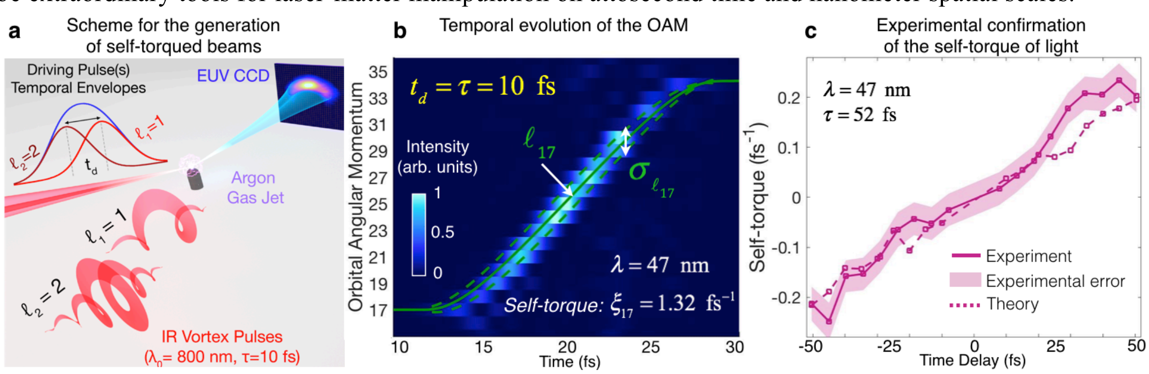

Fig. 1. (a) Scheme for the creation of self-torqued EUV pulses via HHG driven by two IR vortex beams with variable time delay, t_d. (b) Time-varying OAM of the 17th harmonic (47 nm) when HHG is driven by 10 fs drivers delayed by 10 fs. The color background shows the full quantum simulations results, whereas ℓ_{17}(solid green) is the mean OAM, whose slope is the self-torque (ξ_{17}=1.32 fs^{-1}), and $\sigma_{\ell_{17}}$ (dashed-green lines) is the width of the OAM content. (c) Theoretical (dashed line) and experimental (solid line) self-torque versus the time delay between two 52 fs drivers.

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