Shaped laser waves control quauntum dynamics in atoms and relativistic plasma dynamics.

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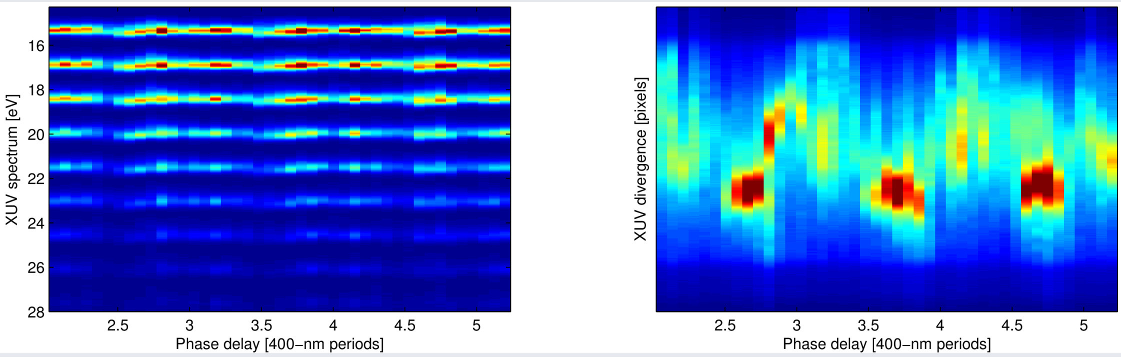
When high-energy femtosecond laser pulses are focused their electro-magnetic field becomes strong enough to tear electrons off their atoms and subsequently accelerate them along quantum trajectories. Trajectories that recollide with the parent atom may lead to the emission of a train of attosecond (~10^{-18} s) XUV pulses, two per driving laser optical cycle. Such pulses, generated in gases, are the fundamental tool of the field of attosecond science, studying the movement on bound and quais-bound electrons in quantum systems. Generating an isolated attosecond requires very short driving laser pulses, not available directly from high energy amplifiers.

Another source of attosecond pulses is created by highly energetic pulses, tightly focused onto a solid surface to orders of magnitude higher intensity. These will create a plasma in which electrons are accelerated to nearly the light velocity, and the ensuing relativistic collective dynamics of the plasma electrons lead to the emission of attosecond XUV pulses.

Both sources have in common that the dynamics are driven by the laser field cycles and can therefore be controlled by the shape of these cycles. Standard pulses from femtosecond lasers have a sinusoidal carrier wave. The combination several laser pulses with different carrier wave frequencies allows shaping the resulting optical field oscillations on the time scale of attoseconds. We have studied, both In theory and experiment, how such cycle-shaped multi-color pulses can be used to control the aforementioned dynamics. For the plasma-based attosecond pulse source, this had never been attempted at the beginning of this project.

For the gas-based attosecond pulses source, we have devised and simulated theorectically a new scheme for limiting the emission of attosecond pulses to a single event per driving laser pulse, which would allow generating an isolated attosecond XUV pulse with very energetic laser drivers of unprecedentedly long pusle duration [1]. The interference of the near infrared laser wave with a suitably tuned longer-wavelength pulse creates a beating that effectively gates the XUV emission. The addition of the second harmonic of the driving laser furhter enhances the gating and boosts the generation efficiency. The preparation of the experimental realization of this scheme is currently underway at the FAB1 beamline of the EquipEx Attolab, and is expected to convert it to France's first source of isolated attosecond pulses.



For the relativistic-plasma-based attosecond pulse source, we have conducted experiments combing pulses from the UHI laser of CEA Saclay with its second harmonic. The creation of cycle-shaped laser fields at relativistic intensity proved very challening, but finally suceed in 2017. By scanning the attosecond phase delay of the two driver-pulse components, we scan the shaped of the ultra-intense laser cycles and observe detailed oscillations of both the XUV emission (see figure) as well as the emission of accelerated electrons. While with sinusoidal driver waves, it had always been observed that both types of emission are correlated and maximized in the same conditions, it came as a surprise that the optimal optical- cycle-shape was not found to be the same for the two. Furthermore, we find a higher XUV yield with an optimized two-color driver than with the standard single-color one. Theoretical simulations are now being run that will elucidate the control mechanism for relativistic plasma dynamics behind our experimental observations.

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