# Attosecond Transient Absorption of High Order Harmonics in Helium

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**Synopsis:** We experimentally observe IR-assisted absorption of an attosecond pulse train in a helium gas target. We find that the transmitted photon yield not only modulates on the timescale of the envelope of the IR pulse but also detect oscillations with twice the fundamental laser frequency. We consider our experiment a first step to all-optical experiments in the attosecond domain.

Recently, it was demonstrated that the probability of ionization of He atoms with XUV photons close to the threshold can be controlled by the presence of a delayed IR field [1]. In that experiment, time-resolved photoelectron-spectra were recorded showing modulations with a periodicity of twice the fundamental laser frequency.

We performed a complementary experiment, detecting photons instead of electrons. We generated high harmonics in a xenon gas target with 30 fs laser pulses centered at a wavelength of 800 nm. The IR radiation was removed from the harmonics using a thin aluminum foil. The obtained harmonics (orders 13 to 19) were confirmed by RABITT to form an attosecond pulse train (data not shown). The harmonics are collinearly recombined with a time-delayed replica of the driving laser pulse using an infrared mirror with a center-hole for transmitting the harmonics. The combined beam is then focused into a second gas target by a toroidal mirror. We reach IR intensities on the order of $5 \cdot 10^{12}$ W/cm$^2$. The harmonic radiation transmitted through the second gas target is detected in a XUV spectrometer.

Helium was chosen as target medium. Its ionization potential is lower than the photon energy of harmonic order 17. Harmonic photons with order ≥17 are absorbed by single photon ionization. The density of the jet was adjusted such that about half of these photons were absorbed. Photons of harmonic 15 and below can only be absorbed in a multiphoton process. As the intensity of the harmonics is low, this is in our arrangement only possible in the presence of an additional and suitably strong IR field.

When adding the IR field and changing the delay between IR and the APT, the envelope structure is clearly visible in harmonics 13 and 15 corresponding to an IR induced absorption in helium. A typical delay scan is shown in Fig. 1. In addition to this femtosecond structure, a sub-cycle modulation of the transmission appears at a periodicity of twice the laser frequency. This modulation is visible on all harmonics, even for those with photon energy higher than the ionization potential of helium.

We experimentally show that the relative phase of this modulation does not depend on the chirp of the attosecond pulses in the train. However, the phase relation clearly changes with the intensity of the IR present in the helium target.

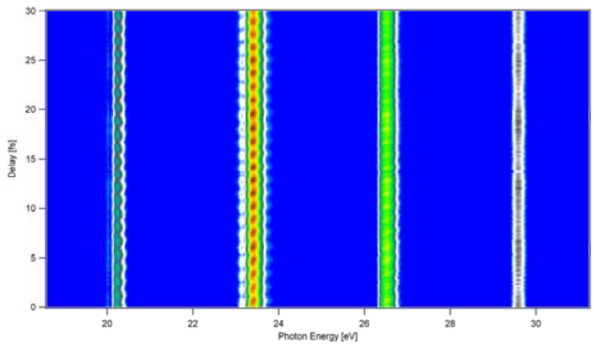


**Fig. 1.** Harmonics 13 to 19 versus IR/XUV delay.

We think that our measurement will help to gain deeper insight into ionization processes in the vicinity of the threshold. Furthermore, we consider our experiment a first step to all-optical experiments in the attosecond domain with the benefit of easier, faster, and cleaner data acquisition compared to the traditional detection of photoelectrons.

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## References

[1] P. Johnsson *et al.*, *Phys. Rev. Lett.* **99,** 233001 (2007).