MAP-fis Essay Proposal, 2016-2017

(*please write in English*)

Supervisor

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Title

High-harmonic generation dispersion-scan: a powerful new tool for attosecond science and metrology

Area

(*Materials, Optics, Condensed Matter Theory, High Energy Theory, ...*);

Ultrafast Optics; Attosecond Science

Summary of Proposal

The accurate measurement of time lies at the heart of experimental science, and is relevant to technological applications with impact in society and everyday life. Gaining access to ever shorter timescales has been the key to gaining real-time insights into microscopic phenomena, ranging from key biological processes to the dynamics underlying high technologies.

Attosecond science is a new and exciting field for the ultimate control of matter, made possible by important advances in ultrafast laser science and technology. These have enabled the real-time observation and time-domain control of atomic-scale electron dynamics with sub-atomic resolution in both space and time [1]. Behind such progress is the generation of intense and extremely short light pulses less than 5 femtoseconds long, comprising only a few oscillations of the electric field with a precisely controlled absolute phase (known as the carrier-envelope phase, or CEP). The subsequent generation of isolated extreme ultraviolet (XUV) attosecond pulses in 2001 via the process of high-harmonic generation in a gas target allowed the fastest of all motions outside the nucleus - electron dynamics in atomic systems - to be captured [2]. Since then, attosecond metrology has provided access to several hitherto immeasurably fast electron phenomena in atoms, molecules and solids, within the limit of Heisenberg's uncertainty principle. Attosecond pulses have also enabled the direct measurement of the electric field of the few-cycle intense light pulse itself, since they provide a sufficiently short gate to probe it.

So far, attosecond metrology has mostly relied on precise measurements of the energy shift experienced by photoelectrons that are ejected by the XUV attosecond pulses in a second gas target as they interact with a replica of the initial CEP-stable light pulse. This method is complex and, for

the moment, exclusive from a few laboratories in the world. Attosecond science still poses many scientific and technological challenges, from the reliable generation and measurement of CEP-stable light pulses to the detection of XUV and electronic spectra under ultra-high vacuum conditions.

In the thesis proposal, we will take advantage of the unique expertise and technological advances that have been obtained at the University of Porto and the University of Salamanca, with the purpose of enabling and performing attosecond metrology based on purely optical measurements (in the visible-NIR and the XUV ranges), which should have a great impact in the applicability and diffusion of attosecond science around the world.

In 2012, a novel and high-performance technique for the measurement and compression of ultrashort laser pulses, known as dispersion-scan (d-scan), was invented in the University of Porto, in collaboration with Lund University in Sweden [3]. With d-scan it is possible to obtain extremely short and CEP stable light pulses, with approximately 3 fs in duration, with unprecedented performance and stability [4]. In Salamanca there is extensive experience and know-how in high-harmonic generation, both from experimental and theoretical perspectives. An important model capable of describing the HHG process under extreme conditions, dubbed the Strong Field Approximation Plus (or SFA+) model [5, 6], has been developed by Salamanca (L. Plaja, C. Hernández García) and is recognized world-wide as a key tool for simulating and interpreting HHG experiments under high density conditions, which have enabled the production of harmonics up to the 5000th order, e.g., the generation of coherent radiation already in the hard x-ray region [7].

Recently, the joint efforts of the Porto and Salamanca team, based on the combination of skills and equipment from both institutions (the laser source from Porto and the HHG system and theoretical capabilities from Salamanca) have allowed us to uncover new physics in HHG, namely with the introduction of a new method for the generation of continuous XUV spectra [8] and the unveiling of a new and previously unreported phase-matching mechanism in HHG [8].

Within the essay work, the candidate is expected to be involved in the first study of the combination of d-scan and HHG models. This will then enable defining a more detailed and personalized workplan, within the scope of a doctoral thesis, which should form an important part of global workplan given below, comprising both theoretical and experimental activities.

The proposed work will be developed along the following lines and objectives:

- The key objective is to extend the concept of dispersion-scan to the process of HHG, both theoretically and experimentally. The combination of d-scan with an adequate model for the HHG process should enable retrieving both~~h the optical and~~ the XUV attosecond and optical pulses (complete with their corresponding CEP) using purely optical measurements.

Theoretical part: to join the d-scan algorithm from Porto with the HHG model from Salamanca and hence implement the first numerical HHG d-scan. The SFA+ can be applied either to the single atom response (faster to calculate, but lacking propagation effects) or to a macroscopic target, in which case the propagation is taken into account but the computational effort is significantly greater. In a first phase, we will try to get the most out of the single atom model, where at least a qualitative agreement with experiments is expected.

Experimental part: based on an experimental design, to be implemented in Porto and Salamanca, aimed at validating the new HHG d-scan technique. Ideally, in a second stage, we should attempt measure the resulting attosecond pulses using a standard technique, such as FROG CRAB or RABBITT (developed and in use by our collaborators in Lund and Imperial College), so as to be able to compare the results from both methods.

- The work will be mostly carried out at the University of Porto (femtolab laboratory, within FCUP and IFIMUP-IN) and the University of Salamanca. In a later stage, we expect to also take advantage of our existing collaborations with key institutions in HHG and attosecond science, namely Lund University and Imperial College London.

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References

(*to allow students a first look at the topic*)

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