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ERASMUS MUNDUS

euro PHOTONICS POESII International Master in Photonics

MASTER IN PHOTONICS – "PHOTONICS BCN"
ERASMUS+ "EUROPHOTONICS-POESII"

MASTER THESIS PROPOSAL

Dates: April - September 2019

Laboratory: Quantum Optics Theory group
Institution: ICFO – The Institute of Photonic Sciences
City, Country: Barcelona Spain

Title of the master thesis: Quantum-optical analysis of high-order harmonic generation

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Keywords: High-Harmonic Generation, Quantum Optics, Nonlinear Optics, Nonperturbative methods

Summary of the subject (maximum 1 page):

Nonlinear optics is the study of the interaction of light and matter in regimes when the intensity of the light is strong enough that the response of the medium's response is no longer linear. This is interesting because nonlinear terms allow for mixing between frequencies: as an example, a quadratic polarization $P = \chi E^2$ responding to an oscillatory field $E(t) = E_0 \cos(\omega t)$ will react as $P(t) = \chi E_0^2 \cos(\omega t) = \frac{1}{2}\chi E_0^2 + \frac{1}{2}\chi E_0^2 \cos(2\omega t)$, i.e. the response now contains a brand new frequency of light at 2ω, a feat which is impossible for linear processes. Moreover, this process can be seen as combining two photons of energy $\hbar\omega$ into a single, larger photon of frequency 2ω – and this can be made precise, exhibiting clear signatures on the quantum state of the produced light, which has been a subject of study of quantum optics for many years.

On the other hand, the perturbative expansion of the medium's response in the driving field as $P = \chi^{(1)}E + \chi^{(2)}E^2 + \chi^{(3)}E^3 + \cdots$ breaks down when the field is strong enough: if you drive a gas with light that is intense enough, then the exponential decay of the harmonic yield with respect to the harmonic order flattens out and gives way to a broad plateau of high-order harmonics that can easily reach harmonic orders in the tens or hundreds, or even thousands. Here the perturbative picture must be abandoned completely, to be replaced with what's known as the Three-Step Model [1]: the laser field is seen as a slowly-oscillating linear potential, which releases an atomic electron to the continuum, accelerates it as the field oscillates, and then drives it back to its parent ion, where it recombines and emits its now sizable kinetic energy as high-frequency radiation.

Until recently, HHG has been treated as a completely classical phenomenon on the side of the radiation, with the driving field seen as an externally-imposed classical potential, and this works well as we're primarily interested in the emitted harmonics. However, recent work [2] has shown that it is indeed possible to study HHG when the driving laser is granted full quantum-mechanical status, and that the result does have physical consequences in the photon statistics of the driver – essentially, one can see direct signatures of the driver photons that were removed by the process [3].

Your project will be to analyse the physics of the quantized-driver solution, as the basic theory is largely soluble but the current solutions do not offer much insight into the physical meaning of its constituent parts. Similarly, you will extend the existing solution to non-monochromatic cases that more accurately describe the pulsed lasers in use. On a longer-term view, you will study entanglement between the driver and the medium, and look for experimental signatures of that entanglement – as well as any other interesting physics that comes up in this brand-new field, non-perturbative non-linear quantum optics.

1. P. Corkum and F. Krausz. *Nat. Phys*. **3**, p. 381 (2007).
2. I. A. Gonoskov et al. *Sci. Rep*. **6**, p. 32 821 (2016).
3. N. Tsatrafyllis et al. *Nat. Commun*. **8**, p. 15 170 (2017).

Additional information:
* Required skills: Familiarity with analytical methods and quantum optics; exposure to strong-field physics and high-harmonic generation is an added bonus.
* Miscellaneous: