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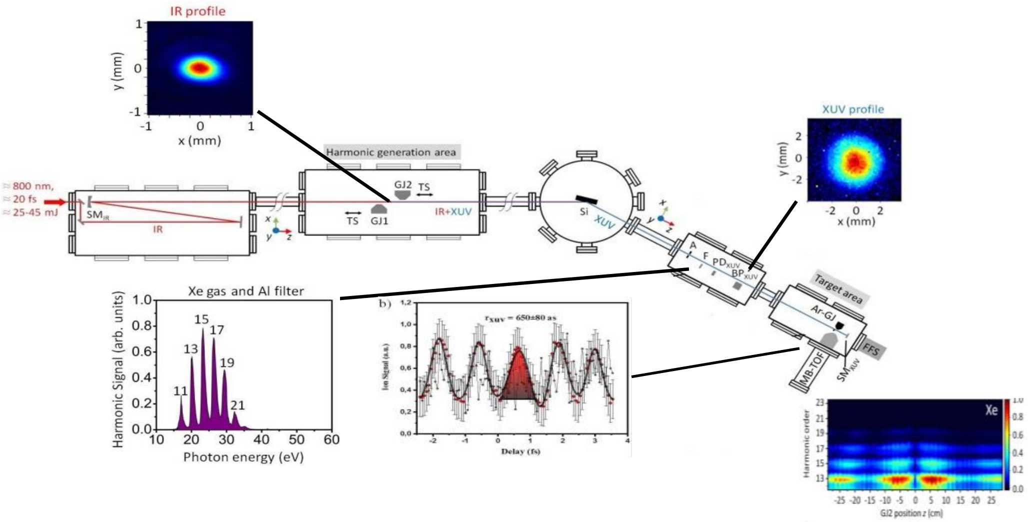
Description of the funded research project

1st Call for H.F.R.I. Research Projects to Support Faculty Members & Researchers and Procure High-Value Research Equipment

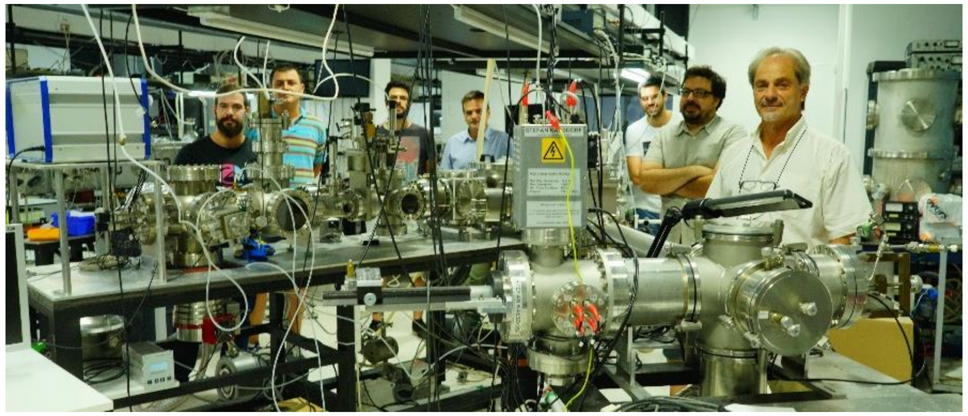
Title of the research project: <u>N</u>onlinear <u>E</u>UV <u>A</u>pplications with <u>A</u>ttosecond <u>P</u>ulse<u>S</u>



Principal Investigator: Prof. Dimitrios Charalambidis

Reader-friendly title: NEA-APS

Scientific Area: Physical Sciences



Institution and Country: FO.R.T.H., Greece

Host Institution: FO.R.T.H.

Collaborating Institution(s):
Univ. Autónoma de Madrid, Univ. College Dublin, Univ. College London, Max Planck f. Kernphysik, ELI-ALPS, Univ. of Bourgogne, Univ. of Göttingen and Univ. of Freiburg.

Budget: 199.980,00 Euro

Duration: 36 months

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Research Project Synopsis

NEA-APS inaugurates the topic of highly non-linear EUV optics at sub-fs temporal scales and exploits lower order non-linear EUV processes in investigating ultrafast dynamics in atoms and molecules. It capitalizes on the capacities of the Attosecond Science and Technology Laboratory (AST-Lab) of FORTH-IESL, currently offering globally unique specs with respect to achievable EUV pulse energies (few hundreds of μJ) at sub-fs pulse durations. It further highlights the scientific case of this central laboratory of the, currently under implementation, National Research Infrastructure HELLAS-CH. Highly non-linear EUV studies address: multiple ionization of rare gases through several-EUV-photon absorption, as well as EUV radiation induced ponderomotive shifts and their exploitation in e.g. a new approach of attosecond pulse metrology. Studies of ultrafast dynamics in atoms and small molecules (H_2, O_2) concern advanced revisits of previous EUV-pump-EUV-probe experiments of the team, applying CEP tagging and using shorter pulses, allowing to reveal hidden information of the previous experiments, such as pulse durations of isolated attosecond pulses, characteristic times of molecular electronic coherences in H_2 and dynamics in the Schumann-Runge continuum of O_2. Additional targets of the project are the photoelectron spectra of He direct double ionization, atomic coherence dynamics in atomic (He and other rare gases) even parity autoionizing manifolds, measurement of autoionization (Fano) phases through quantum interferometric methods involving solely EUV radiation and HCCH $\rightarrow$ CCHH isomerization dynamics.

In the last phase of the project, when the required equipment will become operational at the European research infrastructure ELI, advanced versions of some of the above experiments will be implemented in campaigns at ELI-ALPS, exploiting its high repetition rates in ion-electron and electron-electron coincidence measurements using the relevant reaction microscope end-stations of the infrastructure.

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Project originality

Starting from the uncertainty principle, one easily recognizes that spatial confinement down to the atomic/molecular dimensions translates to characteristic times of motion of the order of 100 attoseconds (1 atto = 10^{-18}) to few fs. Indeed electronic motion in atoms molecules and solids, have typical characteristic times ranging from 1 asec to few fs. Typical molecular vibrational periods range from hundreds to tens of fs, while coupled electron-nuclei motion as well adiabatic molecular motion through e.g. conical intersections is as fast as few fs to several tens of fs. The investigation of such dynamics seeks for pulses with sub-fs/attosecond duration. Attosecond pulses made their debut two decades ago exploiting the process of Higher Harmonic Generation (HHG).

Despite the successful application of combined IR and EUV pulses in pump-probe experiments targeting such ultra-fast dynamics, the IR pulse is often strongly perturbing the potential of the system under investigation, thus modifying its inherent dynamics. It order to access the actual system dynamics “EUV-pump-EUV-probe” approaches are necessary using EUV sources intense enough to induce non-linear EUV processes but not too intense as to perturb the system. In most of the attosecond labs such experiments were not feasible because of the lack of high enough EUV intensities. While short wavelength Free Electron Lasers (FEL) provide pulse energies high enough for EUV-pump-EUV-probe studies, their pulse duration is still longer than that of table top laser driven attosecond sources, a limiting factor in terms of temporal resolution. This is exactly the motivation and novelty of NEA-APS, namely the study of ultrafast dynamics in a number of representative systems, implementing EUV-pump-EUV-probe experiments with attosecond temporal resolution. The research is enabled by the recently upgraded AST Lab that led to the world record of HHG pulse energies of the order of hundreds of μJ and intensities $>10^{15}$ W/cm^2.

Expected results & Research Project Impact

The long standing and for several years positively evaluated operation of the attosecond Science & Technology Lab evidences that the research work carried out in it regularly and often leads to:

1) high-profile publications and invitations to major scientific events enhancing the international visibility of the Lab and the hosting institution
2) attraction of new resources that ensure sustainability of the operation of the laboratory and its activities
3) development of new methods and products that are exploited e.g. through R&D contracts with advanced research infrastructures, indicative of a rather advanced technology readiness level
4) advanced access opportunities to international and national users of the research infrastructure in which the laboratory participates in
5) training of young scientists, several of whom are pursuing successful careers
6) providing an international research environment that facilitates attraction of high level researchers from abroad, repatriation of specialized scientific human potential and an active role in international research developments and policies.

This project will further contribute to all of the above.

The importance of this funding

The establishment of H.F.R.I. in 2017 was a unique reform in Research and Innovation in Greece. It is the first time that the country has an institution which is funding research at different levels of scientific careers and extending from curiosity driven research to the creation and operation of start-ups exploiting research results. With H.F.R.I. we scientist are offered for the first time, on national level, a tool enabling innovative research and training through research as does ERC in Europe, NSF in the US or DFG in Germany to give few examples out of the many existing ones worldwide.

In this context, the present project supplements the funding of the research activities of our team, supports advanced training of several early stage researchers (PhD students and post-doctoral fellows) and facilitates the continuation of the long standing successful research accomplishments of our laboratory. On a personal basis, it supplements the incentives for remaining active as professor emeritus.

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