CEA - Saclay

SACLAY

FRANCE

Address

Laboratory Interactions, Dynamics and Lasers (LIDyL)
CEA-Saclay, Université Paris-Saclay
91191 Gif-sur-Yvette – France

General Contact

http://iramis.cea.fr/LIDyL/en/
caroline.lebe@cea.fr

Scientist in charge

Pascal Salières
+33 1 69 08 63 39
pascal.salieres@cea.fr

Useful Links

www.medea-horizon2020.eu
www-centre-saclay.cea.fr/en
www.cea.fr/english-portal
www.universite-paris-saclay.fr/en
www.paris-touristoffice.com/
www.paris.fr/
www.linkedin.com/grp/home?gid=8277773

DE LA RECHERCHE À L'INDUSTRIE
cea

LIDYL

MEDEA
Molecular Electron Dynamics investigated by Intense Fields and Attosecond Pulses

This project has received funding from the European Union's **Horizon 2020** research and innovation programme under the Marie Skłodowska-Curie grant agreement No 641789.

Home institution

With 6000 people of which ~600 PhD students, CEA-Saclay is the largest center of CEA, the French Alternative Energies and Atomic Energy Commission (Commissariat à l'énergie atomique et aux énergies alternatives). CEA is a public body established in October 1945 by General de Gaulle, and a leader in research, development and innovation. CEA-Saclay covers a wide range of research activities, from physical and life sciences,to climate and environment, nuclear and technological research but also education. The highly scientific and multi-disciplinary nature of research contributes to the diversity and richness of CEA-Saclay. The many programmes of national, European and international research in which it is involved, and the multitude of contacts it has made with regional industry demonstrate its dynamism and its openness to the outside world.

CEA-Saclay is located within one of the largest concentrations of public scientific institutions, academic bodies as well as private company labs in France. The research environment in physics, from particle physics to physical chemistry, includes several CEA and CNRS units, labs in the academic institutions such as University of Paris-Sud and engineering schools (Ecole Polytechnique, Ecole Nationale Supérieure des Techniques Avancées, Institute of Optics Graduate School, etc.), as well as large scale facilities such as SOLEIL synchrotron radiation and laser labs LULI, LOA, APOLLON and ATTOLAB. The "physicists" population represents about 2500 permanent researchers and as many non permanents.

This so-called "Plateau de Saclay" and its surroundings is an attractive area, mixing high tech science and open green fields, urban resources and charming villages in wooden valleys, all this within a 30' train connection to Paris. **Université Paris-Saclay (**www.universite-paris-saclay.fr/en) is now bringing together 19 varied but complementary institutions: 2 universities, 11 prestigious university-level colleges and 7 research organizations (including CEA-Saclay) for establishing as a major scientific pole in Europe. This favours convergence between the different scientific fields, institutions and labs, basic research and R&D, academic and industry. Within the ten forthcoming years, it promises to deeply and positively transform the Saclay area, an already pleasant one to work and to live in, preserving – we all hope – its natural character. The young researchers of the Plateau de Saclay may either prefer the innumerable resources of Paris or the country side surroundings of the labs depending on personalities

Group leader

Name: Pascal Salières
Nationality: French
Date of birth: 23 June 1967

Short CV:

1991: Diploma of Engineer of ESPCI, Paris

1995: PhD in Physics, Pierre and Marie Curie University - Paris

2005: Habilitation, Paris-Sud University - Orsay

Current position: Program leader in Attosecond Science, Laboratory Interactions, Dynamics and Lasers, CEA-Saclay.

When I started my PhD on high-order harmonic generation with Anne L'Huillier in Saclay in 1992, the field was brand new (there was not even an interpretation for this spectacular process) and very challenging! Things went fast from the very beginning: one month later I was performing experiments in Lund (Sweden) on the "cutoff rule", and 6 months later I settled for one year in Livermore, California. Under the invitation by the National Laboratory, we performed a series of experiments ranging from fundamental studies of the HHG process (ellipticity dependence, spatial profiles) to the first attempt ever to use it as a source in atomic spectroscopy. This was successful behind our expectations since we used up to the 69th harmonic (100 eV!) but led to a massive disappointment when the paper bounced back from a "high-impact factor" journal. This taught me that you should never take for granted that people understand the importance of what you are doing ☺. This stay in Livermore was an extraordinary experience, both scientific and personal: the lab hosted the most energetic laser in the world and the environment offered everything one could dream of.

Back in France, after two years of continuous experimental work, I turned to simulations to understand all these results. I had the unique opportunity to work simultaneously with Maciek Lewenstein, invited scientist (and soon hired by Saclay), and Anne L'Huillier, and benefited much from these two giants of our field. Studying the interplay between the microscopic and macroscopic responses, I discovered the importance of the dipole phase in determining the spatial and temporal coherence of the harmonic beam. These phase effects have now become central in the field and, with less pride than real satisfaction, I would advise students: "Look at the phase!"

After my PhD defense in 1995, I was appointed by Saclay on a full researcher position to continue this promising research together with Bertrand Carré (Anne L'Huillier leaving for Lund). After optimizing the conversion efficiency up to the microjoule level, we performed a number of characterization and application experiments (such as XUV interferometry for plasma diagnostic) and in parallel, pushed theoretical investigations towards the emerging field of Attophysics. With Philippe Antoine, we studied how attosecond pulses could be generated in a macroscopic medium, and the dipole phase, again, turned out to be a key element. We also performed a series of investigations to identify and control the different quantum-path contributions.

When Pierre Agostini (at that time in Saclay) and Harm Muller measured the first attosecond pulses in Palaiseau in 2001, I soon proposed them to investigate attosecond pulse generation over a much broader spectral bandwidth, as allowed by the Saclay harmonic beamline, developed and optimized over the years together with Hamed Merdji. This led us to the discovery of the atto-chirp in 2003. This atto-chirp is still today the limiting factor for the duration of the attosecond pulses: if compensated, we could generate close to zeptosecond pulses! This also started an exciting series of experiments that extends up to now where we use characterized and optimized attosecond pulses to investigate ultrafast electronic and nuclear dynamics in matter.

Recently, we generated attosecond pulses in aligned molecules with Thierry Ruchon. This turned out to be extremely fruitful since this allows not only a coherent control of the attosecond emission but also a reconstruction of the radiating orbital by quantum tomography. With the latter, in collaboration with theorists at LCPMR-Paris, we demonstrated that it is indeed possible to combine Angström-spatial resolution with attosecond temporal resolution. This opens wide perspectives for this high harmonic spectroscopy.

In parallel, we performed photoionization spectroscopy, e.g., measuring the molecular-frame electron angular distribution to fully characterize the harmonic polarization, with ISMO-Orsay; the painfully-long acquisition times for these coincidence measurements were worth it since they evidenced for the first time a depolarization in the emission. We also investigated with UAM-Madrid resonant ionization with attosecond resolution allowing us to see, in real time, the buildup of a Fano resonance! All these results are opening exciting perspectives!

The above-mentioned achievements are the result of a remarkable team work between the permanent researchers and the students and postdocs, who were the driving force and brought their enthusiasm: Laurent Le Déroff, Jean-François Hergott, Milutin Kovacev, Yann Mairesse, Armelle de Bohan, Marco De Grazia, Willem Boutu, Stefan Haessler, Zsolt Diveki, Antoine Camper, Nan Lin, Bastian Manschwetus, Vincent Gruson, Sébastien Weber, Lou Barreau; many of them are today key players in our field!

Offered training

Research Training Modules (RTMs)

A. Two-source interferometry of high harmonics (see next pages for details)

B. Electron interferometry - RABBIT (see next pages for details)

C. Weveform synthesis for isolated attosecond pulse generation (see next pages for details)

Scientific Courses at Université Paris Saclay

Master courses at Paris-Saclay University can be followed by students wishing to complement their expertise in different fields. The most appropriate time would be January-February where “options” are taught. One “option” corresponds to 7 courses (one per week) of 3 hours each.

In the Master ‘Laser-Optics-Matter’, a number of different topics are available, ranging from Advanced Photonics and Extreme optics to Generation of ultrashort pulses and Laser-plasma interaction. High harmonic and attosecond pulse generation in gases and on solid targets is taught in some options. A list can be found at:

https://www.universite-paris-saclay.fr/en/node/4964#programmes

Transferable skills Modules (TSMs)

General training on transferable skills is offered by INSTN. Part of the CEA, the National Institute for Nuclear Science and Technology (INSTN) is a higher education institution providing high-tech instruction and acting as an interface between research bodies, universities and industry. Sessions developing non-scientific skills are, for instance:

- two continuous training for PhDs and post-docs called ‘Innovation management in enterprise’ and ‘ Knowledge of enterprises and surroundings’

- One session devoted to ‘Managing a scientific project’

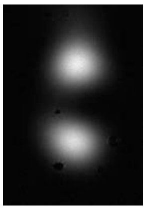
- One session devoted to post-docs called ‘post-doc, how to manage a career, evaluation project, action’

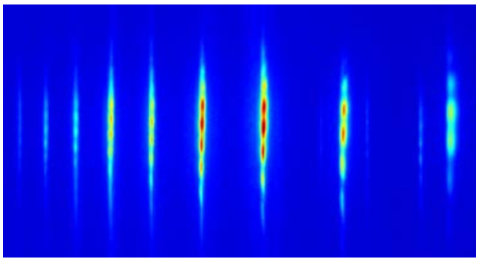
- Courses on French language and culture (also at Alliance Française).

Such sessions are held a few times per year and last from 2 to 4 days. For detailed information:

http://www-instn.cea.fr/formations/formation-par-la-recherche/formations-complementaires-et-insertion-professionnelle.html

A. Two-Source Interferometry of high harmonics





Objective

The goal of the RTM is to perform 2-source interferometry of high harmonics; this implies generating high harmonics in a gas jet using a phase-shaped laser beam. A 0-π phase plate converts the Gaussian mode of the laser to a TEM_{01}, thus creating two bright spots at focus that produce synchronized high harmonic beams that interfere in the far-field. Different phase plates can be used to extend the method from 800 nm to mid-IR light generated by an Optical Parametric Amplifier. This technique provides an extremely stable and robust tool to perform harmonic phase measurements via two-source interferometry when one source is perturbed (e.g. rotational/vibrational excitation) and the other source is used as a reference.

Equipment

Optical mounts	Broadband mirrors	Optical Parametric Amplifier (OPA)
Alignment irises	Beam splitters	Acquisition software
Beam attenuators	Translation stages	Desktop PC
CCD cameras	Mid-IR spectrometer	Personal protection devices
Lenses	Micro Channel Plates + Phosphor screen	0-π phase plates @800nm, 1350nm, 1800nm
Translation stages	Noble gases, N_2(g), CO_2(g)	XUV grating

Implementation

The training will have a series of intermediate milestones and objectives:

- High harmonics generation in gases with 800 nm driving laser
- High harmonics generation in gases with mid-IR (1200-2000 nm) driving field
- Imaging of the IR and mid-IR foci of the phase-shaped beams
- High harmonic generation with phase-shaped laser beams at different wavelengths
- Design of an interferometer to align or excite selectively one harmonic source
- Harmonic phase measurement with two-source interferometry in aligned or excited systems

Duration

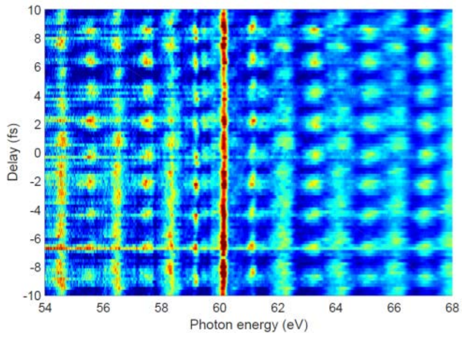
For the complete experiments a period of three weeks is planned. During this time the ESR will be involved mostly in the preparation of the experimental apparatus and in the data acquisition. The completion of the RTM will require a part of data analysis.

The period for the participation to the RTMs should be agreed upon with the tutors.

RTM at a glance

Title	*Host institution*	*Objective*	*Duration/ Period*	*Tutors*
Two-Source Interferometry	**CEA-Saclay**	High Harmonic Generation with phase-shaped laser beams *experimental activity*	3 weeks / to be discussed	Lou Barreau lou.barreau@cea.fr Pascal Salières pascal.salieres@cea.fr

B. Electron Interferometry (RABBIT)



Objective

The goal of the RTM is the design and implementation of an achromatic interferometer to perform RABBIT phase measurements in IR and mid-IR. 800 nm light can be directly used, or converted to mid-IR wavelengths with an optical parametric amplifier, to generate high harmonics in a gas jet. The produced attosecond XUV light is focused on a gas target together with the fundamental field inside a time of flight electron spectrometer (TOF-MBES). Electron interferences are analyzed either to characterize the attosecond pulse trains or to investigate photoionization dynamics in the target.

Equipment

Optical mounts	Broadband mirrors	Optical Parametric Amplifier (OPA)
Alignment irises	Beam splitters	Acquisition software
Beam attenuators	Translation stages	Desktop PC
CCD cameras	Piezo actuators	Personal protection devices
Lenses	Time of Flight – Magnetic Bottle Electron Spectrometer (TOF-MBES)	Toroidal gold mirror
Photodiodes	Noble gases, N_2(g), CO_2(g)	Hole mirrors

Implementation

The training will have a series of intermediate milestones and objectives:

- High harmonic generation in gases with 800 nm driving laser
- High harmonic generation in gases with mid-IR (1200-2000 nm) driving field
- Detection of electrons in the TOF-MBES
- Design and implementation of the RABBIT achromatic interferometer
- Spatio-temporal overlap between the harmonics and the (mid-) IR dressing field
- RABBIT phase measurements on HHG from aligned molecules and/or after photoionization close to a resonance

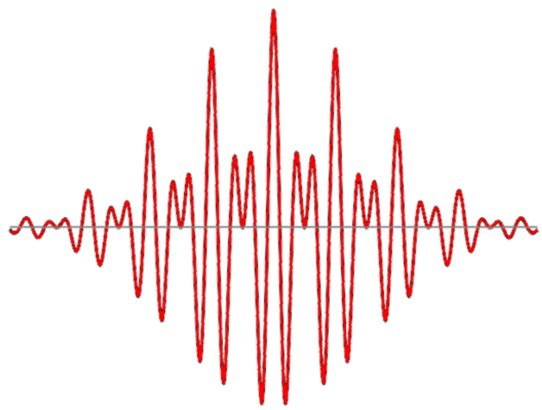
Duration

For the complete experiments a period of three weeks is planned. During this time the ESR will be involved mostly in the preparation of the experimental apparatus and in the data acquisition and analysis.

RTM at a glance

Title	***Host institution***	***Objective***	***Duration/ Period***	***Tutors***
Electron Interferometry (RABBIT)	**CEA-Saclay**	Design and implementation of an achromatic interferometer for RABBIT phase measurements *experimental activity*	3 weeks /to be discussed	Lou Barreau lou.barreau@cea.fr Pascal Salières pascal.salieres@cea.fr

C. Waveform Synthesis for Isolated Attosecond pulse Generation



25 fs, 800 nm + 25 fs, 1200 nm

Objective

The goal of the RTM is the implementation of a stable delay line for the synthesis of two-color pulses. A 800nm 25 fs pulse will be combined with a 1200 nm pulse generated by an Optical Parametric Amplifier (OPA). An active control will be integrated to stabilize the final pulse.

This type of two-color waveform synthesis can be used as a temporal gating for the generation of isolated attosecond pulses in High Harmonic Generation (HHG) experiments.

Equipment

The ESRs will be provided with all optical components for the two-color pulse synthesis:

Optical mounts	Broadband plane and focusing mirrors	Auxiliary laser for alignment and control loop
Alignment irises	Beam splitters	Desktop PC
Mirrors	Translation stages	Photodiodes
OPA	Personal protection devices	Piezo actuators

Implementation

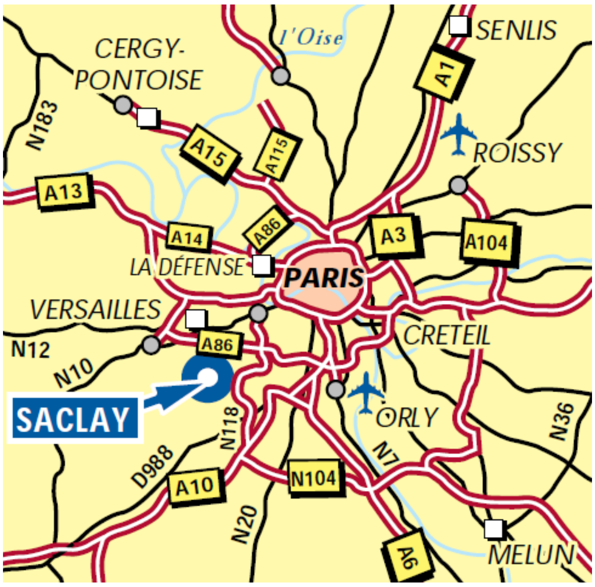
- Introduction to the waveform synthesis principle and to temporal gating for HHG
- Design of the optical setup for the delay line (spatial and temporal superposition)
- Set up and alignment of the auxiliary laser
- Control and stabilization of the delay line
- Evaluation of the residual time jittering
- Measurement of the energy of the combined pulses

Duration

For the complete experiments a period of four weeks is planned. During this time the ESR will be involved mostly in the preparation of the experimental apparatus, measurements and results analysis. The period for the participation to the RTMs should be agreed upon with the tutors.

RTM at a glance

Title	*Host institution*	*Objective*	*Duration/ Period*	*Tutors*
Waveform synthesis for isolated attosecond pulses generation	**CEA**	Implementation of a delay line for two-color pulse synthesis	4 weeks /to be discussed	Margherita Turconi margherita.turconi@cea.fr Pascal Salières pascal.salieres@cea.fr



About life in Paris

The CEA-Saclay is located on the Paris-Saclay University campus, 25 km from the center of Paris. Convenient public transportation (www.ratp.fr available in different languages) goes from the CEA research center to the heart of the "City of Light" in less than 1h.

The Paris Tourist Information Office is available at the following link:

http://www.paris-touristoffice.com/

You will also find information on the Paris City Hall (mairie) site:

http://www.paris.fr/

For a weather report, please consult:

http://www.meteo.fr/