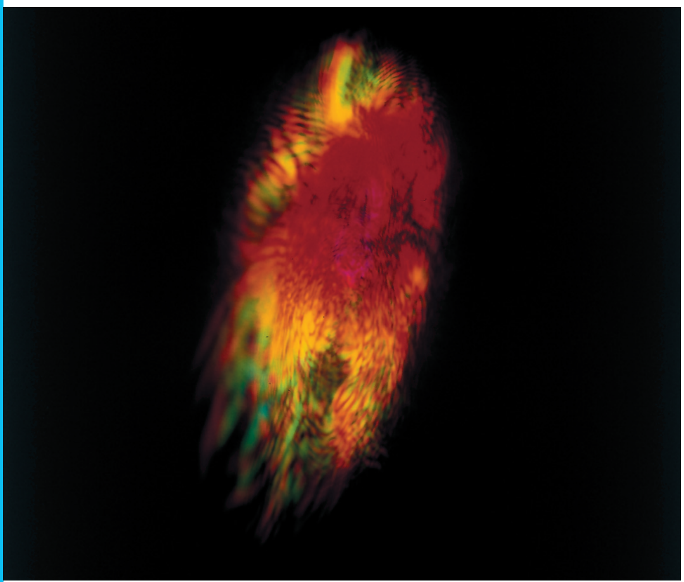
The recent development of high power lasers delivering pulses of intensity up to 10^{19} W cm^{-2} has created the potential for a variety of new activities. These include the study of ultra-fast processes and the investigation of the properties of atoms, molecules, plasmas and condensed matter interacting with superintense laser fields. There are also potentially exciting long term applications, notably in developing high-frequency lasers by using harmonic generation, and in inertial confinement fusion (ICF), making use of a new concept based on fast ignition, in which the compression and ignition phases in laser driven ICF are separated.

Interaction of Superintense, Femtosecond Laser Fields with Atoms, Solids and Plasmas (FEMTO)

An ESF scientific programme



The aim of this programme is to study the physics of matter interacting with super-intense femtosecond laser pulses, and consolidate the world lead Europe already has in this fast growing research field. Leading groups from seven European countries combine their forces to focus on the following areas at the forefront of this domain:
Multiphoton ionisation of atoms in strong laser fields; Dynamics of small molecules in intense laser fields; New physical mechanisms and novel applications in high-order harmonic generation; Generation of pulses in the attosecond (10^{-18}s) range; Relativistic effects in laser-atom and laser-plasma interactions; Physics related to the "fast ignitor" approach to ICF; Study of exotic states of matter for basic physics and astrophysics.

The European Science Foundation acts as a catalyst for the development of science by bringing together leading scientists and funding agencies to debate, plan and implement pan-European initiatives.

Aims and objectives

The ESF Programme covers the main areas of growth in the research domain of superintense laser fields, including the following seven overlapping research objectives:

1) Multiphoton ionisation of atoms in strong laser fields

This is one of the central themes of high intensity laser-atom physics, and therefore research in this domain will be relevant for some of the others. Significant progress has already been made in understanding this phenomenon in the case of atoms, such as hydrogen, with a single active electron, and also larger atoms with just one electron in their outer shell. But the much more complex processes involving two or more electrons are still poorly understood and will clearly require correlation methods to explain them. The aim is to focus on the least complex multiple electron systems, at least to start with, which means He, and atoms with two electrons in their outer shell, such as those of the alkaline-earth elements. In these atoms the double ionisation process will be studied, and also the influence of electron correlations on other important phenomena such as the stabilisation of atoms and ions at ultra-high intensities when they become resistant to the ionisation process. Such effects, which seem surprising, can be explained by the strongly modified atomic structure caused by the intense laser field. This had already been predicted for single electron atoms, and it is likely that the added complexity of multi-electron atoms will give rise to other undiscovered phenomena.

Laser plasma created by focusing an ultrashort (100 fs) and powerful (1 TW) pulse from the Titanium: Saphire laser LUCA at Saclay on a solid metallic target. The light (X-ray to visible) is produced by hot electron to highly stripped ion recombination and bremsstrahlung.

2) Dynamics of small molecules in intense laser fields

The ability to generate ultra-short laser pulses makes it possible to probe molecules and investigate the dynamics of the processes. Several such strong field processes, such as bond-softening and alignment along the direction of light polarisation, have been observed and analysed. Within the ESF programme, we plan to go deeper and conduct both experimental and theoretical investigations into the non-perturbative interplay between the nuclear and electronic motions in molecular systems exposed to intense femtosecond laser pulses. This will enable the programme to address open questions concerning the detailed dynamics of molecular decay, the influence of the initial state on the interaction process, and the role played by quasi-stable vibrational states that are induced by light.

Within this part of the programme, we also plan to study how by coherent control of the molecular dynamics, tuned output light and energy-selective fragments can be produced. Here we will concentrate on small molecular systems such as H_2, H_2^+, and their isotopomers, as well as N_2, ICl and HCl, with particular focus on the hydrogen molecule, and molecular ion. We will perform numerical calculations for coupled electronic and nuclear motions where molecular hydrogen interacts with strong femtosecond laser pulses. We hope as a result to gain a thorough theoretical understanding both of past and planned future experimental work.

3) New physical mechanisms and novel applications for high order harmonic generation

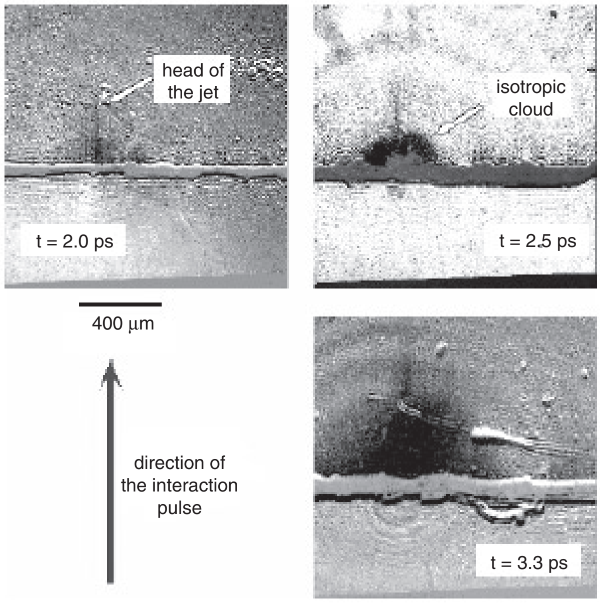
Atoms in an intense laser field emit light in harmonic frequencies of the driving field with very interesting properties. The radiation is highly intense, with short pulse duration and both temporal and spatial coherence. Although progress has been made in understanding the fundamental physical processes involved, much work remains to be done to characterise and also to optimise the radiation.

We are investigating new ways of generating harmonics efficiently by controlling the interaction between the driving field and the atoms, using bichromatic laser pulses and new media. We also intend to develop new applications of high harmonic radiation, exploiting its unique properties of high intensity, extremely narrow pulse width, and its coherence. For example we want to use harmonics to study multiphoton processes in the XUV range, and develop XUV interferometric techniques for probing high-density plasmas.

4) Generation of pulses in the attosecond (10^{-18} s) range

The generation of pulses of attosecond duration opens the door to investigation of electronic phenomena that occur at these very short time scales. This is the next step on from femtochemistry, which exploits femtosecond (10^{-15}s) pulses to probe the dynamics of nuclear motions in molecules.

While the production of pulses of attosecond duration has been theoretically predicted, experiments involving the macroscopic response have not yet been performed. This programme will conduct such experiments, and demonstrate the potential of attosecond pulses for the investigation of extremely fast physical processes such as ionisation dynamics.



Time-resolved observation of ultra-high intensity laser-produced electron jets propagating through transparent solid targets, L.Gremillet, et al. *Physical Review Letters, vol. 83, N.24, pp. 5015-5019,1999).*

5) Relativistic effects in laser-atom and laser-plasma interactions

Modern lasers are already capable of producing such high intensities that relativistic theory will be needed to analyse their interactions with matter. Within this programme, two classes of relativistic processes will be studied with the aim of providing a theoretical description of each. The first class of processes arises from the fact that in an ultra strong laser field, an electron can experience significant relativistic effects as its ponderomotive energy becomes comparable to its rest energy. We will study the influence of these effects on the stabilisation of atoms and emission of high order harmonics.

The second class of processes results from the recent advent of coherent X-ray radiation produced either from X-ray devices, or high-order harmonics. This makes it possible for the first time to observe multiphoton processes involving the inner-shells of heavy atoms or ions. This will complement and elaborate on existing numerical simulations of these inner shell processes and help in the development of more realistic computer models.

In laser-plasma interactions the use of short-pulse ultra-high-intensity lasers allows the production of relativistic electrons and ions and of hard photons. It also leads to collective phenomena such as the formation of relativistic electron jets which propagate in a stable way in dense matter, carrying electron currents exceeding the Alfven limit by many orders of magnitude.

6) Physics related to the "fast ignitor" approach to inertial confinement fusion (ICF).

ICF exploits the inertia of a pellet of fusion fuel, comprising deuterium and tritium, to compress it for ignition. With the standard method, the same nanosecond lasers that achieve the compression also perform the ignition, which occurs when heating in the pellet, caused by energy created by fusion, exceeds the energy applied to it. The fast ignitor approach differs by using a separate pulse of ultra short high energy laser light for the ignition, which occurs locally within the pellet and then spreads through it. This has several advantages over the conventional approach to ICF, the main one being that it allows efficient coupling between the laser light and the electrons in a particular energy range, and in turn with the highly energetic ions needed to initiate a burn. This has enormous potential cost and efficiency savings. Within the present programme, we will focus first on the generation of high energy electrons from the interaction of intense femtosecond lasers with solid density targets and with preformed plasmas. The effect of different temperature and density plasma profiles on the generation of relativistic electrons is also an important aspect which is under study in the framework of this programme.

We will also study the penetration of hot electrons in solid matter which has been compressed with shock waves driven by high-energy nanoseconds laser beams.

7) Study of exotic states of matter for basic physics and astrophysics

The availability of high energy femtosecond lasers allows the physics of matter to be studied under extreme conditions, at an intermediate state between the ideal plasma and cold solid. At this intermediate state, the motion of electrons is influenced not just by the closest ion, as in an ideal plasma, but by other ions, as there is some long distance order. This leads to changes in the macroscopic parametres of the material, such as reflectivity, and both thermal and electrical conductivity. The short duration of the laser pulse that generates the heat allows the time evolution of the system to be studied. These experiments are complementary to those performed using shocks created by nanosecond pulses, and increase the range of measurable parameters. Such experiments are important to bridge the gap between solids and plasmas and build a complete theory of matter. Such understanding will be invaluable in astrophysics and planetology, given that these intermediate states of matter are found inside the largest planets and in both brown and white dwarf stars.

Some experiments have already been performed with gas-guns or with laser driven shock waves, and unexpected results have been obtained. Using femtosecond laser systems, other regimes can be investigated. Furthermore, ultra-strong magnetic fields are expected to develop in plasmas subject to femtosecond laser fields, and these would be comparable with those obtained in astrophysical bodies such as white dwarfs.

The ESF programme

Europe has a world lead in the study of matter interaction with super-intense femtosecond laser fields. Many teams involved have already worked together within the context of bilateral agreements between ESF Member Organisations, such as CNRS, the FNRS, and the EPSRC.

The present ESF programme will involve many of these teams and contribute to maintaining the European lead by building upon existing research links and creating larger scale collaborations. In particular, the ESF funding will be invaluable in encouraging young researchers in the field by making it easier for them to access this fast growing domain via short and longer visits to a variety of research establishments.

The European Community has expressed particular interest in this field by creating a cluster of EC Large Scale Facilities devoted to the study of laser-matter interactions. Several groups participating in this ESF programme belong to this cluster, so that there will be plenty of synergy to exploit. The EC has funded a programme called EC Training and Mobility of Researchers to provide access to these large facilities.

The ESF has organised activities within the programme in four categories as follows:

- **Individual short scientific visits**

These allow both young and senior researchers to spend about one week with other teams in the Network to exchange ideas and foster joint publications.

- **Short fellowships for young researchers**

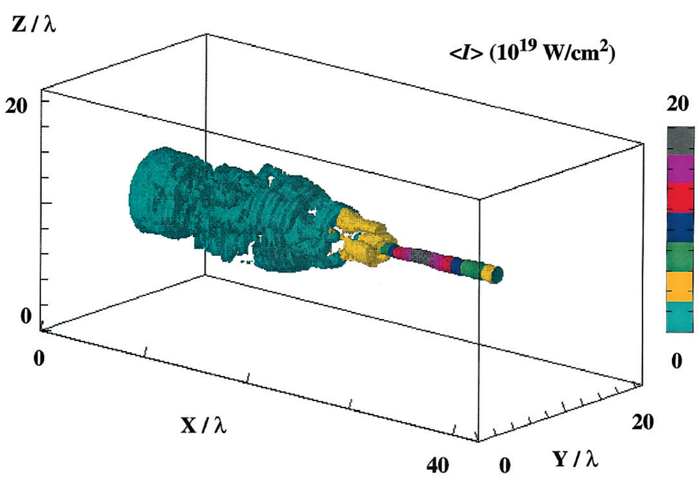
Fellowships will be given allowing pre or post doctoral researchers to work for about one month with teams in the programme. This will allow young researchers to acquire knowledge and experience, as well as develop fruitful collaborations that will encourage them to pursue their careers in European science.

- **Meetings of working parties and topical workshops**

A number of workshops focused on particular themes will be organised. New results will be presented and discussed, and joint projects will be stimulated.

- **Conferences** will be organised involving all the scientists in the programme. These conferences will help scientists in the Network to keep up with all the research and ensure that cross fertilisation occurs between the various research areas.

3D view of a laser beam penetrating and self-focusing in the plasma.
© J. Meyer-ter-Vehn, Germany



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For the latest information on this programme consult the FEMTO home page: *www.esf.org/femto*

Cover picture: An intense laser beam changes a homogeneous medium into a convergent lens and spontaneously concentrate itself (self-focusing phenomenon). At the same time new wavelengths are created and propagate in preferred directions, forming rings. Above a certain intensity the medium is ionised and gives rise to irregular color distributions. Here, a section of an intense infrared beam after propagation through a few centimeters of air is shown. © Antoine Gonin/CEA

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