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X and XUV spectroscopy of ps laser-produced Al and C plasmas

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X-ray spectroscopy plays a key role in the domain of laser-generated plasmas as a crucial tool for the investigation of their atomic properties and hydrodynamic evolution. Its role is essential when the evolution of the plasma is mostly determined by radiative transfer phenomena. This is the case for both direct and indirect-drive in Inertial Confinement Fusion (ICF) configurations.

Reliable atomic models are needed for hydrodynamic and atomic kinetic codes to simulate the evolution of the plasma. To validate their assumptions and approximations, experimental data must be provided that cover both the emission spectrum and the hydrodynamic evolution with mutually independent diagnostics.

We will present the first stage of a pluri-annual project. We tested an experimental setup by characterizing well-known elements: C and Al. The configuration of the target structure and the drive laser parameters have been optimized in order to obtain a homogeneous plasma.

The experimental campaign was realized on the ELFIE laser facility of the LULI laboratory. A 5 ps laser pulse at moderate intensity (I = 10^{15} – 10^{16} W/cm^2) was focused onto a structured target composed by a Si_3N_4 substrate coated by a C or Al layer. The electronic density has been measured with a Nomarski interferometer using the standard Abel transform. The Al X-ray and the C XUV emission spectra was measured with a reflection grating spectrometer. A pinhole camera was used as lens-free X-ray optical tool to measure the plasma lateral dimension.

The experimental results indicate that the plasma was fairly homogeneous. The results concerning hydrodynamic and spectral properties of the laser-generated plasma have been compared to the output of the MULTI hydrodynamic code and of the PrismSPECT atomic kinetic software, confirming the reliability of the setup. Future work should focus on the study of ICF ablators such as Ge.

Thermal and ponderomotive self-focusing for the propagation of a nanosecond-class RPP-beam

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In the context of inertial confinement fusion (ICF), laser-plasma interaction (LPI) refers mainly to the study of ponderomotively driven phenomena that affects the laser propagation and the subsequent laser energy deposition. Due to the multi-millimeters extent and the nanoseconds duration of ICF experiments, the full numerical modeling in production codes of the hydrodynamics evolution coupled with LPI requires strong simplifications. In particular, the complex speckle dynamics of a random phase plate (RPP) laser beams is neglected.

Hence, aiming at improving our modeling of LMJ/NIF/OMEGA-type laser beam, we will show that a modified refraction index can be introduced in classical ray-tracing schemes in order to capture the diffraction of light, and possibly, the resulting speckle dynamics [1]. Likewise, we will address the feasibility of including the speckle self-focusing directly in the refraction index [2,3,4]. Comparison with fluid-based envelop codes (HERA) and kinetic simulations (CALDER) will be shown.

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ps Laser Driven Transient Discharges in Coil Targets with Application to TNSA Beam Micro Lensing

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We present experimental studies of an open-geometry platform for energy selective tailoring of laser-accelerated particle beams, with reference to different target geometries and optimization prospects. The presented results are supported by synthetic reproduction in numerical simulations based on a straight-forward simple electrodynamic modeling.

In the all-optical principle, a high intensity ps-laser pulse drives electromagnetic (EM) target-discharge and subsequent propagation of strong transient EM-fields guided by the target geometry. A sub-mm coil-shaped part of the target rod creates lensing effects that arise due to magnetic- and electric-contributions, in particular we imaged energy-selective proton beam focusing over cm-scale distances and we showed the clear evidence of a some Tesla strong magnetic field component based on its polarity.

The experiment was carried out at the PHELIX/GSI laser facility, using 500 fs, 50 J laser pulses focused at $5{\cdot}10^{18}$ W/cm^2 into a flat-disc target conductively connected to a 50 µm-thick wire shaped as a coil of 500 µm diameter. The discharge time and spatial scales were captured by proton-deflectometry, revealing the propagation of transient EM-fields with a phase speed up to (0.95 ± 0.05) c emanating from the laser-plasma interaction. The discharges stream around the coil over $\approx$ 25 ps, producing efficient focusing of the protons passing inside the coil: 12 MeV-protons are collimated over distances of several cm and the emittance of 6 MeV protons shrinks to 30% of the initial value for best timing. Energy-selection for the focused particles is possible by tuning the delay between the laser pulse driving the coil and the one accelerating the proton beam.

Analysis with transport- and field-simulations using the PAFIN code [1] assuming a dynamic EM-discharge pulse streaming along the target reproduce the discharge dynamics well and indicate field amplitudes of tens of GV/m and tens of T. Building upon this understanding, simulations aiming future experiments on particle beam collimation within the LIGHT framework [2] are presented.

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Développement d'une source de rayonnement X ultra-brève pour l'étude dynamique des transitions de phase du molybdène

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L'irradiation des matériaux par un faisceau laser infra-rouge de durée femtoseconde permet de créer pendant une durée très courte des matériaux avec des propriétés inédites. Ces nouvelles propriétés proviennent du déséquilibre transitoire entre les électrons excités et la structure atomique. A un haut degré d'excitation, des conditions extrêmes de pression et de température sont atteintes dans le régime dit de la « matière tiède et dense », rencontré dans des processus variés depuis l'usinage laser jusqu'aux intérieurs planétaires, ou la compression de cibles pour la fusion nucléaire. La simulation des propriétés de la matière fait appel à des codes de dynamique moléculaire quantique (*ab initio*) dont il s'agit de tester la capacité prédictive dans ce régime thermodynamique d'intérêt et jamais exploré auparavant [1].

L'objectif est d'utiliser un diagnostic de spectroscopie d'absorption X près des seuils (XANES) afin d'évaluer l'effet de l'irradiation laser sur la structure électronique du molybdène, c'est-à-dire de quantifier les effets de l'excitation, et donc de la température électronique, sur l'occupation de la bande *4d* excitée dans le régime dense et tiède. Ce régime est produit en laboratoire à l'aide d'un chauffage par du rayonnement laser de durée femtoseconde. Comme ce régime est très fortement transitoire, les spectres XANES doivent être mesurés avec des résolutions temporelles inférieures ou égales à la picoseconde.

Une campagne expérimentale a été réalisée au laboratoire CELIA, sur la station expérimentale dite « station XANES » [2]. Nous avons développé et optimisé une source de rayonnement X adaptée à l'étude près du flanc L3 du molybdène, autour de 2.52 keV. Cette source est produite lors de l'interaction d'une impulsion laser femtoseconde intense avec une cible solide : nous avons exploré le platine, l'or, le bismuth et le plomb, ce dernier délivrant l'émission la plus intense dans la gamme spectrale d'intérêt. La source a été caractérisée en spectre et en durée au moyen d'une expérience préliminaire de XANES résolu en temps près du flanc L3 du molybdène.

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SEPAGE : un spectromètre protons-ions-électrons pour l'installation LMJ-PETAL

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Le spectromètre SEPAGE (Spectromètre Electrons Protons A Grandes Energies) a été réalisé dans le cadre du projet EQUIPEX PETAL+ financé par l'ANR (Agence Nationale pour la Recherche). Ce diagnostic, installé sur l'installation LMJ-PETAL, permet de mesurer les spectres des particules chargées générées au cours des expériences utilisant le laser PETAL [1] [2].

SEPAGE est un diagnostic plasma inséré dans la chambre d'expérience du LMJ à l'aide d'un SID PETAL+ (Système d'Insertion de Diagnostics). Il est constitué de deux paraboles Thomson permettant de mesurer les spectres des ions et plus particulièrement des protons entre 0,1 et 20 MeV pour la voie basse énergie et entre 8 et 200 MeV pour la voie haute énergie. Les spectres des électrons sont, quant à eux, mesurés sur une gamme en énergie allant de 0,1 à 150 MeV. Sur chaque voie de mesure, les particules chargées sont d'abord sélectionnées par un sténopé d'entrée, sont ensuite déviées par un champ magnétique créé par un couple d'aimants permanents puis par un champ électrique généré entre des plaques parallèles sur lesquelles sont appliquées des hautes tensions. La partie avant du diagnostic permet d'amener une cassette constituée d'un empilement de films jusqu'à 100 mm du centre de la chambre d'expériences du LMJ. Cette cassette permet une caractérisation spectrale et spatiale de l'intégralité du faisceau de protons. Elle permet par ailleurs de réaliser des radiographies protoniques.

SEPAGE a récemment été mis en service sur l'installation LMJ-PETAL et a fourni ses premiers résultats. Le diagnostic est dès à présent opérationnel et disponible sur l'installation.

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Advances in laser-induced microparticle impact experiments

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Understanding high-velocity microparticle impact is essential for many fields, from space exploration to additive manufacturing and needleless drug delivery. While impact dynamics of macroscale projectiles has been studied in real time using high-speed imaging, investigations of microscale impact have been hitherto limited to post-mortem analysis of impacted specimens. In a laser-induced projectile impact test (LIPIT), microparticles are accelerated following laser ablation of a sacrificial gold layer on a glass substrate. By adjusting the laser energy from 0.30 to 20.0 mJ, microparticles can be accelerated from ~50 m/s to ~1500 m/s, depending on the particle characteristics (size and materials). The particles are monitored while in free space and during the impact with an ultrahigh-speed multi-frame camera that can record up to 16 images with a time resolution as short as 3 ns [1]. In one example, we investigate the dynamic impact-induced deformation of poly(urethane urea) (PUU) elastomers through real-time characterization of deformation, including the depth of penetration and the extent of particle rebound [2]. In another example, we study in real time the unit process of metal additive manufacturing by cold spray, namely, single metallic particle impacts on metallic substrates [3,4]. We also study the high-velocity impact response of gelatin and synthetic hydrogel samples in order to predict the high-rate behavior of soft materials, which can guide the development of micrometer-sized drug delivery carriers.

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Maxwell-consistent and energy-preserving focusing of laser beams beyond the paraxial approximation

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Both the wave equation and the paraxial equation have an endless number of solutions. In this work we demonstrate that from any paraxial solution we can build an exact solution of the wave equation, by means of the Lax series [1, 2, 3] which is consistent with Maxwell equations and preserves both the total laser fluence and the symmetry between the electric and magnetic fields [4]. We give recursive relations in order to obtain the high-order corrections of this series. Inversely, each exact solution of the wave equation is related to one paraxial solution. We have demonstrated that such *fundamental* paraxial propagation mode, which contains all the energy of the laser beam, is asymptotically dominant far enough from the beam focus. The latter property can be exploited numerically. Tightly focused beams can thus be introduced into electromagnetic simulations by prescribing paraxial solutions far enough from the beam focal plane. However, which paraxial solution we can prescribe when the numerical aperture is high still remains as open question, since precisely the evanescent energy of the most well-known paraxial solutions, such as Hermite-Gauss and Laguerre-Gauss paraxial propagation modes, increases with the numerical aperture.

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Comportement de matériaux d'intérêt laser - matière en régime ultracourt

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La métrologie de l'endommagement et de l'ablation laser et, de manière générale, le comportement d'un matériau sous flux laser intense, est essentielle pour le développement de chaînes laser intenses (composants optiques) et de leurs applications, par exemple dans le contexte de la mise au point de procédés de micro-usinage. Aujourd'hui, un aspect crucial a trait aux impulsions ultracourtes, de durée de quelques cycles optiques (□ 15 fs) et centrées principalement sur la longueur d'onde du Titane:Sapphire (800 nm). Cette durée d'impulsion constitue en effet le point de fonctionnement des installations ultracourtes de puissance actuellement en émergence dans le monde (par exemple, Apollon-10P en France et ELI en Europe). Elle constitue aussi un avantage pour la structuration contrôlée et de haute qualité d'un matériau en raison du caractère fortement non-linéaire de l'interaction et de la faible quantité d'énergie nécessaire pour transformer localement ce dernier.

Afin d'étudier ces caractéristiques liées à la mise en œuvre des impulsions ultracourtes, nous avons développé un banc d'essai, utilisant la plate-forme ASUR-LP3 (performances nominales: 800 nm, 25 fs, 1-500 mJ), capable de mesurer avec précision la réponse et le comportement de matériaux optiques irradiés par des impulsions laser femtosecondes sous différentes intensités (endommagement, ablation) et conditions de durée (~ 10 - 500 fs). Notons que cette classe d'impulsions présente un spectre large, difficile à manipuler, et une facilité à déclencher des effets non-linéaires lors de leur propagation en raison de leur intensité et puissance élevées. Par ailleurs, leur difficulté de manipulation augmente fortement dans les milieux denses mais aussi dans l'air même à des niveaux d'intensité modérés. Dans ce contexte, des études spécifiques ont été effectuées pour caractériser la propagation du faisceau laser ultracourte dans divers régimes de puissances, fluences et intensités laser afin de déduire des données précises sur le comportement et la réponse des matériaux et des composants optiques sous irradiation laser intense [1]. Nous illustrons ensuite notre travail par plusieurs exemples ayant trait i) à la mesure de seuil d'endommagement surfacique induit par laser (LIDT) de matériaux diélectriques, métalliques ou de composants optiques sous irradiation femtoseconde, ii) à l'évaluation de l'ablation et des avantages spécifiques procurés par l'emploi d'impulsions ultracourtes (< 15 fs) et enfin, iii) à la caractérisation de la réponse optique de matériaux de protection d'éléments optiques sensibles (parabole de focalisation, miroirs de transport, etc.) utilisés dans les expériences de haute intensité (ici à LP3 dans le contexte de génération de sources X pulsées $K_{□}$ induites par interaction laser intense – plasma).

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Study of Novel Guiding Scheme for High Intensity Laser – Application to Laser Plasma Acceleration

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Laser Wave Field Acceleration (LWFA) of relativistic electrons is a promising technic for producing ultra-compact accelerator at energies above several GeV [1]. In order to reach the highest energies, the electrons have to be accelerated in a low density plasma over tens of cm. It requires to guide, in a control way, the high intensity laser over such large lengths. Several methods of guiding have been demonstrated for lengths up to ten cm. Here we analyze a new scheme to be applicable at larger distances. In this scheme, two guiding effects are combined in order to increase the guiding efficiency. A short laser pulse at moderate intensity is first guided inside a capillary tube filled with hydrogen or helium. This laser pulse will create, close to the capillary axis, a plasma that will expand and create a plasma channel. The high intensity pulse, focused at the entrance of the capillary tube, will then be guided by the combined action of the plasma channel and the reflection on the capillary walls.

We will present at the forum, results of our numerical simulation on guiding of a high intensity laser pulse (max intensity of about 10^{18} w.cm^{2}) by a plasma channel with parabolic density profile inside a capillary tube. These simulations have been performed, using an updated version of the Wake code [2] named WAKE-EP [3], in which the boundary conditions at the capillary walls are introduced through an approximated analytical formula [4]. The validity of this formula in our conditions has been checked by direct comparison of the WAKE-EP results with a mode decomposition procedure. As seen in Fig. 1, the agreement between the two results are quite satisfactory.

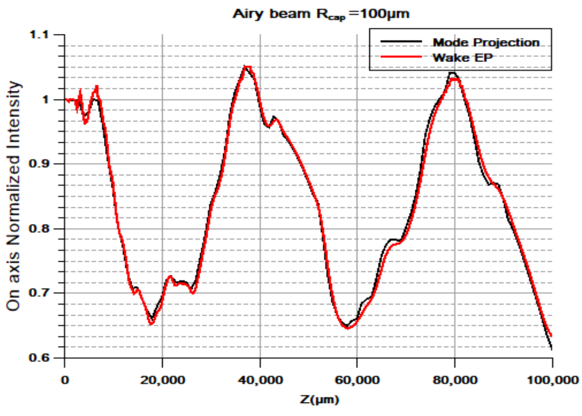

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Figure1. Results of direct mode projection and WAKE-EP for an Airy beam at the entrance of a capillary tube with a radius of

100µm

Réduction de l’émission X et de la dose photon par perte d’énergie des electrons rapides induite par courant de retour lors de l’interaction d’un laser d’impulsion courte et de haute intensité sur une cible solide métallique

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Lors de l’interaction d’un laser d’impulsion courte et de haute intensité avec un préplasma produit par le piédestal de l’impulsion laser devant une cible métallique de numéro atomique élevé, des électrons de haute énergie sont produits, qui à leur tour créent une source X en interagissant avec les atomes de la cible de conversion. Le courant porté par les électrons chauds est presque complètement neutralisé par le courant de retour $\vec{j}$ des électrons de la cible conductrice produisant le chauffage Ohmique $\vec{j}.\vec{E}$, et la force exercée sur les électrons chauds par le champ électrique $\vec{E}$ réduit leur énergie et abaisse donc l’émission X et la dose photons. Cet effet est analysé ici à l’aide d’un modèle simple 1-D de température contenant les termes significatifs de l’équation Fokker-Planck relativiste avec diffusion multiple. Les équations de l’énergie des ions, des électrons froids et des électrons chauds sont résolues numériquement. Cette fraction d’énergie τ_{Oh} perdue par chauffage Ohmique est introduite comme un terme correctif dans un modèle de dose photons. Par exemple, pour une impulsion laser ps de tache focale 10 μm, la dose obtenue avec une cible de tantale est réduite d’environ 10 à 40% par chauffage Ohmique, selon la longueur caractéristique du plasma, de l’épaisseur de la cible, des paramètres laser et en particulier sa tache focale. Les paramètres laser et plasma peuvent être optimisés pour limiter l’effet du chauffage Ohmique, par exemple à faible longueur plasma ou petite tache focale. Inversement, d’autres régimes ne convenant pas à la production de dose sont identifiés. Par exemple, le chauffage résistif augmente pour une cible en mousse ou à long plasma et grande tache focale et intensité laser, puisque l’angle moyen θ_0 d’émission du paquet d’électrons chauds donné par la force pondéromotrice est faible; la dose produite par un laser interagissant sur un jet de gaz est susceptible d’être inhibée dans ces conditions. Le chauffage résistif peut aussi être maximisé afin de réduire le rayonnement X pour abaisser le niveau de radiation dans l’objectif de sûreté radiologique.

Investigation of the spatio-temporal effects in the Apollon 10 PW laser

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Apollon 10 PW project aims to the generation of high contrast ultra-short pulses of 15 fs and an energy of 150 J after compression[1, 2]. For such a laser system with large spectrum, the in-depth study of the spatio-temporal coupling effects is of critical importance.

The spatio-temporal coupling in an ultra-intense laser system could simultaneously degrade the laser pulse and the focal spot quality on the target. Six effects have been identified and studied so far for the Apollon laser:

- Radial group delay generated from refractive-image-relay based systems introduces a huge chromatic time-delay and an enlarged focal spot.
- Low order spatial-to-spectral phase coupling may occur inside a compressor due to flatness imperfections of optical components at positions where the beam is spectrally resolved (gratings and reflectors).
- Spatial dependence of the gain saturation in the Apollon amplification chain leads to inhomogeneous spectral/temporal evolution[3].
- Spectrally resolved diffraction at the edges of the finite size gratings induces a complex spatio-temporal laser performance degradation on the target.
- A residual angular chirp may exist if the stretcher and/or the compressor alignment is not perfect. Pulse front tilt and focal spot deformation could be induced becoming even more critical in the case of larger spectrum and beam size[4].
- High order spatial-to-spectral phase coupling at the level of the convex mirror of the Offner stretcher degrades the temporal contrast close to the main pulse[5].

In this presentation, based on the theoretical and the numerical analysis of all these effects, especially for high order spatial-to-spectral phase coupling, we will show our strategies and solutions to minimize their impacts on Apollon laser performances. Under the collaborations with 3 research establishments and industries and using new diagnostics, we will characterize experimentally the spatio-temporal coupling during the upcoming 1 PW laser commissioning.

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Surface Plasma Waves in High-Intensity Laser-Plasma Interaction.

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The excitation of Surface Plasma Waves (SPW) by high-intensity laser pulses on periodically modulated plasma surface (gratings) has proven to be an efficient way to produce collimated bunches of energetic electrons [1]. The SPW can be excited only under appropriate matching conditions. For a given plasma density (larger than the critical density) with a step-like density gradient, if the laser intensity is relatively low ($I < 10^{18}\mathrm{Wcm}^2$), the matching conditions depend only on the laser incidence angle and the grating size [2]. On the other hand, if the laser intensity is high ($I > 10^{18}\mathrm{Wcm}^2$), the quiver motion of electrons modify the dispersion relation and, as a result, the matching conditions start to depend on the laser intensity [3]. In this work, we explore how taking into account relativistic corrections to the matching conditions results in improved laser-plasma coupling. The optimal angle of incidence in the highly relativistic domain is identified with two-dimensional Particle In Cell (PIC) simulation [4] for different values of the plasma density, and grating depth, and compared with simple theoretical estimates.

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Détente 2D et 3D en cavité vide sur Omega

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Chauffée par l'absorption des faisceaux laser, la paroi d'une cavité se détend. Cette détente influe ensuite sur la propagation des faisceaux laser à l'intérieur de la cavité, donc sur le dépôt d'énergie laser, et donc sur la symétrie d'irradiation de la capsule située au centre de la cavité, quand elle existe. Une série d'expériences a récemment été menée sur l'installation Omega avec pour objectif de mesurer la détente à l'intérieur d'une cavité vide par radiographie de protons. Elle a permis de comparer l'effet d'une irradiation quasi uniforme à 10 spots laser, avec celui d'une irradiation, classique sur Omega, à 5 spots laser, pour lequel on attend de forts effets 3D.

On présente ici les simulations 2D et 3D de ces expériences. On montre en particulier l'importance des effets 3D : la paroi se détend beaucoup plus rapidement en 3D qu'en 2D. Les vitesses sont clairement supersoniques (Mach=3-5) et dépassent 1000 km/s. Cependant, les calculs 3D continuent de sous-estimer la détente telle qu'elle est mesurée dans l'expérience.

Thermo-elasto-plastic modeling of femtosecond laser-induced cavity in silica

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Powerful ultrashort laser pulses are an efficient tool to induce localized structural modifications in transparent materials. In particular, by tightly focusing intense femtosecond laser pulses in the bulk of dielectric materials, submicrometer cavities can be produced [1]. The absorbed laser energy is strongly confined into a volume where the matter evolves towards a warm dense plasma. After the laser irradiation, the plasma expansion, slowed down by the elasto-plastic behavior of the surrounding cold matter, launches strong shock waves. Permanent deformations then may appear in the surrounding solid matter if the induced stress becomes greater than the yield strength. It turns out that the plasma relaxation leads to the formation of a cavity with a size depending on the absorbed energy and the surrounding solid matter response. The latter processes thus have to be described to predict the laser-induced micro-structuration in dielectric materials by tightly focused beams.

To study this physical issue, an elasto-plastic model in a 2D plane geometry [2] has been implemented in a hydrodynamic lagrangian code, including thermal softening. Simulations of cavity formation in fused silica exhibit how the shock induces reversible and permanent deformations. The shape of the shock compared to a classical hydrodynamic model appears significantly different. Calculations also show the various stages of the cavity formation, which are strongly correlated to the elasto-plastic behavior of the surrounding solid matter.

We will present 2D density maps in fused silica at 500 ps after the energy deposition. A cavity where the density is lower than 0.03 g/cm3 appears surrounded by an over-dense shell. The temporal evolution of the cavity radius will be presented, for various absorbed energy densities. The cavity first grows until a maximum size before it relaxes, due to reversible deformation (elastic behavior of cold matter), towards a lower value depending on the amount of permanent (plastic) deformations previously induced. The predicted cavity radius, given by a specifically developed tool to evaluate permanent deformations, is in agreement with both simulations and experimental observations [1]. Furthermore, numerical simulations allow one to describe the structural modifications near the cavity as critical points where the stress exceeds the material resistance in compression or traction, predicting places of potential crack formation and propagation. This modeling offers a new baseline for original laser-designed micro-structures in materials.

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Implémentation parallèle hybride de simulations PIC en géométrie cylindrique avec décomposition de Fourier dans le code SMILEI

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Abstract

Les simulations Particle-in-Cell sont utilisées dans une large variété de problèmes liés à la physique des plasmas. Dans plusieurs cas, une description précise et fiable des effets cinétiques qui se produisent en 3D est requise. Néanmoins, ce type de simulations est très couteux et nécessite beaucoup de ressources de calcul. Ceci est principalement dû à la haute résolution que nécessite les simulations d'interaction laser plasma en général et celles de l'accélération des leptons par sillage laser. Cela implique un nombre de points très important surtout dans la direction longitudinale pour pouvoir décrire le laser en restant fidèle à la réalité physique. Typiquement les simulations d'accélération laser-plasma en 3D nécessitent $10^6 - 10^8$ points. Ce type de simulations demande des codes très parallèlisés et doivent être exécutées sur des grands clusters dans des centres de calcul. La limitation en ressources de calcul nous pousse à chercher des hypothèses simplificatrices qui permettent un gain dans le temps et les ressources nécessaires de calcul. Une des solutions proposées, est la decomposition azimutale des champs en série de Fourier [1]. En pratique cette description peut être limitée aux deux premiers modes. En effet, le sillage du laser, indépendant de θ peut être décrit par le mode 0, le pulse de laser dépend seulement de θ en cas de symétrie cylindrique peut être parfaitement décrit par le mode 1 [2]. Ainsi on peut obtenir une description 3D de l'interaction laser plasma avec un coût de 2D. Cette méthode a été vectorisée et adaptée à la parallélisation hybride MPI et OpenMp par patch du code PIC libre SMILEI [3]. Les résultats ont été comparés avec des simulations 3D complètes.

Mots-clés : Accélération laser-plasma, sillage laser, Particle-in-Cell, Méthodes numériques, SMILEI, décomposition de Fourier

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Damage in Silica Glass due to Laser Shocks : Experiments and Simulation.

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Silica (SiO_2) is one of the most common materials on earth. It is usually encountered in one of its many crystalline forms, but a vitreous form can be obtained by rapid quenching of the molten material. The glass hence obtained is used in many aspects of the everyday life, but is also the main material for some highly critical structures such as space shuttle windows and solar panels. Silica glass has been extensively studied under quasi-static loading conditions, which is distinctly different than those of laser shock involving both high pressures and strain rates. Fracture initiation and propagation under laser shock is the main focus of the current study.

The shock loading condition was generated by a high intensity laser[1]. Recovered samples were observed and their damage was quantified by different techniques (optical, X-Ray tomography). They ranged from no damage at all to a completely damaged sample on both front and rear faces. Micro-CT showed that the most damaged samples also have several types of internal failure.

Peridynamic simulations [2] were used to first study how well it qualitatively compare to experimentation and to obtain more insight on the damage initiation and propagation in silica samples. This method is a non-local formulation that uses integrals instead of tensors, thus removing the singularities caused by geometric discontinuities. The system is discretised into material points, each one interacting with those in its vicinity through bonds. A damage parameter may be defined by the accumulation of broken bonds on a material point. It ranges from 0 (undamaged material point) to unity (completely separated from the rest of the domain), thus allowing for a quantification of the damage in the structure.

The laser-shock experiments were simulated by using a peridynamic grid matching the size of the shocked silica samples. The loading conditions were determined by one-dimensional laser-matter simulations using the ESTHER code (developed by the CEA). They were applied to material points on the front face of the mesh corresponding to the experimental laser irradiated zone. Two specific cases were considered : High Flux (HF) and Low Flux (LF). These cases represent clear differences in both loading conditions and the observed failure modes. In the current study the HF case was used to refine the peridynamic material parameters allowing for a satisfactory description of the experimentally observed damage on both the front and rear faces. This setup was then used in LF case and damage predictions were compared to those of the recovered sample to test the accuracy of the method.

Although the comparison between experimental measurements and peridynamic predictions is encouraging, considering the lack of current data on such studies, results are also discussed in terms of qualitative or quantitative matching in order to set the limitations of the numerical approach [3].

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Ion acoustic turbulence and anomalous laser absorption due to temperature gradient in ICF plasmas

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Hot plasmas with strong temperature gradients, as the one obtained in inertial confinement fusion (ICF) experiments, may present electron heat flux able to generate ion acoustic instabilities. Return current instability (RCI) due to electron heat flux could be the source of stationary ion acoustic turbulence (IAT). Therefore, anomalous laser light absorption due to enhanced anomalous collisionality could occur in plasma where Landau damping of ion is negligible. Such effects are expected to occur inside hohlraum in gold plasma where $ZT_e/T_i >> 1$.
Anomalous absorption and electron heat flux limitation due to RCI has been included as a reduced model in hydro code. Analysis of RCI in gold hohlraums experiments is presented.
A specific experiment will be done on the Omega laser facility in 2018 to measure and identify this instability.
For this experiment, a gold plate heated by many beams will generate expanding plasma, on which a probe beam will be send to measure its absorption. At the same time, Thomson scattering will be done along the path of the probe beam to measure plasma conditions and to measure ion acoustic wave (IAW) of the ion acoustic turbulence. Implications of all these processes for laser plasma interaction experiments are described and discussed.

Enhancement and Control of Laser Wakefields via a Backward Raman Amplifier

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The Backward Raman Amplifier (BRA) is proposed as a possible scheme for improving laser driven plasma wakefields. One- and two-dimensional particle-in-cell code simulations and a 3-Wave coupling model are presented and compared to demonstrate how the BRA can be applied to the laser wakefield accelerator (LWFA) in the non-relativistic regime to counteract limitations such as pump depletion and diffraction. This article provides a discussion on optimal parameters for the combination of BRA and LWFA and a prescription for a BRA pump frequency chirp to ensure coupling beyond the particle dephasing limit. Simulation results demonstrate a reduction or alleviation of the effects of diffraction, an increase in wake amplitude and sustainability, and provide direct insight into new methods of controlling plasma wakes in LWFA and other applications.

SELF FOCUSING OF A LASER BEAM INTO A PLASMA

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Abstract

Self-focusing of a laser beam in a stationary plasma driven by ponderomotive force is studied. It is performed by using the radiative hydrodynamics code CHIC [1] in the context of Inertial Confinement Fusion. In CHIC, the propagation of a Gaussian beam obeys the ray tracing laws, extended to the framework of Paraxial Complex Geometrical Optics (PCGO) [2]: The Gaussian beam propagation is described by the trajectory and complex front curvature thus providing access to the laser intensity in the plasma. So far, optical techniques, such as Kinoform Phase Plate (KPP), have been implemented: the incident laser beams are split into a group of elementary Gaussian beamlets whose envelope creates a "pseudo-speckles" intensity pattern in the plasma. In such a framework, it has been demonstrated that one can take into account nonlinear processes, such as parametric instabilities and hot electron generation. However, the beamlet size is much larger than the real speckles' size and PCGO beamlets may suffer from premature self-focusing.

In this work, we present analysis of the self-focusing process in the PCGO approximation and propose a method of its control, by choosing the beamlet focusing pattern in the far field zone. A definition of the critical power in plasma is revisited for the case of multiple crossing beamlets. The case of a mono-speckle beam composed by several elementary beamlets is studied and the self-focusing is evaluated as a function of the number of beamlets. The conclusions of the PCGO model are compared with full numerical simulations, using the paraxial code HARMONY [3], and appropriate parametrization of the beamlets is proposed. The comparison will be extended to multi-speckled laser beams and cross-beam energy transfer at high laser powers, as well as application to investigate self-focusing in nonstationary plasma.

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Bubble cavitation in water triggered by laser-driven focusing shock waves

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In this study, shock waves are generated in a 10 µm-thick layer of water by focusing intense picosecond laser pulses into a ring of 95 µm radius [1]. First, using a Mach-Zehnder interferometer and time-delayed femtosecond laser pulses, we obtain a series of images tracing the shock wave as it converges at the center of the ring before reemerging as a diverging shock, resulting in the formation of a cavitation bubble. Through quantitative analysis of the interferograms, density profiles of shocked samples are extracted [2]. Then, through time-resolved imaging of shock propagation and bubble wall motion, we observe that the inner diverging shock reaches the surface of the annular laser-induced bubble and reflects at the boundary, initiating nucleation of a tertiary bubble cloud. Our experimental observations of single-bubble cavitation and collapse and appearance of bubble clouds are consistent with our numerical simulations that solve a one dimensional Euler equation in cylindrical coordinates. The numerical results agree qualitatively with the experimental observations, which shows that smaller laser excitation ring diameters lead to denser cavitation (denser bubble cloud). Our technique opens a new way for the investigation of shock-induced cavitation phenomena in thin liquid layers.

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Réduction simultanée du développement de l'instabilité Brillouin stimulée et de la conversion FM-AM

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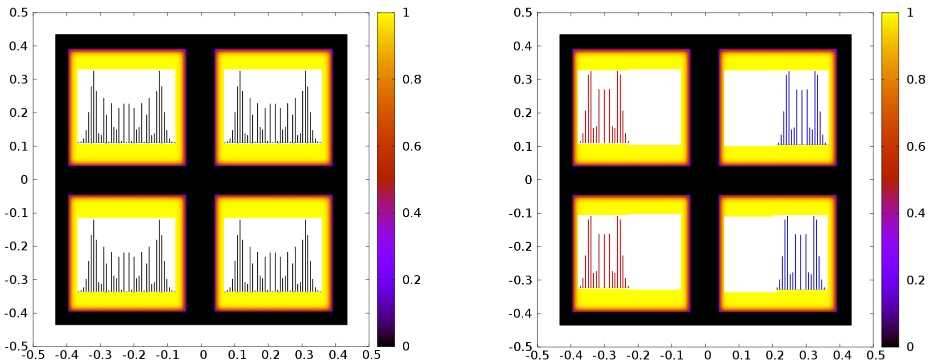
Dans le contexte des expériences de fusion par confinement inertiel, l'objectif est de rendre l'irradiation laser homogène afin de limiter le développement d'instabilités laser-plasma, en particulier la rétrodiffusion Brillouin stimulée (RBS) du laser sur les ondes acoustiques ioniques. Pour cela, différentes techniques de lissage optique ont été développées. Ces méthodes combinent une mise en forme spatiale produisant une figure de tavelures comportant de nombreux points chauds et froids, et un lissage temporel permettant l'addition de figures différentes au cours du temps.
Le Laser MégaJoule (LMJ) est composé de nombreux faisceaux lasers, groupés en quadruplets. La solution retenue sur le LMJ est la technique de lissage dite « par dispersion spectrale longitudinale ». La mise en œuvre de cette technique requiert une lame de phase aléatoire et un réseau focalisant pour l'ensemble du quadruplet (voir figure) et utilise une modulation de phase pour élargir le spectre.
Plus le spectre est large, plus la RBS est atténuée. Mais malheureusement, plus le spectre est large plus la chaîne laser est sujette à des effets néfastes dits de conversion FM-AM, qui consiste en une conversion partielle de la modulation de phase en modulation d'intensité. Nous démontrons ici qu'il est possible de maintenir l'efficacité du lissage vis-à-vis de la RBS en répartissant le spectre sur les différents faisceaux du quadruplet. La conversion FM-AM diminue puisqu'elle ne dépend que du spectre de chaque faisceau. En pratique pour le LMJ, le spectre ne pourrait être découpé qu'en deux et pas en quatre : les faisceaux de droite d'un côté et les faisceaux de gauche de l'autre. Profitant néanmoins de ce degré de liberté supplémentaire, nous avons mené une étude paramétrique sur la RBS en fonction de la largeur spectrale des spectres des faisceaux de droite et de gauche et de leur écart spectral. Il est même ainsi possible d'augmenter l'efficacité du lissage tout en réduisant la conversion FM-AM. Nous retrouvons également le comportement asymptotique du lissage dit multi-couleurs pour lequel la largeur spectrale est nulle et montrons pourquoi il a été abandonné.



Quadruplet LMJ : à gauche le même spectre est appliqué sur chaque faisceau. A droite, le spectre est coupé en deux : une partie est apportée par les faisceaux de droite et l'autre partie par les faisceaux de gauche.

SPECTIX

Spectromètre Petal à Cristal en Transmission pour les rayons X

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L'EquipEx PETAL+ a pour objectif la fourniture de diagnostics pour l'installation laser formée par l'association du Laser multipetawatt PETAL (PETawat Aquitaine Laser) et du Laser Méga Joule. L'un de ces diagnostics est dédié à enregistrer le spectre intégré en temps, dans la gamme X-dur (8 – 100 keV) produit sur l'installation PETAL avec une impulsion laser intense. Ce spectromètre est nommé SPECTIX (Spectromètre PETal à Cristal en Transmission X), comporte deux cristaux en transmission pour couvrir toute la gamme spectrale. La détection est faite avec des imaging plates qui sont insensibles aux champs électro-magnétiques. Il a été construit et utilisé sur des expériences avec PETAL. Ce poster fait un point sur les performances actuelles de ce spectromètre.

Seront présentées en particulier les spécifications de SPECTIX, les performances qu'il peut atteindre, les résultats d'étalonnage des cristaux utilisés, sa structuration actuelle, ainsi que les résultats des expériences de qualification qui ont été effectués avec PETAL.

Le développement de ce diagnostic est réalisé dans le cadre de l'EquipEx PETAL+ qui est financé par l'Agence Nationale pour la Recherche (ANR) et coordonné par l'Université de bordeaux.

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Cross-beam energy transfer (CBET) in ICF : laser speckle effects in presence of ponderomotive self-focusing and flow

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Both in the direct- and the indirect drive scheme for Intertial Confinement Fusions (ICF) Crossed beam Energy Transfer (CBET) between laser beams is a major issue. Part of this problem is the complexity of the process involving both the plasma hydrodynamics and its interaction with the numerous incident laser beams.

We model CBET by taking into account the speckle substructure of "smoothed" laser beams that has been disregarded in most of the previous studies. By means of numerical simulations [1], it can be shown that transfer from laser hot spots of one beam to the another beam, via self-focusing in presence of plasma flow [2,3] and "beam bending"[4,5], proves to affect considerably the angular spread of the light behind the region of beam overlap for laser intensities $I\,\lambda^2 > 10^{14}$ W cm^{-2} µm^2 . The angular distribution of transmitted light from laser beams with speckles is therefore very different from the angular distribution of beam when the beam speckle structure is disregarded. We also show the importance flow for self-focusing in a non linear stage, as well as for the formation of shock-like structures of ion waves, responsible for enhanced plasma-induced smoothing.

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Generation of high photon flux and micron size Kα Mo x-ray source at 100 Hz

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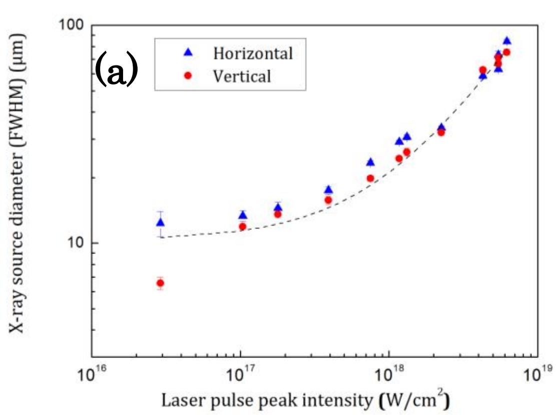
Femtosecond laser-driven plasma X-ray sources are practical alternatives to accelerator-based X-ray sources with striking advantages related to low investment and low operational running costs, reduced footprint, high versatility and intrinsic synchronization for pump and probe experiments [1,2]. Among different laser plasma sources, monochromatic Kα emission from laser plasma interaction is promising for applications such as X-ray absorption spectroscopy, X-ray diffraction or phase contrast imaging due to its simplicity, reliability and perspective of scalability to high repetition rate compared to Betatron radiation or Compton backscattering X-ray source [3,4].
Key factors to optimize Kα X-ray source emission depend on the driving laser pulse parameters like intensity and pulse duration, or temporal contrast ratio. Moreover, to reach high photon fluxes and reduced time exposure, a high repetition rate of the driving laser system is an important parameter.
Thereby, in this work, we present an intense Kα hard X-ray (17.4 keV) produced by interaction of a multi-TW peak power infrared femtosecond laser pulse with a thick molybdenum target at 100 Hz repetition rate. The experiment is described in details in [5,6]. We measure the highest molybdenum K_α photon production reported to date corresponding to a K_α photon flux of 1×10^{11} ph/(sr.s) and an estimated peak brightness of ~ 2.5×10^{17} ph/(s.mm^2. mrad^2 (0.1 % BW)) at ~ 5×10^{18} W/cm^2 driving laser intensity.



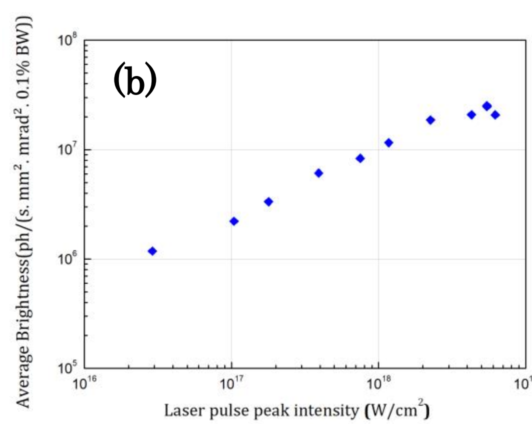


Fig. 1 a,b X-ray source size measurements as a function of the laser peak intensity (a). The average brightness is plotted as a function of laser intensity (b).

Experiment	Laser pulse energy (mJ)	Intensity (10^{18} W/cm^2)	Contrast ratio	Kα photon number (photons/sr.shot)	Kα conversion efficiency (laser energy to Kα) in 2π sr	Repetition rate (kHz)	Kα photon number (photons/(sr.s))
[7]	1.3	2.2	~10^6	1.22×10^6	1.6×10^{-5}	0.4	4.9×10^8
[8]	14	1.2	~10^6	4.7×10^7	5.7×10^{-5}	1	4.7×10^{10}
[2]	245	1.75	~10^{10}	2.8×10^9	2×10^{-4}	0.01	2.8×10^{10}
Our source	**122**	**6.2**	**~10^{10}**	**1×10^9**	**1.3×10^{-4}**	**0.1**	**1×10^{11}**

Table 1: Comparison of molybdenum Kα production, conversion efficiency and X-ray source size obtained by means of high peak power laser interaction with thick Mo solid target. The table presents laser parameters for each reported work: intensity, energy, temporal contrast ratio and repetition rate.

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EuPRAXIA: The worldwide first 5 GeV plasma-based accelerator with industrial beam quality

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On behalf of the EuPRAXIA WP4 team (laser design work package) and the EuPRAXIA project.

The EuPRAXIA infrastructure design study [1] is paving the way to the development of a compact European plasma-based accelerator comprising novel acceleration schemes to drive radiation sources and large-scale user areas for applications. Being applications and users the main concern of the whole EuPRAXIA project, high acceleration performances need to go along with high stability and reliability, as well as with a high repetition rate, allowing users to carry out either their work or their research in a more reasonable time.

The starting and fundamental step for EuPRAXIA project in order to fulfil all these requirements is to design a laser system that can give a solid basis to all subsequent processes up to the user final objective. In order to fulfil the high performances requirement, the design foresees a petawatt-peak-power laser with unprecedented temporal and spatial quality. Reaching high energy, temporal and spatial stability is of paramount importance to fulfil the reliability requirement and, finally, a repetition rate of 100Hz will provide the users with high statistics and tens of kilowatts of average power.

These very challenging needs are being thoroughly examined, in view of the current dramatic developments of high average power systems and optical components, in order to guide the architecture and technology down-selection and the preliminary design of the laser system.

I will give a summary of the laser specifications in view of the expected staged accelerator performances and foreseen applications, together with a global description of the laser design and main subsystems compatible with the project physics requirements. I will submit to the attention of the reader the main issues of designing a high peak – high average power laser. For example, one of the bottlenecks when trying to reach high repetition rates concerns pump lasers for the amplifications stages. A solution could be the use of Diode-Pumped Solid State Lasers (DPSSL). After that, it is necessary to deal with how thermal effects due to the high repetition rate affect the whole system, including amplification, compression and transport stages.

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Prospects of strongly magnetized plasma experiments as a testbed for development of spectroscopic diagnostics

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The advent of 0.1 – 10 PW laser user facilities and the opening of multi-beam ns-laser facilities of large energy for academic research in Europe, along with novel laser-driven, controlled sources of strong quasi-static magnetic fields is nourishing the interest for laser-driven magnetized high-energy-density systems. In the context of inertial confinement fusion (ICF), magnetized implosions can lead to higher fusion gains through mitigation of hydrodynamic instabilities, reduced heat conduction or by an enhanced confinement of the thermonuclear particles. Anisotropic thermal-electron diffusion and enhanced collision rates may impact on the micro-fields and ion dynamics and on the shell or dopant material opacities. Improvements on Stark-Zeeman line shape calculation can provide a new analysis and interpretation of existing and future ICF spectroscopic data.

The work presented here, is a part of the international research project *StarkZee*, recently funded through the EUROfusion Enabling Research program which aims at developing an accurate Stark-Zeeman line shape code for any emitter and any plasma conditions especially when the effects of an external magnetic field dominate over the spin-orbit interaction. The code should be fast enough to be implemented in transport codes, and will be benchmarked by confrontation with spectroscopic data from well controlled laboratory experiments able to generate quasi-static magnetic fields of controlled strength and polarization. After a summary of the goals and work-plan of the project, the first results corresponding to various possible schemes of experiments will be presented.

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Etude expérimentale des diffusions Brillouin et Raman collectives stimulées en configuration multi- faisceaux dans les expériences FCI

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Les schémas de fusion par confinement inertiel laser en irradiation directe et indirecte utilisent un grand nombre de faisceaux dans une distribution angulaire symétrique. La géométrie préférentielle des couplages résonnants à trois ondes, principalement responsable de la lumière rétrodiffusée dans les expériences mono-faisceau, peut être profondément modifiée dans les régions de croisement de faisceaux symétriques où des instabilités laser-plasma collectives pourraient se développer [1]. De telles instabilités peuvent exister pour des faisceaux laser ayant un axe de symétrie le long duquel ils stimulent une onde fille commune. Ces instabilités collectives correspondent à des décompositions de côté et sont ainsi responsables de pertes d'énergie dans de nouvelles directions par rapport à la rétrodiffusion, lesquelles augmentent très rapidement avec le nombre de faisceaux couplés. Deux catégories d’expériences ont été réalisées sur l'installation Omega pour étudier ces instabilités collectives.

Des pertes d’énergie importantes par diffusion Brillouin de côté (> 30%) ont été mises en évidence dans des expériences réalisées en configuration d'attaque indirecte avec 42 faisceaux [2]. Ces pertes proviennent de l’amplification Brillouin collective d'une onde acoustique ionique partagée, stimulée le long de l'axe de la cavité par un cône de 10 faisceaux.

Les expériences réalisées dans une géométrie plane ouverte ont permis de mettre en évidence la Diffusion Raman stimulée (SRS) à grands angles du gradient de densité [3]. Cette observation a été possible par la production de plasmas chauds de grande longueur dans lesquels deux faisceaux laser amplifient une même onde électromagnétique diffusée démontrant de plus pour la première fois cette diffusion SRS collective à faisceaux multiples. La nature collective du couplage et l'amplification à grands angles par rapport au gradient de densité augmentent considérablement les pertes SRS globales et produit de la lumière diffusée dans de nouvelles directions en dehors des plans d'incidence des faisceaux laser.

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Enhanced relativistic electron beam collimation using two consecutive laser pulses

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Here we report an experimental investigation of a scheme based on using of two consecutive intense laser pulses in order to optimize electron transport and collimation in dense matter. The two laser pulses, of different intensities, are focalized in a solid target at a given delay to generate two successive co-axial electron populations, where the azimuthal magnetic field generated by the first electron beam can guide the second one [1]. Previous experimental results have confirmed the general validity of the scheme: optimum delay time and intensity ratio yielding the best guiding effect [2]. It was shown that the ratio between the pre-formed magnetic field extension and the diameter of the second electron beam plays a major role in determining the guiding efficiency [3]. A systematic investigation of the scheme, exploring the role played by the radial extension of the seed magnetic field and the delay time between seed and main laser pulses, was recently carried out on the LULI-ELFIE facility. The experimental results showed a reduction of the electron beam size in the optimum conditions of both focal spot ratio and delay time betweenthe first and the second laser pulses, yielding in factor of 2. In addition, we present the numericalsimulations using hybrid PIC code and kinetic transport code that reproduce performed experimental parametrical study and benchmark the scheme efficiency.

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