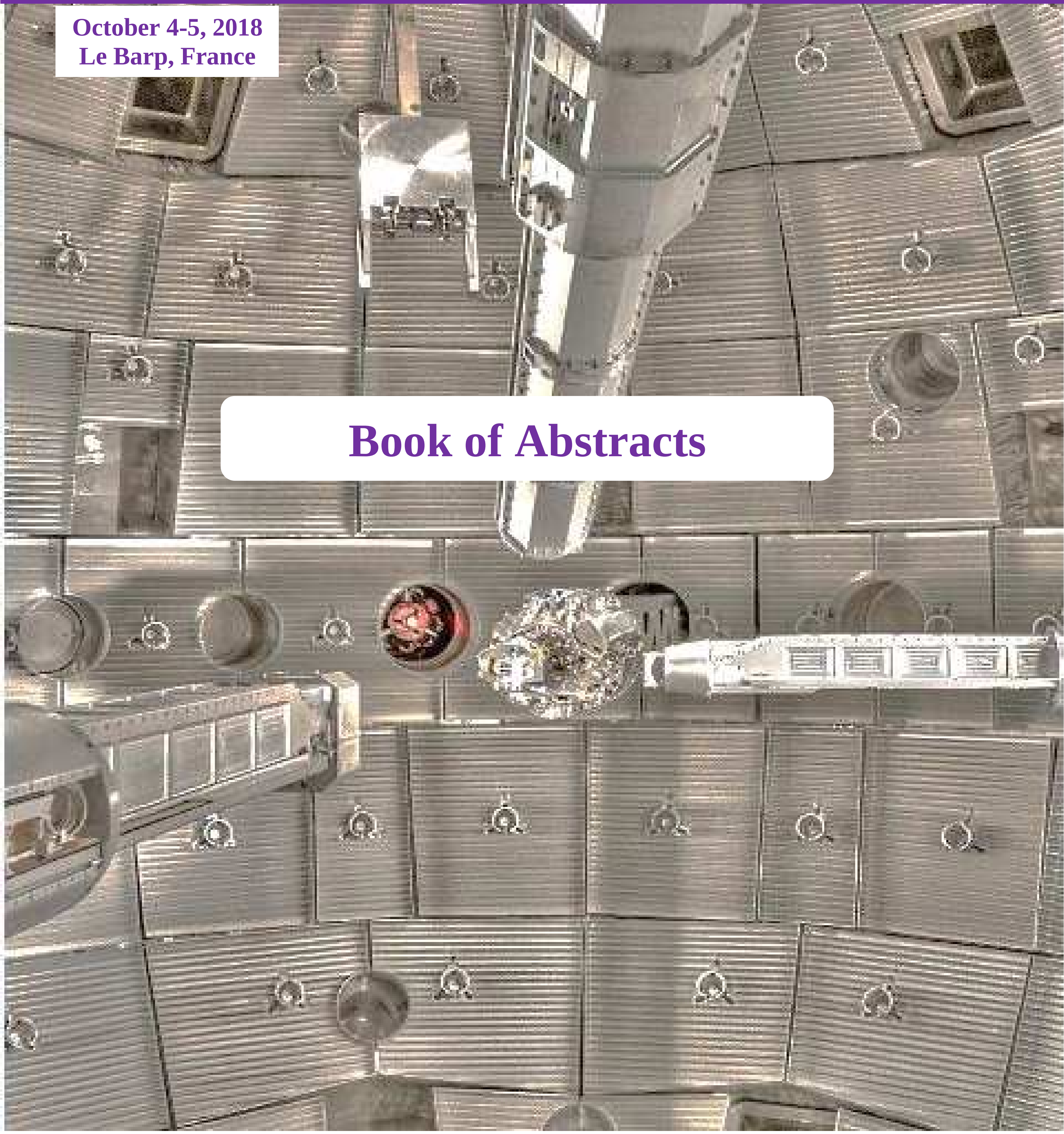
First LMJ-PETAL User Meeting

October 4-5, 2018
Le Barp, France



Book of Abstracts

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Program LMJ-PETAL User Meeting

Thursday 4 October 2018

Schedule	Duration	Title	Speaker	Institution
8:00 AM	0:30	Accueil ILP		
8:30 AM	0:30	Welcome		
		Plenary session-1 : LMJ-PETAL performance **Chairman :**	**JL. Miquel**	**CEA/DAM**
9:00 AM	0:25	LMJ Facility: Status and Performance	P. Delmas	CEA/DAM, France
9:25 AM	0:25	PETAL laser performance	N. Blanchot	CEA/DAM, France
9:50 AM	0:25	Status on LMJ-PETAL plasma diagnostics	R. Wrobel	CEA/DAM, France
10:15 AM	0:25	Preliminary results from the qualification experiments of the PETAL+ diagnostics	D. Batani	CELIA, France
10:40 AM	0:20	*Break*		
		Plenary session-2: Next user experiments **Chairman :**	**D. Batani**	**CELIA**
11:00 AM	0:25	Effect of hot electrons on strong shock generation in the context of shock ignition	S. Baton	LULI, France
11:25 AM	0:25	Investigating magnetic reconnection in ICF conditions	S. Bolanos	LULI, France
11:50 AM	0:25	Efficient Creation of High-Energy-Density-State with Laser-Produced Strong Magnetic Field	S. Fujioka or K. Matsuo	ILE, Osaka U., Japan
12:15 PM	2:00	*Lunch / **Posters session***		
2:15 PM	1:30	**Round table -1**		
		Targets **Chairman:**	**M. Manuel**	**General Atomic**
	0:20	Target laboratory on LMJ Facility	O. Henry	CEA/DAM, France
	0:20	Review of General Atomics Target Fabrication : Facilities, Capabilities and Notable Recent Developments	M. Manuel	General Atomic, USA
		Diagnostics **Chairman:**	**W.Theobald**	**LLE Omega**
	0:20	Visualization of fast heated plasma by X-ray fresnel phase zone plate	K. Matsuo	ILE, Osaka U., Japan
2:15 PM	1:30	**Round table - 2**		
		Codes **Chairman:**	**E. d'Humières**	**CELIA**
	0:20	Numerical investigation on non-thermal electron effects measured in a Gekko experiment at intensities relevant to shock ignition	Ph. Nicolaï	CELIA, France
	0:20	Laser-driven experiments shedding light on turbulent dynamo: Platform design and numerical modeling with FLASH	P.Tzeferacos	U. of Chicago, USA
3:45 PM	0:20	*Break*		
		Plenary session-3: Advices and Perspectives **Chairman :**	**P. Renaudin**	**CEA DAM**
4:05 PM	0:25	Experimental Process on LMJ	B. Loupias	CEA/DAM, France
4:30 PM	0:30	**Tutorial:** Practical advices on how to perform ns X-ray radiography on LMJ	C. Courtois	CEA/DAM, France
5:00 PM	0:25	A Perspective on the Future of ICF and HEDP Research	M. Campbell	LLE, USA
5:25 PM	0:25	Exploring the universe through Discovery Science on NIF	B. Remington	LLNL, USA
6:00 PM	1:00	***Cocktail (ILP)***		
7:00 PM	0:30	Transportation to Gala dinner		
7:30 PM	2:30	***Gala Dinner Cité du Vin / Hôtel Mercure***		
10:00 PM		Transportation to hotels		

Program LMJ-PETAL User Meeting

Friday 5 October 2018

Schedule	Duration	Title	Speaker	Institution
8:00 AM	0:15	Accueil ILP		
		Parallel session - 1: ICF and WDM Chairman:	**A. Casner**	**CELIA**
8:15 AM	0:20	Hydrodynamics studies of shock ignition targets	S. Atzeni	U. di Roma "La Sapienza", Italy
8:35 AM	0:20	Kinetic effects in laser-driven spherical implosions	G. Kagan	LANL, USA
8:55 AM	0:20	Auxiliary Heating for Inertial Fusion	P. Norreys	U. of Oxford, UK
9:15 AM	0:20	Demonstration of Imprint Mitigation in Planar Geometry by a Combination of X-Ray–Driven Picket-Pulse Shocks and Directly Driven Targets	W. Theobald	LLE, USA
9:35 AM	0:20	A preparatory experiment to 2017 LMJ-SI (S. Baton) experiment: Radiography of shocks and hot electron preheat on OmegaEP	J. Trela	CELIA, France
9:55 AM	0:20	*Break*		
10:15 AM	0:20	Ion stopping measurements in plasma targets	L. Volpe	CLP, U. of Salamanca, Spain
10:35 AM	0:20	Experimental observation of non local electron transport in warm dense matter	K. Falk	HZDR, Germany
		Parallel session - 2: Astrophysics and UHI Chairman:	**M. Koenig**	**LULI, France**
8:15 AM	0:20	Optical generation of strongly magnetized plasma	Ph. Korneev	NRNU-MEPhI, Russia
8:35 AM	0:20	Exploration of astrophysical phenomena with scaled laboratory experiments	C. Li	MIT, USA
8:55 AM	0:20	Weibel-mediated collisionless shocks driven by supersonic plasma flows	V. Tikhonchuk	CELIA, France
9:15 AM	0:20	Observation of Collisions of Magnetized-Plasma Bubbles Mediated by Anisotropic Pressure	N. Woolsey	U. of York, UK
9:35 AM	0:20	Using thermal fields to investigate QED processes with high-power lasers	S. Rose	Imperial College, UK
9:55 AM	0:20	*Break*		
10:15 AM	0:20	Overview of Laser Driven Relativistic Pair Jets Experiments at LLNL	H. Chen	LLNL, USA
10:35 AM	0:20	Laser-Driven Neutrons as a new Probe for HED Plasmas	M. Roth	Technology U. Darmstadt, Germany
10:55 AM	0:20	X-ray sources from laser-wakefield acceleration on picosecond, kilojoule-class lasers	F. Albert	LLNL, USA
11:15 AM		**Plenary session - 4: Conclusions**		
11:15 AM	0:30	Magnetic field amplification experiments on large-scale laser facilities	G. Gregori	U. of Oxford, UK
11:45 AM	0:45	Round tables wrap-up	3 chairmans	
12:30 PM	0:20	Conclusions : Organization, next User-meeting	Organizing committee	
12:50 PM	2:00	*Lunch* / ***Posters session***		
2:50 PM	0:10	Transportation to LMJ-PETAL		
3:00 PM	2:00	**LMJ-PETAL tour**		
5:00 PM		Adjournment, transportation to hotels		

CONTENT

ORALS

POSTERS

Orals

Oral

X-ray sources from laser-wakefield acceleration on picosecond, kilojoule-class lasers

F. Albert[1], N. Lemos[1], J. L. Shaw[2], C. Goyon[1], K. A. Marsh[2], B. Pollock[1], A. Pak[1], J. Ralph[1], A. Saunders[4], W. Schumaker[3], R. Falcone[4], J. D. Moody[1], S. H. Glenzer[3], C. Joshi[2]

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This talk will discuss the prospects of developing x-ray and gamma-ray sources based on laser-wakefield acceleration (LWFA) for probing high energy density science experiments at large-scale laser facilities, including NIF-ARC at the Lawrence Livermore National Laboratory, and LMJ-PETAL.

High Energy Density Science laser facilities are now uniquely able to create conditions of temperature and pressure that were thought to be only attainable in the interiors of stars and planets. To diagnose such transient and extreme states of matter, the development of efficient, versatile and fast (sub-picosecond scale) x-ray and gamma-ray probes has become essential for HED science experiments.

We will present recent experiments on the production of LWFA-based radiation, with photon energies from a few keV to a few MeV, using picosecond laser pulses. Using the Titan laser (LLNL, 150 J, ps), we demonstrated evidence of betatron, Compton scattering, and bremsstrahlung emission in the self-modulated regime of laser wakefield acceleration (SMLWFA), for laser intensities around 10^{18} W/cm^2 [1]. For each radiation generation mechanism, we will go over detailed experimental properties and characterization of the sources, as well as supporting Particle In Cell simulations [2].

Finally, we will discuss planned experiments (2019-2020) to demonstrate LWFA-based x-ray sources at ARC, and our proposal for LMJ-PETAL experiments.

Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344, supported by the LLNL LDRD program under tracking code 16-ERD-041, and supported by the DOE Office Science Early Career Research Program under SCW 1575-1.

References

[1] F. Albert et al, *Physical Review Letters* 118, 134801 (2017)

[2] N. Lemos et al, *Plasma Phys. Controlled Fusion* 58, 034018 (2016)

Oral

Hydrodynamics studies of shock ignition targets

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Shock ignition [1] is a laser direct-drive inertial confinement fusion (ICF) scheme in which the stages of compression and hot spot formation are partly separated. The fuel is first imploded at a lower velocity than in conventional ICF, reducing the risks due to Rayleigh-Taylor instability. Close to stagnation, an intense laser spike drives a strong converging shock, which contributes to hot spot formation. Shock ignition shows potential for ignition and energy gain at laser energy below 1 MJ [2], and could in principle be tested on the National Ignition Facility or Laser MegaJoule. Novel crucial issues related to intense laser–plasma interaction and shock generation are actively investigated both experimentally and theoretically [3].

In this talk, we present an overview of recent work by our group, concerning hydrodynamic studies of shock ignition targets. We used analytical models and 1D and 2D numerical simulations with the goal of designing robust targets. We considered both a pure-DT and a DT-CH target. We evaluated target ignition margins, and showed how these margins depend on implosion velocity, spike intensity, timing and inner DT vapour density. We generated gain curves with different safety factors, by means of 1D simulations. The robustness of the designs to low-mode perturbations was evaluated using 2D simulations. In particular, we studied yield degradation as a function of perturbation mode and perturbation amplitude, for different values of laser compression power, laser spike power, and DT vapour density.

In the talk, we will also discuss possible shock-ignition relevant experiments on LMJ in the present configuration, and full-scale experiments on the completed full energy facility.

Work supported by Sapienza Project C26A15YTMA, Sapienza 2016 (n. 257584), Eurofusion Project AWP17-ENR-IFE-CEA-01.

References

[1] R. Betti, et al., Phys. Rev. Lett. 98,155001 (2007)
[2] S. Atzeni et al. Nucl. Fusion 14, 054008 (2014)
[3] D. Batani et al. Nucl. Fusion 14, 054009 (2014); D. Batani et al, submitted to Nuclear Fusion (2018)
[4] S. Atzeni, A. Marocchino, A. Schiavi, Plasma Phys. Control. Fusion 57, 014022 (2015); S. Atzeni et al., *43rd EPS Conference on Plasma Physics (Leuven 2016)* paper P4.092

Oral

Preliminary results from the qualification experiments of the PETAL+ diagnostics

D. Batani[1], J-E. Ducret[2], S. Hulin[2], D. Raffestin[2], N. Rabhi[2], K. Jakubowska[2], G. Boutoux[3], I. Lantuéjoul[3], B. Vauzour[3], L. Lecherbourg[3], B. Marchet[3], Ch. Reverdin[3], A. Duval[3], JL. Miquel[3], B. Rossé[3], Ch. Rousseaux[3], J-Ch. Toussaint[4], A. Chancé[4], D. Dubreuil[4], B. Gastineau[4], J-Ch. Guillard[4], F. Harrault[4], D. Leboeuf[4], X. Leboeuf[4], D. Loiseau[4], A. Lotode[4], C. Pès[4], T. Caillaud[5], F. Granet[5], P. Prunet[5], T. Ceccotti[6], J. Fuchs[7], M. Koenig[7], L. Sérani[8]

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The EquipEx PETAL+ is a project funded by French ANR (National Research Agency) with the goal of developing the first plasma diagnostics for the PETAL laser coupled to LMJ. The project runs from 2011 to 2019 with a total budget of 9.3 M€.

The following diagnostics have been realized within the project:

- SEPAGE: a Thomson Parabola for ions/protons in the 100 keV–200 MeV range, and for electrons in the 100 keV-100 MeV range
- SESAME: two electron spectrometers for the 0.1–150 MeV range placed at two different positions (to get information on the angular distribution of emitted electrons)
- SPECTIX: a crystal X-ray spectrometer (Cauchois geometry) for 6-135 keV with $\Delta\lambda/\lambda$ = 1/300
- CRACC: a radiographic unit (cassette) containing stacks of radiochromic films or imaging plates (IP) for proton / X-ray radiography using PETAL as a backlighter source

Such diagnostics are associated to "systems for the insertion of diagnostics" (SID), which allow bringing the devices close to the target within the 10-m diameter LMJ interaction chamber, pre-aligning them, extracting the imaging plates, while keeping the vacuum and, even more important, while maintaining the nuclear segregation of the chamber. Unlike other diagnostics, SESAME modules are placed on the wall of the interaction chamber.

Two campaigns in November 2017 and April/May 2018 have been done to test the performance of the diagnostics and, at the same time, characterise the emission of protons, electrons, X-rays from targets irradiated with the PETAL laser.

The talk will present the experimental results obtained during these campaigns and the preliminary analysis of results.

PETAL+ diagnostics have been successfully used in the first "Academic Opening" experiments on LMJ/PETAL allowing in particular to obtain high-quality proton radiography images of irradiated samples

Oral

Effect of hot electrons on strong shock generation in the context of shock ignition

Sophie Baton[1], Edouard Le Bel[2], Stéphanie Brygoo[3], Christophe Rousseaux[3], Jocelain Trela[2], Michel Koenig[1], Didier Raffestin[2], Dimitri Batani[2], Alexis Casner2, Wolfgang Theobald[4], Arnaud Colaitis[4], Guillaume Boutoux[3], Laurent Jacquet[3], Leonida Gizzi[5], Gabriele Cristoforetti[5],

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The proposed experiment on the LMJ-PETAL facility addresses the study of the physics related to the shock ignition approach in Direct Drive Inertial Confinement Fusion studies for future energy production. Shock ignition is a promising scheme relying on the assembly at low implosion speed of a deuterium tritium mixture, being ignited by a strong shock launched just before the end of the compression phase. The intensity of the final laser drive (spike) should be close to 10^{16} W/cm^2. Important issues of SI are the interaction of the laser pulse with a long scale-length plasma formed by the CH ablator, the role of hot electrons to the shock characteristics, and the shock propagation in the compressed shell.
Parametric instabilities at high laser intensities reduce the collisional laser-plasma coupling thereby affecting the generation and propagation of the high-pressure shock. The intense energetic electron flows, generated by stimulated Raman scattering and two-plasmon decay, propagate and deposit their energy inside the target. They may preheat the target hardening its compression, but, on the contrary, may enhance the ablation and the strong shock pressure. This depends on the number and average energy of the hot electrons, which depend on the details of the hot-electron generation.
The experiment aims to investigate:

- laser-target coupling in realistic inertial fusion conditions obtained with the LMJ laser beams and its effect on the strong shock generation;
- the characteristics of hot electrons energy distribution and fraction;
- the effect of the laser beam smoothing (SSD) on the hot electrons production and shock strength.

The experiment is scheduled in two parts: in the first one (in April 2019), it is planning to characterize the hot electron population in terms of temperature and total energy, to study LPI physics at these high laser intensities and to obtain X-ray radiographs of the curved shock front in the target. During the second one (in 2020), we will estimate the shock speed under SI relevant conditions.

We will present the set-up of the experiment, the diagnostics and their specific role.

This experiment is supported by the «ToIFE » (Towards Demonstration of Inertial Fusion for Energy) EUROfusion Consortium and by Institute Lasers-Plasmas.

Oral

PETAL laser performance

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The Petawatt Aquitaine Laser (PETAL) [1] facility has been designed and constructed by the french Commissariat à l'énergie Atomique et aux énergies alternatives (CEA) to deliver laser pulses in the kJ-picoseconde range at the wavelength of 1053 nm and is an additional short pulse beam to the Laser MegaJoule (LMJ) facility. PETAL energy is limited to less than 1 kJ at the beginning due to the damage threshold of the final optics [2].

The commissioning of focal spot on target and the main performance during the first campaigns (2nd semester 2017 and 1st semester 2018) on target will be presented. It will concern: alignment of the sub-aperture compression stages in order to optimize the pulse compression (the mean duration was 685 fs for the 2018 ps shots, the best 2018 value being 570 fs), the intensity on target of 7.9 10^{18} W/cm² (intensity inferred from measurements at the end of the compressor for the 409 J @ 660 fs shot), the alignment performance (positioning, pointing) and demonstration of the first associated LMJ and PETAL laser shots on target. The temporal contrast will be also addressed.

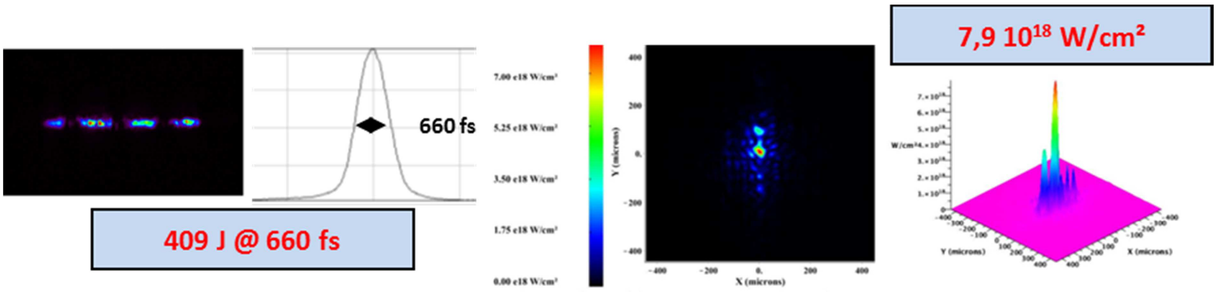

Figure 1: autocorrelation trace (left) and focal spot (right) measured on the compression diagnostic table for the 409 J @ 660 fs shot giving 7.9 10^{18} W/cm².

The PETAL construction was performed by the CEA ("maître d'oeuvre") under the financial auspices of the Nouvelle-Aquitaine Region in France (project owner), of the French Government and of the European Union.

References

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[2] M. SOZET et al., “Sub-picosecond laser damage growth on high reflective coatings for high power applications,” Opt. Express 25(21), p. 25767-25781 (2017).

Oral

Investigating magnetic reconnection in ICF conditions

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Magnetic reconnection (MR) is a process which occurs in many astrophysical plasmas, e.g. in solar flares, in coronal mass ejecta, or at the outer boundary of the Earth magnetosphere. However, as of now, the fundamental microphysics implied in this process is far from being well understood. Most of the investigations on this long standing issue come from numerical studies and space observations. Laboratory modelling of plasmas, including those that can be generated by high-power lasers, offer now new perspectives to investigate MR and the processes governing it.

We will present recent experiments, performed using the LULI2000 facility, aimed at investigating the dynamic of magnetic reconnection in a non-coplanar configuration between two magnetic toroids induced by two near-by laser spots irradiating solids targets. Despite being distinct from the astrophysical plasmas where the beta parameter is low ($\sim 10^{-3}$ in solar corona and ~ 1 in solar winds), such HEDP reconnection experiments are of interest to investigate fundamental issues in MR such as the influence of a guide field on the dynamic of the MR.

Then we will present the future experiment on MR that will take place at LMJ/ PETAL facility. This facility offers the possibility to investigate an unexplored set of parameter for MR and in the same time, we will be able to evaluate for the first time the importance of the effect of MR and their consequence in the ICF context.

Oral

A Perspective on the Future of ICF and HEDP Research

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Significant advances have been made worldwide in inertial confinement fusion (ICF) since its beginnings nearly five decades ago. While research was originally focused on the physics of ICF, the facilities, diagnostics, modeling, and simulations that were initially developed to explore fusion have enabled the growing and vibrant field of high-energy-density physics (HEDP) with impact in condensed matter and astrophysical, stellar, and planetary physics. The detailed "microphysics" of HEDP will also improve the understanding and expanded the design space for ICF. Facilities in the United States including the National Ignition Facility (NIF) and Omega Laser Facility, the Z Pulsed Power Facility, Orion, the lasers at the Central Laser Facility, LMJ, Petal and the ELI initiative in Europe, and the SG-III and GEKO lasers in Asia will ensure a vibrant future for ICF/HEDP in the decades ahead. Combining HEDP facilities with free electron lasers such as the MEC station at SLAC will also enable innovative and impactful HEDP research. In this presentation, a perspective on the present state of the field and a future vision for research will be discussed.

This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944, the University of Rochester, and the New York State Energy Research and Development Authority.

Oral

Overview of Laser Driven Relativistic Pair Jets Experiments at LLNL

Hui Chen on behalf of the Team

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High-flux jets of electron-positron pairs at 10s of MeV energy range have been produced in experiments at high-intensity laser facilities. The laser intensities were 10^{18} - 10^{21} W/cm^2 with pulse duration of 1-10 ps and energy 100 - 2000 J. This presentation reviews the experimental results from multiple laser facilities including Titan, Omega EP, Osaka LFEX and NIF ARC. The characterizations of the pair jets include the energy distribution, angular divergence and emittance; the pair jet temperature and density; pair production scaling and collimation by external magnetic fields and the pair yield scaling. The presentation concludes with discussion of possibilities to exploit laser-produced pair jets for diagnosing high-energy-density physics, and for laboratory astrophysics experiments.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344 and funded by LDRD (#17-ERD-010).

Oral

Tutorial: Practical advices on how to perform ns X-ray radiography on LMJ

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Several campaigns using laser produced ns X-ray radiography have been performed on LMJ since the 2014 first experiments. The objective of this tutorial is to share our experience with users by giving practical advices on how to perform such a radiography on LMJ. Considerations on target alignment, radiography scheme and plasma diagnostic performances will be discussed in this talk.

Oral

LMJ Facility: Status and Performance

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LMJ is a neodymium glass laser (1.053 µm wavelength) under commissioning at CEA/CESTA at a primary stage of 176 beams (44 quads). The 1.053 µm light is frequency converted to the third harmonic (0.351 µm) and focused, by means of gratings, on a target at the center of target chamber. The target chamber is equipped with two hundred ports for the injection of the laser beams and the location of diagnostics

The PETAL laser consists of one short-pulse (500 fs to 10 ps) ultra-high-power, high-energy beam (few kJ) synchronized with the nanosecond beams of LMJ.

The first CEA-DAM physics experiments on LMJ was performed at the end of 2014 with a limited number of beams and diagnostics. The LMJ operational capabilities increase gradually by the commissioning of news bundles and plasma diagnostics each year.

For the facility operation, we set up an organization allowing to follow and guarantee our capacity to carry out in parallel the experiment campaigns with the assembly and the commissioning of new the equipment's. The use of Petal in experimental campaigns in 2017, has to lead us to set up new means to manage the radiological risks

Oral

Experimental observation of nonlocal electron transport in warm dense matter

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We present the first experimental observation of nonlocal electron transport in warm dense matter using X-ray Thomson Scattering (XRTS) measurement from low-density CH foams compressed by a strong laser-driven shock at the OMEGA laser facility [1]. The XRTS measurement was combined with velocity interferometry (VISAR) and optical pyrometry (SOP) providing a robust measurement of thermodynamic conditions in the shock and the preheated region. Evidence of significant preheat contributing to elevated temperatures reaching 17.5 − 35 eV in the shocked CH foam was measured by XRTS. These measurements were complemented by abnormally high shock velocities observed by VISAR and early emission seen by SOP. The experimental measurements were compared to radiation hydrodynamics simulations using the PETE code [2] that include explicit treatment of nonlocal electron transport in WDM with an excellent agreement.

References

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Oral

Efficient Creation of High-Energy-Density-State with Laser-Produced Strong Magnetic Field

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The quest for the inertial confinement fusion (ICF) ignition is a grand challenge, as exemplified by extraordinary large laser facilities like National Ignition Facility (NIF). Although scientific break-even, the energy released by fusion reaction exceeds the energy contains in the compressed fusion fuel, was achieved on NIF, the pathway to the ignition is still unclear.

Fast isochoric heating of a pre-compressed plasma core with a high-intensity short-pulse laser is an attractive approach to create ultra-high-energy-density states like those found in inertial confinement fusion ignition sparks. This avoids the ignition quench caused by the hot spark mixing with the cold fuel, which is the crucial problem of the currently pursued ignition scheme.

Relativistic-intensity laser-plasma interactions efficiently produce relativistic electron beams (REB). However, only a small portion of the REB collides with the core because of its large divergence. Here we have demonstrated enhanced laser-to-core energy coupling with a magnetized fast isochoric heating method. The method employs a kilo-tesla-level magnetic field that is applied to the transport region from the REB generation point to the core which results in guiding the REB along the magnetic field lines to the core. 7.7 ± 1.3 % of the maximum coupling was achieved even with a relatively small radial area density core ($\rho R \sim 0.1$ g/cm^2).

A simple model shows 6.2% of the coupling with the experimentally measured parameters, this value is fairly consistent with the coupling measured in the integrated experiment, and the simple evaluation reveals that higher area density core leads to higher laser-to-core coupling. An energy density increment of the heated core is about 1 Gbar, which corresponds to 50 J of the energy deposition in a 100 μm-diameter spherical volume. An ultra-high-energy density state could be efficiently created by the magnetized fast isochoric heating.

Finally, plasma hydrodynamics, generation and transport of electron/ion beams, thermal conduction and α particle transport will be able to be controlled by the externally applied strong magnetic field. There is no doubt that laser-plasma experiments with strong magnetic fields contain a lot of unexplored physics, therefore this research also stimulates spin-off sciences in the field of atomic physics, nuclear physics, and astrophysics which act to broaden inertial fusion sciences and high energy density sciences.

Oral

Magnetic field amplification experiments on large-scale laser facilities

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Magnetic fields are ubiquitous in the Universe. The energy density of these fields is typically comparable to the energy density of the fluid motions of the plasma in which they are embedded, making magnetic fields essential players in the dynamics of the luminous matter. The standard theoretical model for the origin of these strong magnetic fields is through the amplification of tiny seed fields via turbulent dynamo to the level consistent with current observations. Experimental demonstration of the turbulent dynamo mechanism has remained elusive, since it requires plasma conditions that are extremely hard to recreate in terrestrial laboratories. Here we demonstrate in experiments at large scale laser facilities (Omega, NIF and LMJ), using laser-produced colliding plasma flows, that turbulence is indeed capable of rapidly amplifying seed fields to near equipartition with the turbulent fluid motions. These results apply to both compressible and incompressible flows, and support the notion that turbulent dynamo is a viable mechanism responsible for the observed present-day magnetization.

Oral

Target laboratory on LMJ facility

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The LMJ/PETAL facility has a specific laboratory for the assembly and metrology of the targets. This laboratory is in charge of the target of the LMJ/PETAL and Omega installations but can also be used for LULI installations. The team of 6 engineers and technicians deals with 10 to 15 campaigns per year representing more than 100 targets.

The laboratory facilities are constantly evolving to take into account the increasing complexity of the targets. The geometries will be more complex with many elements arranged in space and positioned in the center of the LMJ chamber with six CCD. The materials used, rare earth or foam, will have to be handled and stored under special conditions.

The assembly and metrology of the target buildings meet external requirements whose purpose is the alignment in the center chamber. The laboratory relies on two means of metrology and a set of opto-mechanical benches for assembly to satisfy these requirements. The metrology means allow measurements in volumes of several hundred mm with accuracies of the order of 10 microns. The future needs of the LMJ, 3D accuracy of 5 μm, are taken into account for the implementation of new means. The assembly, which is based on old-generation opto-mechanical stations, is also redesigned to take into account the future requirements of the LMJ. All of these future needs must make it possible to maintain the requirement of alignment in the center chamber.

As part of the preparation of the campaigns and the safety of the facility, the laboratory is also in charge of EMI protection and debris. Shield were developed and tested as well as debris collectors. The campaigns of 2017 and 2018 made progress on this issue

Finally, the laboratory is developing a new mean associated with the target positioner that allows to guarantee the gas pressure in the LMJ cavities. This mean will be deployed during the campaigns of 2019

Oral

Kinetic effects in laser-driven spherical implosions

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Experiments are indicative of substantial kinetic effects during the course of a spherical implosion. The effects appear as the plasma mean-free-path grows relative to the background scale making standard rad-hydro single-fluid description invalid. To understand their mechanics and implications it is convenient to consider the thermal and suprathermal particles separately. For the former, sharp gradients can drive the inter-ion-species diffusion, so the fuel composition no longer remains constant unlike what the standard, single-fluid codes assume. Atomic mix at interfaces is, fundamentally, due to the same diffusion process. For the latter, the mean-free-path is much larger than that of their thermal counterparts, so their distribution function may be far from Maxwellian, even if thermal ions are nearly equilibrated. It is these suprathermal, or *tail*, ions that fuse in subignited implosions. Their distribution is thus the key to proper interpretation of nuclear diagnostics employed in HEDP experiments in general and to correct fusion yield prediction in particular. Furthermore, suprathermal electron distribution shows similar behavior, affecting the X-ray diagnostics. Basic mechanisms behind and practical consequences of these groups of effects in ideal and non-ideal HED plasmas will be discussed.

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Oral

Optical generation of strongly magnetized plasma

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Hot magnetized plasma may be generated by intense laser light, interacting with dense or dilute targets, when the symmetry of interaction is broken. Among many different possibilities, some appear to be rather stable and effective. In this study, we present some theoretical and experimental results showing the possibility of the all-optical generation of hot magnetized plasmas with some specific target geometries.

As an example, targets with cavities ("snails"), directing the light along their internal surfaces, demonstrate a very efficient absorption and generation of intense geometrically defined currents. Recent experiments showed the robustness and stability of the main processes, resulting in the magnetic field generation. The structures in the target volume are defined by many factors, and at some situations may be interesting in studies related to reconnection phenomena. Besides, other unusual processes in curved targets, related to the strong magnetic field generation, were observed. Considering the possible ways of generating the azimuthal currents in laser-matter interaction, we discuss the possibility of using the targets with internal chirality.

The optical plasma magnetization makes possible preparing a wide range of experimental studies in the astrophysical context. Other ways, such as conventional discharge schemes, at some situations are not effective as they can not provide necessary magnetic field gradients and strength in hot collisionless plasmas.

Oral

Exploration of astrophysical phenomena with scaled laboratory experiments

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We have made significant progresses recently in exploring several important astrophysical phenomena at OMEGA. These scaled laboratory experiments are highlighted by a number of high-profile publications: First, we have explored the kink behavior of the Crab Nebula jet in laboratory with a plasma jet and associated magnetic fields that were created by high-power lasers through well-defined physical scaling laws. We show exactly how MHD instability develops and causes the kinks and resultant changes of direction in the jet, mimicking the scenario of Crab jet; Second, we have performed the first laboratory experiments successfully involving the generation and observation of Weibel-mediated, electromagnetic collisionless shocks in astrophysical regimes. We reveal a novel physical mechanism showing how the Weibel-driven filaments penetrate into the pre-compressed magnetic turbulent region, resulting in entropy production and the formation of the Weibel-mediated shock. We also demonstrate particle acceleration via the first-order Fermi mechanism, a unique and critical feature of astrophysically relevant, electromagnetic collisionless shocks that previously has not been achieved in laboratory experiments. Third, we have studied ^{3}He+^{3}He, T+^{3}He, and p+D nuclear reactions in the regime relevant to stellar and Big-Bang Nucleosynthesis, using inertially-confined plasmas. The advantage of using these thermal plasmas is that they better mimic astrophysical systems than conventional cold-target accelerator experiments. Important results were obtained, including using the resulting T+^{3}He γ-ray data to rule out an anomalously-high ^{6}Li production during the Big Bang as an explanation to the high observed values in metal poor first generation stars. And fourth, we have studied Megagauss magnetic reconnections in rapidly-expanding laser-generated plasmas. This experiment offers a unique laboratory opportunity relevant to high-β reconnection environments such as the Earth's magnetopause.

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Oral

Experimental Process on LMJ

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The presentation is dedicated to describe the experimental process on LMJ and the role of the experiment manager at CEA in charge of the preparation of accepted experiment in collaboration with the PI.

Once the experiments have been selected, the experimental campaigns are included in the schedule of the facility by the CEA-DAM Programming Committee. At the same time, Experiment Managers from CEA are designated in order to prepare the experiment in close collaboration with the PI and the selected groups.

The key milestones in the PETAL-LMJ experimental process will include several reviews in order to evaluate the experimental preparations and readiness. The presentation will describe all these reviews.

Oral

Review of General Atomics Target Fabrication: Facilities, Capabilities, and Notable Recent Developments*

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TARGET FABRICATION

General Atomics along with its partners have been supporting the DOE/NNSA Stockpile Stewardship Program since 1992 with target fabrication activities. Over the last five years GA has provided targets in support of Laboratory Basic Science, National Laser User Facility, High Energy Density Physics, Fundamental Science, National Security, and Inertial Confinement Fusion campaigns conducted on multiple facilities.† Advancements in GA's capabilities and facilities such as implementation of robotics and the use of automation to complete target characterization and builds have occurred to enable the fabrication and delivery of target components and fully assembled targets. In this talk we will review the current status of GA's Inertial Fusion Technology (IFT) group: its facilities, fabrication capabilities, deliveries, research activities and recent developments.

†Omega/EP, National Ignition Facility, Jupiter Laser Facility, Trident Laser Facility, Linac Coherent Light Source, Scarlet Laser System, Texas Petawatt Laser Facility, Center for Ultrafast Optical Science's Hercules laser, Rutherford Appleton Laboratory Vulcan Laser, Orion Laser Facility, Laboratoire pour l'Utilisation des Lasers Intenses, Institute of Laser Engineering, Centre Lasers Intenses et Applications

Oral

Visualization of fast heated plasma by X-ray fresnel phase zone plate

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X-ray measurements are powerful diagnostics for high energy density plasma. They have been used in both self-emission and absorption geometries to measure high energy density plasma parameters such as temperature and density.

Especially, X-ray measurement is indispensable to prove direct-drive fast-ignition (FI). Direct-drive fast-ignition is an attractive approach for inertial confinement fusion ignition. It is relaxed requirements regarding implosion uniformity compared with central hot spot ignition. In the FI scheme, first multiple nano-second laser beams (the implosion lasers) compress a spherical fusion fuel. After the compression, the dense fuel core is heated by fast electrons generated by an intense pico-second laser pulse (the heating laser). In this context, to determine the fast electron penetration efficiency into the dense fuel core are essential for understanding the fast electron transport and optimizing the target design.

Jarrott *et al* reported on the first visualization of fast electron transport in a laser-compressed FI target. [1] The experiment performed by doping the target with copper and imaging the Kα radiation with an imaging crystal. K radiation, characteristic of the target material, is generated when an electron creates a vacancy via electron impact ionization. When an L-shell electron fills the vacancy, a Kα photon is emitted. Visualization of Kα radiation distribution clearly showed fast electron transport.

However, X-ray imaging technique using the Kα radiation is limited by Kα line shifting and broadening. After the plasma heating, the plasma ionizes. Some resonance X-rays, such as Heα radiation are emitted from the ionized plasma. These resonance X-ray distributions reflect the heating distribution. Therefore we need to image Kα and Heα X-ray for characterization.

In this study, we succeeded in measuring the two-dimensional heating distribution of the fast heated high energy density plasma. A heavy hydrogen target containing Titanium as a tracer was compressed with a nanosecond laser and then heated with a picosecond laser. TiKα and TiHeα X-ray generated from the target were imaged using a Fresnel Phase Zone Plate (FPZP). The two-dimensional distribution of the imaged TiKα and TiHeα X-ray characterized the fast heated high energy density plasma.

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Oral

Numerical investigation on non-thermal electron effects measured in a Gekko experiment at intensities relevant to shock ignition.

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The shock ignition direct-drive approach may induce non-thermal electrons at the end of the compression phase. Depending on the areal density of the target and the electron characteristics, they may have beneficial or detrimental effects [1]. Recent experiments have been realized at Gekko laser facility to better characterize these electrons [2]. Multi-layered foils, without and with internal gap, were irradiated by short (300ps) and high intensity (above 1016W/cm2) laser pulses at the first harmonic (1.06 µm). We will present first simulations of non-thermal electron effects on shock propagation, shock pressure and rear side emission [3]. Both Stimulated Raman Scattering and Two Plasmon Decay play a role in the non thermal electron generation even if the latter process is not important in this experiment. We will show, for some target geometries, these electrons may modify temporally but also spatially the X-ray and visible emissions emitted by the target.

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Oral

Auxiliary Heating for Inertial Fusion

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I will review some progress that has been made by British, Portuguese and American colleagues in the EUROFusion ToIFE project, which gathered fourteen European laboratories from nine nations, with the aim of achieving an overall understanding in physics required to demonstrate the viability of laser-driven fusion. The project hinges on (i) a program of experiments and numerical simulations to understand underlying obstacles to central hot spot ignition on MJ-scale laser facilities (ii) a program of experiments and numerical simulations for the demonstration of shock ignition on LMJ in the 2020's (iii) a program of numerical simulations and experiments to test the viability of alternative ignition schemes and (iv) the conceptual design of an Inertial Fusion Energy (IFE) reactor based upon key technologies such as high repetition rate lasers.

In this presentation, I will discuss the idea of combining hydrodynamically stable, low convergence ratio "wetted foam" implosions, as recently demonstrated on the NIF [R.E. Olson et al., Phys. Rev. Lett. 117 235001 (2006)] with the new concept of heating of the hot spot by crossing relativistic electron beams [N. Ratan et al., Phys. Rev. E 95, 013211 (2017)], developed under the ToIFE project over the past four years. In support of this novel approach, evidence is presented of stable formation, using 2nd harmonic petawatt laser pulses from the ORION laser facility at AWE, Aldermaston. These experiments are ideally suited to scaling to the LMJ-PETAL laser facility. I will also discuss recent developments in Raman amplification studies that are a key element in this "auxiliary heating" concept.

Oral

Exploring the universe through Discovery Science on NIF*

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An overview of recent research done on the 2 MJ, 192 beam, 1-30 ns NIF laser facility, including the 4 beam, ~1 kJ/beam, 1-30 ps ARC laser at LLNL through the NIF Discovery Science program will be presented. Examples will be drawn from experimental studies of equations of state of H, C, CH, and Fe at high pressures (1-60 Mbar) and high densities relevant to planetary interiors; Rayleigh-Taylor hydrodynamic instability growth in high energy density (HED) settings relevant to core-collapse supernovae and supernova remnants; high velocity, low density interpenetrating plasma flows that can lead to collisionless astrophysical shocks relevant to colliding galaxies, supernova remnants, and Herbig-Haro jets; photoionized plasmas surrounding accreting compact objects such as white dwarfs ("cataclysmic variables"), neutron stars, or massive black holes at galactic centers and known as active galactic nuclei (AGN); particle acceleration from collisionless shocks, 3D turbulence, or magnetic field reconnection that can lead to cosmic ray generation; and perhaps the most enigmatic of all, gamma-ray bursts. We will then focus on and conclude with a summary of recent experiments done on NIF, Omega, and other HED laser facilities to study unique regimes of plasma nuclear astrophysics relevant to star formation, stellar evolution, supernova explosions, and big bang nucleosynthesis (BBN). We will also mention some very new results using the ~1018 W/cm2 ARC laser to generate ~MeV slope temperature plasmas from which we observed relativistic electron-positron pair plasma generation and 10-20 MeV TNSA (target normal sheath acceleration) protons. These latest results will enable relativistic laboratory astrophysics studies in the future at NIF.

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Oral

Using thermal fields to investigate QED processes with high-power lasers

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Many experiments have been proposed and undertaken that use ultra-intense laser radiation to investigate QED effects. These experiments generally investigate high-field non-linear QED where the electron is often treated theoretically as a dressed Volkov state. Here we identify a separate and new category of experiments that use high-power lasers to create thermal (or quasi-thermal) radiation fields that can be used to investigate linear QED processes which are of interest in astrophysics, cosmology and are also of fundamental interest.

We describe an experiment (Pike et al 2014) which has the aim of demonstrating the two-photon Breit-Wheeler process ($\gamma\gamma\rightarrow e^+e^-$), the simplest mechanism by which light can be transformed into matter. This linear two-photon Breit-Wheeler experiment involves using one arm of the UK's Gemini laser operating at 30fsec pulse duration to produce laser-driven electron acceleration followed by conversion to high-energy gamma-ray photons by bremsstrahlung. This beam of gamma-ray photons is then incident on a thermal radiation field generated using the second Gemini beam operating in an uncompressed mode interacting with a converter foil. The particularly new aspect of the proposed experiment involves using a thermal radiation field as the 'target' for the collider.

We see this experiment as the first in a new class of experiments that use such a photon-photon collider produced using high energy density facilities such as LMJ-PETAL, which will investigate fundamental QED processes in the laboratory. Future experiments are being considered including the measurement of photon-photon (light by light) scattering. This measurement is particularly important and interesting because it gives a route to identify beyond-Standard-Model physics, such as axion physics and Born-Infeld electrodynamics.

'A photon-photon collider in a vacuum hohlraum', O J Pike, F Mackenroth, E G Hill and S J Rose, Nature Photonics, **8**, 434 (2014).

Oral

Laser-Driven Neutrons as a new Probe for HED Plasmas

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Short-pulse laser-driven neutron sources have become a topic of interest since their brightness and yield have recently increased by orders of magnitude. Using novel target designs, high contrast - high power lasers and compact converter/moderator setups, these neutron sources have finally reached intensities that suits interesting applications.

We present the results of experimental campaigns on the GSI PHELIX and the LANL Trident lasers. We have produced an unprecedented neutron flux, mapped the spatial distribution of the neutron production as well as its energy spectra and ultimately used the beam for first applications to show the prospect of these new compact sources. We also made measurements for the conversion of energetic neutrons into short epithermal and thermal neutron pulses in order to evaluate applications for non-destructive testing, radiography and nuclear safeguard applications.

PETAL as one of the highest energy short pulse laser would allow for unprecedented neutron bursts that could be used for fast neutron radiography, neutron imaging, temperature measurements of WDM and even activation of nuclear material on a nanosecond timescale. Thus we believe the new neutron production scheme is of interest to the PETAL user community.

The results also address a large community as it paves the way to use short pulse lasers as a neutron and hard x-ray source. This can open up neutron research to a broad area of applications as those potentially compact and mobile sources could lead to testing and inspection systems. We already demonstrated the use in active interrogation of sensitive nuclear material and Isotope identification by neutron resonance spectroscopy. Future laser systems with high average power could complement or even replace large scale facilities like reactors or particle accelerators.

Oral

Demonstration of Imprint Mitigation in Planar Geometry by a Combination of X-Ray–Driven Picket-Pulse Shocks and Directly Driven Targets

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A new scheme was tested to mitigate laser imprint in direct-drive inertial confinement fusion. It is based on the idea that the initial shock wave is driven by x rays generated by a short laser pulse followed by a long main laser pulse that directly drives the target. This hybrid scheme uses a target design with a 0.5-μm-thick CH membrane coated with 40 nm of Au to generate the initial shock with x rays. The membrane is located several hundred microns away from the imploding shell. Using x rays to drive the first shock promises to significantly eliminate short- and medium-wavelength modes from laser imprinting. A proof-of-principle experiment was performed in planar geometry showing promising results. We demonstrate x-ray–driven shocks at peak pressures of up to 8 Mbar in quartz and CH layers for different picket energies and distances of the membrane. Face-on x-ray radiography measurements show an imprint reduction in the hybrid target compared to standard plastic foils, most obviously for short wavelengths. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

Oral

Weibel-mediated collisionless shocks driven by supersonic plasma flows

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Collisionless shocks, a consequence of supersonic flows sweeping across an interstellar or intergalactic medium, are ubiquitous in the universe. They have been speculated to cause many fundamental astrophysical phenomena by heating and compressing background plasmas; seeding and amplifying magnetic fields; and accelerating cosmic rays. Despite the importance of shocks and their underlying physics, the shock structure and fundamental behaviors remain controversial, as there have been few ways to study them experimentally.

We report on the laboratory experiments and their theoretical interpretation involving the generation and observation of Weibel-mediated, electromagnetic collisionless shocks in astrophysical regimes, manifested by critical physical parameters. The spatially resolved filaments at the front of the magnetosonic shocks indicate the compelling evidence of Weibel currents driven by two interpenetrating ion streams in front of a magnetic piston. We reveal a novel physical mechanism explaining how the Weibel-driven filaments penetrate into the magnetized region of interaction and amplified downstream in the pre-compressed magnetic turbulence, resulting in entropy production and shock mediation. We also demonstrate particle acceleration via the first-order Fermi mechanism, a unique and critical feature of astrophysically relevant, electromagnetic collisionless shocks that previously has not been achieved in laboratory experiments.

The experiments directly mimic the scenario of collisionless shocks in nonrelativistic astrophysical contexts such as supernova remnants, and provide a roadmap into the shock physics in relativistic regimes such as afterglow of cosmological γ-ray bursts. This experimental scheme can be reproduced on a larger scale on the LMJ-PETAL laser facility.

Oral

A preparatory experiment to LMJ-SI (S. Baton) experiment: Radiography of shocks and hot electron preheat on OmegaEP

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The shock ignition scheme is an alternative approach to the classical direct drive inertial confinement fusion. It uses an intense laser spike at the end of the compression phase in order to drive a strong shock inside the target, igniting it. The intensity required for such shock (5.10^{15} W/cm² to 10^{16} W/cm²) is sufficient for the excitation of parametric instabilities leading to a significant amount of laser energy transfer to supra-thermal electrons. The effect of these electrons on the hydrodynamic of the ignitor shock is not yet well understood, or well simulated in hydro-radiation codes. Dedicated experiments are required in order to quantify the hot electrons source parameters in the regime of intensity and plasma gradient length relevant for shock ignition.

An experiment will be conduct on LMJ in 2019 and 2020, aiming to characterize the hot electron population generated by a laser spike in conditions relevant to the shock ignition scheme. As preparation, a smaller scale experiment has been realized on OmegaEP. In this experiment, one or two beams have been used to irradiate of plastic target with a square pulse at an intensity of 5.10^{15}, 10^{16} W/cm², corresponding to a shock ignition spike. Due to the energy limitation of the installation, the plasma conditions of the shock ignition scheme were not reproduced. The main diagnostics for this experiment were:

- Bremsstrahlung cannon and copper K-alpha spectrometry to determine the hot electrons population.
- Side radiography to image the effect of the hot electron energy deposition on the hydrodynamic (both of the shock and of a buried copper layer).

Additionally, the effect of a ~20 T transversal magnetic field (generated with MIFED) have been investigated. The magnetic field is expected to deviate the hot electrons, reducing the preheat of the target.

We will present the set-up of the experiment and the preliminary results.

Oral

Laser-driven experiments shedding light on turbulent dynamo: Platform design and numerical modeling with FLASH

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LMJ TDYNO

Cosmical magnetic fields are ubiquitous in the Universe, with energy densities typically comparable to that of the fluid motions of the plasma in which they are embedded. This makes magnetic fields essential players in the dynamics of observable matter in the Universe. The standard model behind the origin of intergalactic magnetic fields is through the amplification of seed fields via turbulent dynamo to the level consistent with current observations. We have conceived and conducted a series of high-power laser experiments at Omega, NIF, and LMJ to study the dynamo amplification of magnetic fields in different plasma regimes. The properties of the fluid and the magnetic field turbulence are characterized using a comprehensive suite of plasma and magnetic field diagnostics. In this talk, we describe the large-scale 3D simulations we performed with the radiation-MHD code FLASH on ANL's Mira to help design and interpret the experiments. The simulations indicate that magnetic Reynolds numbers above the expected dynamo threshold are achieved and seed magnetic fields, produced by the Biermann battery mechanism, are amplified by turbulent dynamo.

Oral

Ion stopping measurements in plasma targets

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We propose to measure the energy loss of light ions in a warm dense plasma at low projectile velocities. In this parameter range, significant theoretical uncertainties are reported on the stopping power due to electron degeneracy and coupling, and experimental data are missing. The understanding of ion stopping in this regime is of great interest both from a fundamental scientific point of view and for the modeling of inertial confinement fusion plasmas. The considered projectiles are quasi-monoenergetic light ions created from a D3He “exploding pusher” capsule imploded by 6 LMJ quads. The probed warm dense plasma is created by the isochoric X-ray heating of a thin low Z material located inside a metal-coated plastic cavity by X-rays driven by 6 other LMJ quads. Temperatures close to 30 eV at solid density are expected, corresponding to a target electron coupling of $\Gamma \sim 0.3$ and an electron degeneracy ~ 2. The energy spectra □ of the ions that passed through the target are recorded with the SEPAGE charged-particle spectrometer. The target conditions are probed with the Thomson scattering technique by using K-alpha radiation induced by the heating of a back-lighter foil with the PETAL beam. The scattered X-ray spectra are measured with the HRXS (DP10) spectrometer. Proton imaging of the target with radiochromic films (using CRACC) also enables to diagnose the electron density as well as the electric and magnetic fields in the target.

Oral

Observation of Collisions of Magnetized-Plasma Bubbles Mediated by Anisotropic Pressure

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Magnetized plasma interactions are ubiquitous in astrophysical, space, and laboratory plasmas. Various physical effects have been deemed important in supporting the magnetic field dynamics within plasma flows, particularly colliding plasma flows with opposing magnetic fields. We discuss an Orion laser campaign that utlitises the long-pulse and short-pulse beam capability to create two separate focal spots and probe the Biermann generated magnetic fields generated at the laser focus and in the reconnection reconnection region between the spots. Measurements are made in two directions using both protons and optical probe. The detailed measurements of magnetic fields, plasma flows and temperatures of the laser spots have enable detailed understanding the experiment and the opportunity to compare measurement with simulation. The magnetic fields generated in the reconnection region reach a steady maximum by 1 ns and detailed plasma kinetic models are needed to reproduce the strength of the magnetic field, the field configuration and dynamics

Oral

Status of LMJ-PETAL plasma diagnostics

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Since the first experimental campaign conducted in 2014, the LMJ operational capability is growing up. LMJ is now operating with 40 beams (150 kJ), and a set of ten diagnostics are now qualified. X-ray imaging capabilities are provided by two mid-field hard Gated X-ray Imager (GXI) with respectively a spatial resolution of 30 µm and 150 µm and a field of view of 3 mm and 15 mm. Hohlraum energetics performances are measured by the absolute calibrated time resolved broad band spectrometer DMX. DMX is also equipped with an X-ray laser entrance hole imaging system and a time resolved X-ray spectrometer with gratings and streak camera. DMX is set up on the target chamber with a specific collimator inserter. Initially installed on the D9 port, at an angle of 70° to the north pole, DMX was moved at the summer to the D8 port, at an angle of 24°, in a position compatible with the new symmetric irradiation capabilities of the facility. To complete the dynamics of hohlraum energetics measurements, another broad band spectrometer, mini-DMX, used in an insertor, has been developed. Recently, SSXI, a soft X-Ray spectro-imaging system, has been also qualified. SSXI records time-resolved 1D image or time resolved spectra in the soft X-ray spectral region, to analyze radiative waves and target emission. A set of five diagnostics were also specifically designed for use with PETAL (Petal+ Project). SPECTIX measures the hard X-ray spectra in the 6.5 keV – 100 keV range. SESAME 1&2 are two electron spectrometers, installed on fixed location of the target chamber, at 0° and 45° of PETAL axis. They measure electron energies from 5 MeV to 150 Mev and proton energies from 1 to 15 MeV. SEPAGE diagnostic records charge particles spectra (100 keV – 200 MeV for ion / proton spectra, and 100 keV – 150 MeV for electron spectra). SEPAGE is also equipped of an imaging module for proton radiography. The imaging module for proton radiography can also be used in a lighter way by mounting it alone on an arm (CRACC diagnostic).

In the following years, LMJ will increase its capacities with the completion of other beams and the development of new diagnostics. We propose to give an overview of the plasma diagnostics development status conducted at CEA for experimental purpose in the LMJ and PETAL facilities.

Posters

Poster

Utilizing multiple fusion reaction-histories, x-ray emission histories, and charged-particle stopping to evaluate high-energy-density-plasma (HEDP) transport properties at OMEGA

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We present a new technique that is used to evaluate HEDP transport properties, including stopping power and ion-electron equilibration, in D3He thin-glass exploding pushers. This technique is based on measurements of DD and D3He reaction histories, and x-ray emission histories in different energy bands from which time-resolved ion and electron temperatures are inferred. It is also based on measurements of energy loss of the low-velocity ions: DD-3He, DD-triton and D3He-alpha, which is directly related to ion-electron equilibration. From these two complementary measurements, the ion-electron equilibration rate can be determined. Long term, this technique will be extended to more broadly explore transport properties in HEDP at various conditions. The work was supported by DOE, LLNL and LLE.

Poster

EMP studies on the LMJ-PETAL facility

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The interaction of a Petawatt laser with a flat target can produce intense electric field [1] which may exceed 1 MV/m. Such a field leads to equipment failures, may damage diagnostics and produce spurious signals in detectors. As part of the PETAL project, we have studied the EMP generation mechanisms. A 3D, multi-physics, simulation chain has been developed. An EMP diagnostic has also been developed and set up inside the LMJ experimental chamber. Mitigation devices have been developed and tested on different campaigns, in several facilities, at low and high laser energy, in order to prepare the first PETAL experiments.

A mechanism of the EMP generation has been identified [2, 3]. The proof of concept of this scheme is a major scientific breakthrough which has allowed us to develop a multi-physics simulation chain. The simulation is performed in four subsequent steps with a suite of numerical codes. First, the effect of the laser pre-pulse on the solid target is simulated with a hydrodynamic code developed at CEA/DIF. Second, the main laser-plasma interaction is simulated with a particle-in-cell (PIC) code developed at CEA/DIF. The electrons are propagated inside the target by a Monte-Carlo code. Finally the escape of electrons from the target and their propagation to the laser chamber is simulated by another PIC code developed at CEA/CESTA. This simulation chain has been validated on different experimental campaigns. Magnetic field measurements have been compared to numerical results.

New target holders have been designed by numerical simulations. They are composed of a glass capillary with inside resistive gel. One end of this capillary is fixed to the target and the other end is fixed on a conducting cylinder surrounded by a magnetic material which operates as an inductance. The goal of this new holder is to mitigate the discharge current produced and to limit the generation of the electromagnetic radiation. These devices have been tested, first, at low laser energy (0.1 J), than, at higher energy (80 J) on the POPCORN campaign at the LULI2000 facility and finally on the first PETAL experiments up to 400 J. For these last campaigns, the results show a very good agreement on the radiated magnetic field between the simulations and the measurements. As expected, the new target holder with integrated mitigation device, reduce the radiated electromagnetic field by a factor greater than 3 on the frequency bandwidth of interest. The next step will be to validate the performances of this new target holder at higher laser energy closed to 1 kJ.

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Poster

Experimental investigation of pre-magnetization effects on laser-plasma dynamo processes

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It has recently been demonstrated experimentally on the OMEGA Laser Facility that a turbulent plasma created by the collision of two destabilized (but initially unmagnetized) plasma jets is capable of generating strong stochastic magnetic fields via the small-scale turbulent dynamo mechanism, provided the magnetic Reynolds number of the plasma is sufficiently high (Tzeferacos *et. al.*, *Nat. Comm.*, vol. 9, 2018, 591). In this talk, we compare such a plasma with one arising from two pre-magnetized plasma jets, whose creation is identical save for the presence of a 10 T external magnetic field imposed by a pulsed magnetic field generator. We investigate differences between the two turbulent systems using Thomson scattering diagnostics, self-emitted X-ray imaging and proton radiography. While the Thomson scattering spectra are broadly similar between the magnetized and unmagnetized interactions, the proton radiographs are qualitatively different. In addition, the self-emitted X-rays in the magnetized interaction show a greater variation in relative magnitude between adjacent structures, a possible indication that the external field is capable of significantly altering the dynamics of the turbulent plasma despite only possessing a finite fraction of the initial plasma-jet kinetic energy.

Poster

X-ray imagers for the Laser MégaJoule (LMJ)

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The Laser MégaJoule (LMJ) target bay systems is now equipped with a set of four inserters that can be loaded with several target diagnostics which are: a mid-field Gated X-ray Imager (GXI), a large field 2D GXI and a Streaked Soft X-ray Imager (SSXI). Moreover, a high resolution 2D GXI is also under development for studying target implosion. A Streaked Hard X-ray Imager (SHXI) will be delivered soon for measuring the laser beam-to-beam synchronization and implosion velocities. A specific set of two soft X-ray imagers for LEH characterization is under manufacturing. We will describe the design and the diagnostics performances goal in terms of spatial, temporal and spectral resolutions. We will present the plasma diagnostics development status conducted at CEA for experimental purpose.

Poster

3D Broadband Bubble Dynamics for the Imprinted Ablative Rayleigh-Taylor Instability

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An experiment was performed at the National Ignition Facility to investigate the three-dimensional ablative Rayleigh-Taylor Instability (RTI). In this experiment, a 300 µm thick polystyrene disk was irradiated with 450 kJ of 3ω (351 nm) laser light over 30 ns. The initial seeds of the instability were formed using an early well-characterized imprinting laser beam both with and without continuous phase plate smoothing. Growth of the optical depth modulations and the acceleration of the foil were observed using time-resolved x-ray radiography. The results closely follow the classical self-similar bubble distribution until late times when the bubble sizes approached the foil thickness. Due to the remarkably long laser drive and travel distance, multiple generations of merging were observed, and measurements of the nonlinear saturation velocities have been extended to unprecedented long wavelengths. Smoothing of the imprint beam showed a large decrease in RTI modulations amplitude, though its late-time evolution approached the early-time distribution of the unsmoothed seed measurements, suggesting the beginning of a loss of memory of initial conditions. These experiments are of crucial importance for turbulence studies and for benchmarking 3D radiation hydrodynamics codes used in Inertial Confinement Fusion.

Poster

Electron acceleration and generation of betatron x-ray radiation with the kilojoule and subpicosecond PETAL laser

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Recent progress in high-power laser technology has spurred development of petawatt and picosecond laser facilities, which raises the question of the extension of some applications developed for high intensity and short pulse laser (< 100 fs) to new regimes. This paper concentrates on the possibility to generate an electron wakefiled accelerator and an associated betatron X-ray source on the kilojoule and subpicosecond PETAL laser. We explore two distinct scenarios through Particle-in-Cell simulations. A denser plasma ($\sim 10^{18}$ cm^{-3}) is first used, such that the period of electron Langmuir oscillations is much shorter than the pulse duration, leading to longitudinal self-modulation of the picosecond-scale laser pulse and excitation of a rapidly evolving plasma wave. It is found that electron beams with a charge of several tens of nC can be accelerated by the wakefield, with a quasi-Maxwellian energy distribution including a tail extending to a few-GeV level. In the second scenario, at lower plasma densities ($\sim 2.8\ 10^{16}$ cm^{-3}), the pulse blows out plasma electrons, creating a single accelerating cavity, while the use of a density downramp helps to inject a nC quasi-monoenergetic electron bunch, which is then accelerated beyond 1 GeV. In both case the X-ray sources offer broad-band spectra with a slowly decaying amplitude extending on 10's of keV. A high number of photons ($\sim 10^{12}$) is calculated in the self-modulated regime. The lower value obtained in the blowout regime ($> 10^9$ photons) is compensated by a smaller source duration and transverse size, which increase the x-ray brilliance by more than an order of magnitude against the self-modulated case, also favoring high spatial and temporal resolution in x-ray imaging. In all explored cases, accelerated electrons emit synchrotron x-rays of high brilliance, $B > 10^{20}$ photons/s/mm^2/$mrad^2$/0.1%BW. Synchrotron sources driven by picosecond kilojoule lasers may thus find an application in x-ray diagnostics on facilities such as the LMJ or National Ignition Facility (NIF).

Poster

Collisionless magnetized shock formation and particle energization in scaled astrophysical conditions

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Collisionless shocks, which are held responsible for generating nonthermal particles and radiation in high-energy astrophysical objects, are widely believed to originate from micro-instabilities triggered in colliding flows. Recently, rapid theoretical developments have gone hand in hand with experimental efforts to generate collisionless shocks using powerful lasers. We have investigated both theoretically and numerically the possibility to use such lasers to study plasma collisions in strong large volume pulsed external magnetic fields. The presence of an external magnetic field can speed up the development of a collisionless shock that would otherwise be outside the reach of the largest laser systems available. The external magnetic field compression and the binary collisions between charged particles can also strongly affect the shock formation and the subsequent particle energization.

Poster

SESAME, « Spectromètre ElectronS Angulaire Moyenne Energie » for LMJ-PETAL

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SESAME is a component of the first set of diagnostics for the LMJ-PETAL LASER facility, called the PETAL+ project.

This project was supported by the French ANR (National Agency for Research).

SESAME is a magnetic electron spectrometer. It is composed of a 10 centimeter tungsten radiative shielding, an adjustable entrance slit and of a 0.5 T NeFeB permanent magnetic dipole. The recording media are imaging plates. In order to measure both spectrum and angular distribution of the electrons produced by PETAL, two identical vessels are mounted directly on the wall of the LMJ chamber, each containing a SESAME spectrometer. They are located at 0° and 45° relative to the PETAL axis. No electronic nor active devices are used in the signal pathway. This choice comes from the huge electromagnetic pulse that can be generated by experiments using PETAL. SESAME is equipped with imaging plates on both sides of the magnetic dipole and also in the direct line of sight. Then, SESAME is able, in addition to the electron spectrum, to measure protons–ions spectra and also hard X rays spectra with a rudimentary bremsstrahlung cannon.

The electrons energy range is 5 to 150 MeV.

The protons-ions energy range is about 5 to 50 MeV.

The imaging plates have to be removed after each experiment for analysis. To comply with the safety regulation of the LMJ facility, a special door has been developed and patented. It is based on the double door principle and withstands the vacuum of the chamber.

Both SESAME spectrometers are under the control of a nuclear ventilation system for nuclear confinement concerns.

Poster

Proposing and Planning Experiments at the NIF

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The NIF experimental process for proposing, scheduling, planning, and setting up an experiment exists to ensure communication with NIF on a timeframe that supports successful execution of an experiment. Fixed points in time have been strategically placed throughout the process where the experimental team provides information about the experiment to support any reviews, subsequent work and facility feedback.

Poster

Analytical modeling of 3D imprinted Rayleigh-Taylor Instabilities

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Hydrodynamic instabilities occurring during the shell implosion prevent efficient target compression and still constitute the principal hurdle towards ignition by Inertial Confinement Fusion (ICF). In this work, we concentrate on direct-drive ICF where the seeds of the ablative Rayleigh-Taylor Instability (RTI) originate mainly from laser imprinted perturbations. Based on experimental data acquired with a very long acceleration drive on the NIF [1], an analytical study was conducted to increase our knowledge of these phenomenons by using numerical simulation parameters obtained from 2D CHIC computations [2]. The case considered is a CH-foil (300µm thick and 2mm width) irradiated by 450 kJ of 3w laser irradiation distributed over a 2-mm wide focal spot. The imprinted seeds come either for an unsmoothed laser beam without any CPP, or a smoothed one with regular CPP. Three different theoretical models [3,4,5] which describe imprinting, ablative Richtmyer-Meshkov and Rayleigh-Taylor phases are intended to be matched together in order to reproduce the chronological profile of the foil surface. Model's parameters can be adjusted thanks to simulation's outputs and tested to fit experimental data measured in RTI phase. As a benchmark, single mode pre-imposed modulations were considered and compared to experimental data. The final goal is to reproduce late-time profiles from experimental data with a multi-mode imprinted pattern.

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Poster

Iron And Iron alloys under extreme conditions for geoscience application

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An accurate knowledge of the properties of iron and iron alloys at high pressures and temperatures is crucial for understanding and modelling planetary interiors. While Earth-size and Super-Earth Exoplanets are being discovered in increasingly large numbers, access to detailed information on liquid properties, melting curves and even solid phases of iron and iron at the pressures and temperatures of their interiors is still strongly limited. In this context, X-ray sources coupled with high-energy lasers afford unique opportunities to measure microscopic structural properties at far extreme conditions.

Here we present recent studies devoted to investigate the solid-solid [1] and solid-liquid transition in laser-shocked iron and iron alloys (Fe-Si, Fe-C and Fe-O alloys) using X-ray diffraction, X-ray diffuse scattering and X-ray absorption spectroscopy. Experiment were performed at XFEL facilities (LCLS at SLAC, USA and EH5 at SACLA, Japan). Detection of the diffuse scattering allowed the identification of the first liquid peak position along the Hugoniot, up to 4 Mbar. While the pressure and tempature ranges were strongly limited to several hundreds of GPa along the Hugoniot at XFELs, the time resolution shows ultrafast (between several tens and several hundreds of picoseconds) solid-solid and solid-liquid phase transitions. Access to X-ray sources coupled with higher energy laser facility is of the utmost importance to study solid and liquid structures of iron and iron alloys at further extreme pressure and at out-of-Hugoniot conditions, more relevant to planet interiors.

We will also present the recent target developments performed within the ERC PLANETDIVE program.

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Poster

Kinetic modeling of nonlocal electrons and self-consistent electric field in ICF relevant plasmas

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The interaction of lasers with plasmas very often leads to nonlocal transport conditions, where the classical hydrodynamic model fails to describe physical phenomena related to highly mobile particles. In this study the electron distribution in plasma is investigated for the conditions relevant to ICF. In particular, we focus on the transport of nonlocal (supra-thermal) electrons streaming down the temperature gradient in the ablating plasma. Nevertheless, the nature of plasma (ionized gas) requires a correct response of background electrons too. This is achieved by the action of an electric field, which is provided self-consistently based on the kinetic modeling. Our approach leans on the Albritton-Williams-Bernstein-Swartz collision operator providing a simple, computationally efficient, transport equation of electrons and is further benchmarked against full Fokker-Planck and collisional PIC codes Aladin and Calder.

Poster

The role of quasi-static channel fields in Direct Laser Acceleration of electron beams to 0.6 GeV

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Experimental measurements using the OMEGA EP laser facility demonstrated Direct Laser Acceleration (DLA) of electrons up to a record 0.6 GeV using a high-energy, picosecond pulse at an optimal plasma density. Two-dimensional PIC simulations with conditions designed to match OMEGA EP were conducted using the EPOCH code to diagnose the influence of plasma density on the generation of high-energy, high-charge electron beams. Particle tracking enables further investigation into the dynamic role of quasi-static channel fields on electron energy enhancement, beam pointing and divergence, elucidating the mechanisms and action of DLA at different plasma densities and pulse durations. Electron beams generated by this scheme could be used to obtain brilliant, spatially coherent X-rays with the capability to be accurately synchronized to short pulse laser initiated events and for experimental verification of the two-photon Breit-Wheeler process.

Poster

Observations of multi-ion and kinetic effects in OMEGA shock driven implosions relevant to ignition experiments

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DT Kinetics

Inertial confinement fusion implosions are almost exclusively modeled as hydrodynamic in nature where the electrons are treated as a fluid and the ions separately as a single average-ion fluid. However, in the shock convergence phase of virtually all inertial fusion implosions, the mean-free path for ion-ion collisions becomes sufficiently long that both the shock front itself and the resulting central plasma are inadequately described by hydrodynamic modeling. A series of OMEGA experiments relevant to the shock convergence phase of ignition implosions shows little to no species separation in a DT plasma, but they do implicate other kinetic effects, like reactivity reduction, decreased shock energy coupling, and thermal decoupling of the D and T ions, which may play a role in ignition implosions. This work was supported by DOE, NLUF, LLNL, and LLE.

Poster

FLASH MHD simulations of LMJ experiments that study compressible magnetized turbulence and turbulent dynamo

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Magnetized turbulence and dynamo action are ubiquitous in the Universe and spa very disparate scales: from the Earth and the Sun, the interstellar medium, t whole galaxies and galaxy clusters. The compressibility of turbulent plasma varies significantly within and across these astrophysical environments, affectin the turbulent properties and the behavior of the dynamos they sustain. Extendin our previous work on incompressible turbulent dynamo at the Omega laser facility and the National Ignition Facility, we have conceived experiments for the Lase Megajoule facility in France to study magnetized turbulence and turbulent dynam in the compressible limit. Here, we describe the design of these experiment through large-scale 3D FLASH simulations on the Mira supercomputer at ANL an demonstrate that the proposed experimental platform is capable of producing high-Mach number turbulence that rapidly amplifies seed fields to nea equipartition with the turbulent fluid motions.

Poster

SPECT3D, Imaging and Spectral Analysis Package

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SPECT3D is a collisional-radiative spectral analysis package designed to compute detailed emission, absorption, or x-ray scattering spectra, filtered images, XRD signals, and other synthetic diagnostics. The spectra and images are computed for virtual detectors by post-processing the results of hydrodynamics simulations in 1D, 2D, and 3D geometries. SPECT3D can account for a variety of instrumental response effects so that direct comparisons between simulations and experimental measurements can be made. We will present new features of SPECT3D and highlight their application to the analysis of HEDP experiments. Recent additions to SPECT3D include an updated version of Prism's Atomic Database that incorporates NIST atomic data version 5.0 and improves the consistency for modeling He- and Li-like satellite transitions. X-Ray Thompson scattering calculation times have been improved for the RPA model, and multi-threading has been added for the short characteristics method. Future development plans for SPECT3D will also be discussed.

Poster

SEPAGE: a proton-ion-electron spectrometer for LMJ-PETAL

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The SEPAGE spectrometer (Spectromètre Electrons Protons A Grandes Energies) was realized within the PETAL+ project funded by the French ANR (French National Agency for Research). This plasma diagnostic, installed on the LMJ-PETAL facility, is dedicated to the measurement of charged particle energy spectra generated by experiments using PETAL (PETawatt Aquitaine Laser) [1] [2].

SEPAGE in inserted inside the 10-meter diameter LMJ experimental chamber with a SID (Diagnostic Insertion System) in order to be close enough to the target. It is composed of two Thomson Parabola measuring ion spectra and more particularly proton spectra ranging from 0.1 to 20 MeV and from 8 to 200 MeV for the low and high energy channels respectively. The electron spectrum is also measured with an energy range between 0.1 and 150 MeV.

At the entrance of each Thomson Parabola, charged particles are first selected by a pinhole. They are then deviated by a magnetic field created by a magnetic dipole using two permanent magnets and then by an electric field generated between parallel plates on which high voltages are applied. The front part of the diagnostic carries a film stack that can be placed as close as 100 mm from the target center chamber. This stack allows a spatial and spectral characterization of the entire proton beam. It can also be used to record proton radiographies.

SEPAGE was recently implemented on the LMJ-PETAL facility and the first ion spectra were measured with different targets and laser conditions.

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Poster

Two-sided conical laser target design for fusion-fission reactor.

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Abstract: It is shown, that the use of two-sided conical targets, irradiated by long plus short laser pulses, enables to attain thermonuclear gain in order to 1. It needs to create powerful thermonuclear neutron source for the fusion-fission reactor.

2D numerical simulations demonstrates the thin dense layer acceleration up to 300-400 km/s inside a conic channel with the use of a UV laser pulse with the energy of ~ 1 MJ and a duration of 20-100 ns. As shown by our 2D numerical simulations, it is possible to compress a liquid DT mixture by a factor of 30-50. The whole compression proceeds under the action of the incident and reflected shock waves. In these conditions one might expect that mixing would not lead to a target breakdown. The fuel density ~ 10 g/cm^3 and temperature ~7-8 keV are achieved in the collision (near cone summit).

The sequence of short pulses (a single pulse power~ 1 PW) with a total energy 50-60 kJ, which injected into the target through the openings located near the cone summits, must fulfil two functions: local confinement and additional heat of the thermonuclear fuel. We have proposed a peculiar target design to produce counterpressure near the walls. A low-density substance and corrugated layers in absorber of short laser pulses could be capable of flattening of the counterpressure.

There is a possibility of carrying out a full-scale experiments on NIF or LMJ facilities. According to our estimates, the neutron yield for two-sided targets be equal to 10^{16} per pulse, i.e. be comparable to the yield observed in indirect drive experiments at NIF.

Poster

Ultra-Broadband x-ray sources from a self-modulated laser wakefield accelerator at the Titan laser facility

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The ability to create and study high energy density (HED) matter is improving our understanding of inertial confinement fusion, astrophysical systems, planetary interiors and fundamental plasma physics. Photon beams in the X/ Gamma ray range, produced by relativistic electrons from intense laser-plasma interactions, are key tools in the exploration of HED science. In this work, we utilize the high-energy electron beam from a Self-Modulated Laser Wakefield Accelerator (SM-LWFA) to generate a broadband (0.01-1 MeV) X/Gamma-ray source. SM-LWFA can generate relativistic electrons for applications that require a high-charge but low divergence electron beams. The Titan laser at Lawrence Livermore National Laboratory is capable of providing high-energy, picosecond laser pulses that can be focused to give intensities approaching 10^{20} W/cm^2, ideal for generating 10nC electron beams in the 10-400 MeV energy range via SM- LWFA. The electrons generate X-rays via their betatron motion (few-30 keV) [1,2] and hard X-rays to gamma rays through inverse Compton scattering (10-300 keV) or Bremsstrahlung (up to 100 MeV) radiation [3]. Due to its unique characteristics, the source will be an ideal probe and backlighter for future time-resolved spectroscopy, imaging, Compton radiography and Laue diffraction experiments.

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Poster

Numerical simulations of Ion stopping in degenerate and coupled plasma

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Here we present the simulations performed for the proposed experiment for the measurements of the energy loss of light ions in a warm dense plasma at low projectile velocities. This experiment is aimed to investigate this parameter range, where significant theoretical uncertainties are reported on the stopping power due to electron degeneracy and coupling, and experimental data are missing. The understanding of ion stopping in this regime is of great interest both from a fundamental scientific point of view and for the modeling of inertial confinement fusion plasmas. The considered projectiles are quasi-monoenergetic light ions created from a D3He "exploding pusher" capsule imploded by 6 LMJ quads. The probed warm dense plasma is created by the isochoric X-ray heating of a thin low Z material located inside a metal-coated plastic cavity by X-rays driven by 6 other LMJ quads.
The temperature and density profiles of the isohorically x-ray heated target sample were simulated with 2D hydrodynamic code. Temperatures close to 30 eV at solid density are expected, corresponding to a target electron coupling of $\Gamma \sim 0.3$ and an electron degeneracy ~ 2. The estimations of the ion energy loss in the plasma with such parameters were performed by using various models such as T-Matrix, Li, Li-Petrasso etc.
In experiment , the energy spectra of the ions that passed through the target are recorded with the SEPAGE charged-particle spectrometer. The target conditions are probed with the Thomson scattering technique by using K-alpha radiation induced by the heating of a back-lighter foil with the PETAL beam. The scattered X-ray spectra are measured with the HRXS (DP10) spectrometer. Proton imaging of the target with radiochromic films (using CRACC) also enables to diagnose the electron density as well as the electric and magnetic fields in the target.

Poster

Biermann-Battery reconnection in 3-D colliding laser-driven plasmas

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Recent High Energy Density plasma experiments have demonstrated magnetic reconnection between colliding plasma plumes, where the reconnecting magnetic fields were self-generated in the plasma by the Biermann battery effect. Using fully kinetic 3-D simulations, we show the full evolution of the magnetic fields and plasma in these experiments including self-consistent magnetic field generation about the expanding plume. The collision of the two plasmas drives the formation of a current sheet, where reconnection occurs in a strongly time- and space-dependent manner, demonstrating new 3-D reconnection mechanisms. In particular, we observe fast, vertically-localized Biermann-mediated reconnection, an inherently 3-D process where the temperature profile in the current sheet coupled with the out-of-plane ablation density profile conspires to break inflowing field lines, reconnecting the field downstream. Fast reconnection is sustained by both the Biermann effect and the traceless electron pressure tensor, where the development of plasmoids appears to modulate the contribution of the latter. We present a simple and general formulation to consider the relevance of Biermann-mediated reconnection in general astrophysical scenarios. In addition, we investigate particle energization due to reconnection within these highly 3-D systems and compare our results with those of 2-D HED reconnection studies.

Poster

Development of PETAL diagnostics: PETAPhys project

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End of 2017 and beginning of 2018, PETAL, a Petawatt laser beam, was operated for diagnostics qualification experiments on the LMJ facility at the CEA/ Cesta research center. The PETAPhys project provides a support to the commissioning phase of the PETAL laser operation*. It is complementary to the Equipex project PETAL+, which delivers the major diagnostic equipment. Within the PETAPhys project, we have developed two simple and robust diagnostics to characterize the focal spot of the PETAL beam and to measure the hard X-ray spectrum on each shot.

The first diagnostic (Twist) is the optical imaging of the PETAL beam focal spot in the spectral range of the second and third harmonic radiation emitted from the target. The second diagnostic (CRACC X) is a hard X-ray spectrometer consisting in a stack of imaging plates (IP) and filters either held by SEPAGE or CRACC inserter.

Numerical simulations as well as experiments on small scale facilities have been performed to design these diagnostics and will be compared to first results from PETAL experiments.

*We acknowledge the financial support from the French National Research Agency (ANR) in the framework of "the investments for the future" Programme IdEx Bordeaux-LAPHIA (ANR-10-IDEX-03-02)

Poster

SPECTIX, a PETAL+ X-ray spectrometer

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The aim of the EQUIPEX PETAL+ is to provide diagnostics for the LMJ (Laser Mega Joule) and PETAL (PETawat Aquitaine Laser) laser facility. One of these diagnostics is dedicated to record time integrated spectra, generated by the interaction of the PETAL laser pulse with a target, in the hard X-ray range (8 – 100 keV). The name of this spectrometer is SPECTIX (Spectromètre PEtal à Cristal en TransmIssion X). It is based on two transmission crystals in order to cover the whole spectral range. Detection is performed by using imaging plates which are insensitive to strong electro-magnetic pulses. It was built and used on the first PETAL experiments.

The specifications of SPECTIX, its design, its shielding, its present performances as well as the calibration results of its crystals and spectra obtained during the qualification campaign of PETAL will be presented.

This work for diagnostic development takes place within the EQUIPEX PETAL+ funded through the PIA by the French National Agency for Research (ANR) and coordinated by the University of Bordeaux.

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Poster

GXI-1 & GXI-2 gated x-ray imaging diagnostics for the Laser Megajoule facility

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The Laser Megajoule facility started to operate in the early 2014 with one bundle consisting of two quadruplets (20 kJ at 351 nm) focused on target for the first experimental campaign. We present here the first set of gated x-ray imaging (GXI) diagnostics implemented on LMJ since mid-2014. This set consists of two imaging diagnostics with spatial, temporal, and broadband spectral resolution. These diagnostics will give basic measurements, during the entire life of the facility, such as position, structure, and balance of beams, but they will also be used to characterize gas filled target implosion symmetry and timing, to study x-ray radiography and hydrodynamic instabilities. The design requires a vulnerability approach, because components will operate in a harsh environment induced by neutron fluxes, gamma rays, debris, and shrapnel. Grazing incidence x-ray microscopes are fielded as far as possible away from the target to minimize potential damage and signal noise due to these sources. These imaging diagnostics incorporate microscopes with large source-to-optic distance and large size gated microchannel plate detectors. Microscopes include optics with grazing incidence mirrors, pinholes, and refractive lenses. Spatial, temporal, and spectral performances have been measured on x-ray tubes and UV lasers at CEA-DIF and at Physikalisch-Technische Bundesanstalt BESSY II synchrotron prior to be set on LMJ.

Poster

SSXI, Streaked Soft X-ray Imager on LMJ

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The first streaked soft X-ray imager, SSXI, has been commissioned on LMJ facility in 2018. It has successfully recorded time-resolved 1D image as it can measure a time / space-resolved spectra in the soft X-ray spectral region. It is dedicated to the analysis of soft x-ray emission (< 1 keV) and of phenomena driven by radiative transfer in the sub-keV domain (propagation of radiative waves, radiation burnthrough …).

It consists of the association of an optics assembly and a spectral selection device. As no filter can be used due to soft X-ray bandwidth, the optical scheme of the diagnostic is entirely based on grazing incidence optics.

The optics assembly is composed of a blast shield which is a large flat mirror, with grazing incidence, that can be shifted shot after shot, and an X-ray microscope with two channels each made of two toroidal mirrors for improving spatial resolution.

The spectral selection is provided by two low-pass mirrors combined with a reflective flat field grating that can be substituted by a mirror to increase the diagnostic sensitivity. Depending on the orientation of the streak camera on the central channel, a temporally resolved X-ray image with spectral selection or a temporally resolved X-ray spectrum can be acquired, together with one time integrated image (for the second channel) on a customized CCD camera.

Poster

Self-Focusing of a Laser Beam into a Plasma

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P*ROJECT*

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 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): 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, 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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Poster

VISRAD, 3-D Target Design and Radiation Simulation Code

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The 3-D view factor code VISRAD is widely used in designing HEDP experiments at major laser and pulsed-power facilities, including NIF, OMEGA, OMEGA-EP, ORION, LMJ, Z, and PLX. It simulates target designs by generating a 3-D grid of surface elements, utilizing a variety of 3-D primitives and surface removal algorithms, and can be used to compute the radiation flux throughout the surface element grid by computing element-to-element view factors and solving power balance equations. Target set-up and beam pointing are facilitated by allowing users to specify positions and angular orientations using a variety of coordinates systems (*e.g.*, that of any laser beam, target component, or diagnostic port). Analytic modeling for laser beam spatial profiles for OMEGA DPPs and NIF CPPs is used to compute laser intensity profiles throughout the grid of surface elements. We will discuss recent improvements to the software package and plans for future developments.

Poster

Ultrahigh pressure generation with laser-produced hot electrons for shock ignition scheme

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We performed an experiment on ultrahigh pressure generation with hot electrons produced by high-intensity laser plasma interactions. Hot electrons with small temporal duration might be ultra-high pressure source by absorption of matter within very thin layer that is comparable to mean free path of hot electrons [1]. The ultrahigh-pressure generation exceeding GBar regime is very important for shock ignition scheme of ICF targets, as well as fundamental ultrahigh-pressure experiments.

Experiments were done on GEKKO-HIPER laser irradiation facility at ILE, Osaka University. We irradiated three-layered foils (CH-Cu-Quartz) in order to generate the ultrahigh pressure with hot electrons, and observe shock wave into the third quartz layer. The pulse duration and the intensity were 300 ps and 10^{15} – 10^{16} W/cm^2, respectively (ω, 2ω or 3ω light). For some data shots, we applied pre-pulse for enhancement of effects by hot electron generation and pre-compression. We estimated laser intensity on the target with a static x-ray pinhole camera. The absorption area by hot electrons was measured by a Cu-Kα imager. The shock wave parameters were taken by VISAR and streaked optical pyrometer (SOP).

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Poster

Diagnosing fuel areal-density asymmetries in cryogenic deuterium-tritium implosions at OMEGA using knock-on deuteron spectra

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PROJECT

Determining fuel areal-density (ρR) asymmetries is vital to assessing the performance of inertial confinement fusion implosions. The Charged Particle Spectrometers (CPS's) on OMEGA have been used to infer fuel ρR asymmetries in cryogenic deuterium-tritium (DT) implosions by measuring the spectrum of knock-on deuterons emitted along different lines-of-sight. These knock-on deuterons are produced by elastic scattering between primary DT neutrons and the deuterons in the fuel. The CPS's, which are located along different lines-of-sight, provide a complimentary measurement to the neutron-based ρR measurements. In this work, we discuss the knock-on deuteron spectra obtained in the 1-D cryogenic DT Campaign at OMEGA. Preliminary data analysis suggests that ρR varies significantly along different measurement lines-of-sights, indicating ρR asymmetries and systematic 3-D effects in the implosions.

Poster

Time evolution of ion and electron temperatures in shock-driven implosions at OMEGA

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Time evolutions of ion and electron temperatures in shock-driven implosions are separately assessed using simultaneously measured nuclear-reaction and X-ray-emission histories. In these DT^3He-gas-filled implosions, the Particle X-ray Temporal Diagnostic (PXTD) on OMEGA is fielded to measure the DT and D^3He reaction histories, as well as several X-ray-emission histories in different energy bands. A spatially-averaged Ti(t) is inferred from the reaction histories using the different temperature sensitivities of the DT and D3He reactions. A spatially-averaged Te(t) is inferred from the ratios of the X-ray histories at different energy bands. These measured Ti(t) and Te(t) have been used to explore ion-electron equilibration rates in different plasma conditions. Finally, the implementation and use of PXTD, which represents a significant advance at OMEGA, has laid the foundation for the implementation of a Te(t) diagnostic in support of the main cryogenic DT programs on OMEGA. This work is supported in part by the U.S. DOE, LLNL, LLE, and NNSA SSGF.

Poster

Tomographic Reconstruction of Magnetic Field structures from Proton Radiography Data

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We present recent progress in our development of techniques and algorithms used to recover spatially-resolved magnetic field structures from measurements made using the proton radiography diagnostic. The nature of proton radiography places severe limitations on the angular resolution achievable by tomographic measurements, due to space constraints in the target chamber as well as the difficulty of simultaneously producing many suitable proton beams; we investigate the effectiveness of a "compressed sensing" real-space regularisation approach as well as a Fourier-domain "sinogram inpainting" technique to avoid the severe artefacts usually associated with tomographic reconstruction of sparse-view tomographic data.

Finally, we demonstrate a full run-through of the reconstruction process, from particle-in-cell simulation-generated magnetic fields to synthetic proton radiographs, then to line-integrated magnetic fields recovered from raw radiographs using the Monge-Ampere formalism and finally to a slice of spatially-resolved magnetic field, which can be compared to the input field to assess the fidelity of the techniques used.

Poster

The DMX X-ray broad-band spectrometer

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A primordial diagnostic for indirect-drive physics is an absolutely calibrated time-resolved spectrometer for absolutely calibrated measurement of the photon flux in the photon energy range from 0.05 keV to 20 keV. LMJ-DMX has been especially developed to match the constraints of the Laser MegaJoule facility. DMX-LMJ is composed of a set of four diagnostics: firstly, a time resolved broad-band X-ray spectrometer, equivalent to DANTE at LLNL, made of 20 measurement channels (covering the 50 eV – 20 keV range) combining mirrors, filters, specially designed flat X-ray diodes and high bandwidth scopes (time resolution of 100 ps), secondly, a time resolved soft X-ray spectrometer (100 eV – 1500 eV) with gratings and streak camera (time resolution of about 50 ps), thirdly, a time integrated X-ray Laser Entrance Hole imaging with pinhole and CID camera and fourthly a time resolved X-ray power measurement spectrally integrated. DMX-LMJ is now operating since winter 2015. Experimental set-up and first results are presented.

Poster

The mini-DMX spectrometer

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In addition to the primordial diagnostic for indirect-drive physics on LMJ, DMX, an absolutely calibrated broadband soft x-ray spectrometer, we installed a smaller version, called mini-DMX to provide a second measurement axis on hohlraum experiments.
Mini-DMX is composed of 16 measurement channels (covering the 50 eV – 7 keV energy range), one half combining mirrors, filters and detectors, the other half without mirror. Mirrors are used to improve hard x-ray rejection.
The x-ray coaxial diodes combined with high bandwidth oscilloscopes allow a time resolution of 100 ps.
Mini-DMX is positioned on the chamber with the diagnostic insertion device called SID (Système d'Insertion des diagnostics). Two working distances, 1000 and 3500 mm from the target, are available to extend the intensity range that can be measured . To change from one configuration to the other, it is necessary to exchange the collimators and the filter holder and realign the whole system on a bench in the preparation diagnostic area.
Mini-DMX-LMJ is now operating since spring 2016. Experimental set-up and first results are shown.

Poster

Development and utilization of the DT3He multi-particle backlighter for stopping-power experiments and for radiography of strong fields at MJ-scale laser facilities

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Implosions of thin-shelled capsules filled with fusion fuel are a source of charged particles for probing experiments at MJ-scale laser facilities. The D^3He backlighter, developed for use at OMEGA and the NIF, allows for two separate radiographs to be recorded with the 14.7-MeV and 3.0-MeV protons from the D+^{3}He and D+D reactions. Additionally, the 14.7 MeV proton has been used for stopping-power studies in warm dense matter. Monoenergetic charged particle radiography with the D^3He backlighter is a highly-utilized experimental platform in basic science experiments on both OMEGA and the NIF.

To significantly advance this work, a new tri-particle mono-energetic backlighter based on a DT^3He gas-filled capsule implosion that provides 14.7-MeV and 3.0-MeV protons plus 9.5-MeV deuterons from the T+^{3}He reaction is being developed at OMEGA. Initial tests using 860 µm diameter, thin-glass capsules filled with 20:40:40 DT^3He (atomic ratios) fuel produced 1e10, 1e9, and 8e8 D^3He-p, DD-p, and T^3He-d yields, respectively. Other performance characteristics of the backlighter, including source size, burn duration and line widths are discussed. Radiographs of laser-driven foils and measurements of stopping power in cold beryllium were made with the backlighter particles and the results are shown. This work was supported by DOE, NLUF, LLNL, and LLE.

Poster

Extrapolation of 2D planar CHIC simulation into 3D geometry for the calculation of realistic synthetic radiography

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The shock ignition scheme is an alternative approach to the classical direct drive inertial confinement fusion. It uses an intense laser spike at the end of the compression phase in order to drive a strong shock inside the target, igniting it. The intensity required for such shock (5.10^{15} W/cm² to 10^{16} W/cm²) is sufficient for the excitation of parametric instabilities leading to a significant amount of laser energy transfer to supra-thermal electrons. The effect of these electrons on the hydrodynamic of the ignitor shock is not yet well understood, or well simulated in hydro-radiation codes. Dedicated experiments are required in order to quantify the hot electrons source parameters in the regime of intensity and plasma gradient length relevant for shock ignition.

An experiment will be conduct on LMJ in 2019 and 2020, aiming to characterize the hot electron population generated by a laser spike in conditions relevant to the shock ignition scheme. The planar geometry of this experiment allows the side radiography of the shock front propagating in the target and perturbated by the hot electrons. 2D radiation hydrodynamic simulations, using the code CHIC, have been performed in order to evaluate the optimal parameters for the radiography (such as the target transverse thickness or the backlighter material). Yet, due to the lack of cylindrical symmetry of the experiment, an Abel inversion cannot be performed in order to evaluate the expected radiography from the simulations. A 3D tomographic post-processor has been developed to extrapolate the 2D planar symmetry simulations, allowing the calculation of synthetic radiographies.

We will present the model used in the tomographic post-processor and its validation though the comparison with expected radiographies from 2D axisymmetric CHIC simulations. Finally, we will present CHIC simulations for the upcoming experiment with the corresponding expected radiography.

Poster

Overview of the Fundamental Science Program on the Omega Laser Facility

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The Omega Laser Facility is a U.S. national user facility operated by the University of Rochester's Laboratory for Laser Energetics (LLE) for the National Nuclear Security Administration (NNSA) of the Department of Energy (DOE). The facility houses two of the most powerful laser systems in the world: OMEGA – a 60-beam Nd:glass laser system with a total energy >30 kJ in ultraviolet (UV), and OMEGA EP – a 4-beam Nd:glass laser system capable of producing picosecond kJ-class high intensity infrared pulse or nanoseconds UV pulse with total energy up to 30 kJ. The two laser systems are routinely re-configured overnight between shot days for a wide variety of target and beam configurations including the joint OMEGA EP and OMEGA shots where the OMEGA EP beams are propagated into the OMEGA chamber. The facility delivers more than 2000 target shots per year for the inertial confinement fusion and the high energy density (HED) campaigns in support of the NNSA's stockpile stewardship program and for the peer-reviewed fundamental science program that uses ~25-30% of the facility time with experiments mostly led by external users from the U.S. academia, industry and national laboratories. The facility also provides opportunities for international research collaborations.

The Omega Laser Facility's unique combination of high energy and high intensity lasers with a large number of diagnostics and mature platforms has facilitated a variety of fundamental science experiments covering a wide range of topics on laboratory astrophysics, magnetized HED, nonlinear laser plasma interactions, relativistic HED and particle acceleration, fast and shock ignition, and new states of matter under extreme conditions pertinent to planetary and stellar interiors, etc. A selection of examples highlighting the fundamental science programs on Omega will be presented.

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