Proposal for a Postdoc

Optimization of a Polar Direct Drive configuration on the Laser Mégajoule (LMJ) using Artificial Neural Networks

Team: J. Mathiaud, A. Colaïtis, J.-L. Feugeas, X. Ribeyre

Training objectives:

Develop numerical skills on artificial neural networks and the physics of direct drive and shock ignition for inertial confinement fusion. The postdoctoral candidate will work at the CELIA laboratory. The candidate will participate in the development of the numerical codes at CELIA used for laser plasma interaction and hydrodynamics.

Context:

Three major avenues to Inertial Confinement Fusion (ICF) are currently being explored worldwide: Laser Direct-Drive (LDD), Laser (x-ray) Indirect-Drive (LID) and magnetic drive using pulsed power. Among those, the privileged avenue for the production of clean energy is the LDD approach, where lasers are used to directly compress and ignite a cryogenic DT fuel shell. In the standard LDD approach, the shell is simultaneously compressed and ignited at stagnation. This requires high degrees of laser irradiation symmetry (pointing and balance) and high energies, in the order of several MJ. A more efficient ignition scheme was proposed about ten years ago, using a lower energy pulse to first compress the shell, and then ignite it separately using a high intensity nanosecond pulse. This is the Shock Ignition (SI) approach [1], which in theory requires lower laser energies of the order of 500 kJ.

On the one hand, the main MJ-scale facilities worldwide, NIF and LMJ, are configured in the LID geometry; lasers are disposed in cones gathered preferentially toward the poles of the chamber. While this approach is optimized for LID, spherical Direct-Drive experiments have been performed on the NIF in the so-called Polar Direct-Drive (PDD) configuration [2], that is designed to reproduce a Direct-Drive-like configuration on a LID machine. The PDD configuration is challenging because of its high dependency on the non-linear (and highly 3-D) Cross Beam Energy Transfer (CBET) effect that occurs during the shell compression [3,4]. In that regard, PDD requires the use of state-of-the-art laser codes in order to design and interpret experiments. On the other hand, experiments on the LIL facility [5] and theoretical work [6] suggest that non-uniform irradiation configurations such as PDD should benefit from SI scheme, where strong asymmetric bi-polar shocks can be generated from laser beams gathered at the poles. As such, the SI approach presents higher degrees of freedom to accommodate LID laser facilities.

The PDD configuration and its equivalent in an SI framework possesses a high number of free parameters: for each beam of each quad, one may change the individual pointing, power balance, pulse shape, phase plate, wavelength detuning, and this separately for the compression and ignition pulses. These degrees of freedom, in addition with the target design itself, produce a large parameter-space that can be explored to produce a configuration as robust as possible. Artificial neural networks are particularly well suited for this kind of optimization problem where the number of parameters is too large for a conventional parameter scan study, and have been used for LID studies in the past few years [7].

The first objective of this postdoc is to train an artificial neural network by processing examples resulting from 2-D axisymmetric radiative hydrodynamics simulations using the CHIC code. This phase will be conducted without CBET physics in order to simplify the problem, and will serve as a test bed. A collaboration with CEA CESTA is envisioned on the use of the neural networks developed by G. Poëtte and his PhD student P. Novello.

Since the PDD configuration, and especially CBET, is inherently 3-D, the second objective of the postdoc is to transition to the 3-D geometry. The current 3-D radiative hydrodynamics code used at CELIA for ICF studies is the ASTER code from LLE, coupled to the IFRIIT laser propagation module from CELIA [8]. However, full 3-D ASTER simulations are too costly to run in a neural network optimization problem. As such, the candidate will interface the IFRIIT laser code with the 3-D hydrodynamics and diffusion solver available at CELIA. Optimization of the scheme will then rely on a study of the hot-spot characteristics from a pure hydrodynamics + CBET standpoint. The configurations considered will include regular PDD but also asymmetric SI drive and other configurations [9].

This project also interfaces with several proposals being prepared at CELIA, one for experiment on the LMJ, and one for experiment on the NIF, for studying shock propagation in solid spheres in the PDD geometry for shock ignition.

Scientific objectives of the postdoc:

- Interface a 2-D hydrodynamics code to a neural network for optimization of a preliminary PDD configuration; in absence of CBET and for laser beams modeled as asymmetric cones
- Couple the IFRIIT laser propagation code to the CELIA 3-D hydrodynamics and diffusion solver
- Study PDD schemes based on 3-D simulations of pure hydrodynamics shell compression in presence of CBET in the SI scheme, using the neural network.

Tools:

Use of numerical simulation codes and artificial neural networks developed or available at CELIA.

Contact: arnaud.colaitis@u-bordeaux.fr or julien.mathiaud@u-bordeaux.fr

[1] Shock Ignition of Thermonuclear Fuel with High Areal Density, R. Betti et al., Phys. Rev. Lett. 98, 155001 (2007)
[2] A polar-drive–ignition design for the National Ignition Facility, T. J. B. Collins et al., Physics of Plasmas 19, 056308 (2012)
[3] Polar-direct-drive experiments on the National Ignition Facility, M. Hohenberger et al., Physics of Plasmas 22, 056308 (2015)
[4] Mitigation of cross-beam energy transfer in ignition-scale polar-direct-drive target designs for the National Ignition Facility, T. J. B. Collins et al., Physics of Plasmas 25, 072706 (2018)
[5] Shock generation comparison with planar and hemispherical targets in shock ignitionrelevant experiment, S. D. Baton et al., Physics of Plasmas 24, 092708 (2017)
[6] Shock ignition: an alternative scheme for HiPER, X. Ribeyre et al., Plasma Phys. Control. Fusion 51 015013 (2008)
[7] Deep Jointly-Informed neural networks., Humbird et al. Computer Software. https://github.com/LLNL/DJINN. USDOE National Nuclear Security Administration (NNSA). 11 Jan. 2018. Web. doi:10.11578/dc.20180724.1.
[8] Adaptive inverse ray-tracing for accurate and efficient modeling of cross beam energy transfer in hydrodynamics simulations, A. Colaitis et al., Physics of Plasmas 26, 072706 (2019)
[9] On the Fielding of a High Gain, Shock-Ignited Target on the National Ignition Facility in the Near Term, Perkins, L. J. et al., Plasma Physics and Fusion Technology, 42 (2010)