WP4: Light assisted magnetized plasma studies for laboratory astrophysics and inertial confinement fusion

PhD proposition, starting on Sep-Oct 2023

Magnetohydrodynamic and kinetic studies in HED magnetized plasmas towards magneto-inertial fusion

Context:

The recent demonstration of nuclear fusion breakeven at the National Ignition Facility (NIF) is a major milestone towards fusion energy. One appealing scheme to further increase fusion yields is the addition of a background magnetic field (B-field). Indeed, the B-field compressed with the target acts in addition to inertia to confine the hot spot, resulting in a hotter fuel, allowing to ignite at lower areal densities than otherwise possible and with slower implosions that are less susceptible to hydrodynamic instabilities. The recent capability to generate strong B-fields coupled to MJ laser facilities relaxes important constraints of conventional ICF and sets the path toward magneto-inertial fusion demonstration. A cylindrical implosion platform facilitates less convoluted analysis of the magnetized transport of heat and magnetic flux and measurements of the imploding and stagnated plasma conditions, compared to spherical implosions. That is what we have proposed [1] and are already exploring at the OMEGA laser facility, with 15 kJ of laser drive energy, deuterium-filled cylindrical targets and a seed B-field of 30 T. The implosions' trajectory was followed by X-ray framed imaging [2], and the compressed core conditions obtained via Ar K-shell emission spectroscopy. Our first results are consistent with a compressed B-field reaching ~10 kT and the subsequent reduction of the heat conduction along the radial direction enhanced the temperature of the hot spot by ~70% [3], a record in magnetized implosion experiments.

Proposals to scale this platform to 300 kJ of laser energy-drive have been accepted at both Laser Mega Joule (LMJ) [4] and NIF, both scheduled for FY 2024. These larger-scale experiments will enlarge the level of achievable magnetizations and foreseeing diagnostic improvements, namely the use of dual dopant (Ar and Kr) spectroscopy to achieve effective spatial resolution of the core temperature, and B-field compressibility measurements from angularly-resolved spectra of secondary neutrons. The progressive rise in drive energy is crucial to reach the self-sustained nuclear fusion.

[1] C.A. Walsh *et al.*, Plasma Physics and Controlled Fusion **64**, 025007 (2022).
[2] G. Pérez-Callejo *et al.*, Rev. Sci. Instrum. **93**, 113542 (2022).
[3] M. Bailly-Grandvaux *et al.*, in preparation.
[4] G. Pérez-Callejo *et al.*, Phys. Rev. E **106**, 035206 (2022).

Workplan:

The PhD student will integrate a CELIA team leading international (EUROfusion, NLUF, LBS) and national (ANR) projects on laser-driven plasma studies under strong B-fields in relation to thermonuclear fusion and laboratory-astrophysics. He/she will contribute to:

- Increase the understanding of laser-induced hot-electron generation and electron energy transport in broad ranges of plasma collisionality and magnetization → robust experimental references for model benchmarking or new theoretical input into simulation codes.
- Develop and explore platforms for magnetized plasma experiments in presence of seed B-fields (either laser-driven or from pulsed-discharges in coils) → energy transport, diffusion of magnetic flux, magnetized hydrodynamic instabilities.
- Develop novel high-resolution X-ray instrumentation and data analysis dedicated to the characterization of magnetized HED plasmas → high-

resolution X-ray spectrometry, X-ray Talbot-Lau interferometry, X-ray phase contrast imaging, proton radiography.

Experiments are already accepted at LULI, ELI-NP, LMJ-PETAL, and NIF; Future proposals to XFEL-HED end-stations (SACLA, EU-XFEL).

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