Progress in shock ignition

Dimitri Batani
[1] CELIA, University of Bordeaux, France
e-mail: dimitrri.batani@u-bordeaux.fr

Direct-drive "Shock Ignition" is an interesting alternative to the classical approach to ICF investigated on NIF and could relax the problems met on the pathway to ignition. This approach is based on the idea of imploding an ICF target (ablator plus DT ice) at low velocity and, just before stagnation, irradiating the target with a high-intensity laser spike (duration a few hundred ps) launching a very strong shock (at least 300 Mbar at the ablation surface) which converges to the hot spot providing the conditions for triggering nuclear fusion reactions. The low implosion velocity of a more massive and ticker shell provides robustness against the effect of Rayleigh-Taylor instability. However the intensity on target needed for the final laser spike (up to 10^{16} W/cm^2) are far above the threshold for parametric instabilities like SRS and TPD which will produce a large number of hot electrons (HE). In the conventional approach, HE are dangerous because they induce target preheating making compression more difficult. In SI, however, HE generated by the final laser spike at the end of compression, when the accumulated target $\langle\rho r\rangle$ is large enough, may increase laser-target coupling and strengthen the shock with a positive impact. Hence, their characterization is crucial for assessing SI feasibility. Within the Enabling Research EUROfusion Project «ENR-IFE19.CEA-01 «Study of Direct Drive and Shock Ignition for IFE: Theory, Simulations, Experiments, Diagnostics development», we are conducting experiments in Europe and the US to contribute answering these open questions.

At the PALS laboratory in Prague we characterized HE produced by high-energy laser pulses of 300 ps at 1ω[1] and 3ω of the iodine laser (wavelengths λ = 1315/438 nm, focused to intensities 9×10^{15}/ 2×10^{16} W/cm^2). We studied the correlation of HE and Stimulated Raman Scattering (SRS) and assessed the impact of HE on target preheating and on shock dynamics. Results were compared to advanced hydro simulations done with the code CHIC that takes into account parametric instabilities and HE in a self-consistent way.

At the Omega EP facility in Rochester, we characterized HE by X-ray imaging and spectroscopy and evaluated their impact on preheating and shock dynamics by time-resolved X-ray radiography. Finally, the addition of an external magnetic field (MIFED device) affected HE trajectories affecting their capability of penetrating into the target.

A significant effort was also done to optimize diagnostics, including time-resolved X-ray radiography (experiments at LULI and GEKKO), shock breakout diagnostics (LIL facility) and X-ray phase contrast imaging (Phelix laser). This work contributed to our understanding of SI physics but also to consolidate a European research network on IS, serving as preparation for future experiments to be done on the LMJ/PETAL laser facility at the relevant energy scale.

References:

1. D. Batani, S. Baton, A. Casner, S. Depierreux, M. Hohenberger, O. Klimo, M. Koenig, et al. «Physical issues in shock ignition» Nuclear Fusion, 54 (2014) 054009
2. G.Cristoforetti, A.Colaïtis, L.Antonelli, S.Atzeni, F.Baffigi, D.Batani, et al. «Experimental observation of parametric instabilities at laser intensities relevant for Shock Ignition» Europhysics Letters, 117, 35001 (2017)
3. L.Antonelli, S.Atzeni, A.Schiavi, S.D.Baton, E.Brambrink, D.Batani, et al. «Laser-driven shock waves studied by X-ray radiography» Phys. Rev. E 95, 063205 (2017)
4. S.D.Baton, E.Le Bel, S.Brygoo, X.Ribeyre, D.Batani, D.Raffestin, et al. «Shock generation with planar and hemispherical targets in shock ignition relevant experiments» Physics of Plasmas, 24, 092708 (2017)
5. D. Batani, L.Antonelli, F.Barbato, G.Boutoux, A.Colaïtis, J.-L.Feugeas, et al. "Progress in understanding the role of hot electrons for the shock ignition approach to inertial confinement fusion" Nucl. Fusion 59, 032012 (2019)
6. G.Cristoforetti, L.Antonelli, D.Mancelli, S.Atzeni, F.Baffigi, F.Barbato, D.Batani, et al. "Time evolution of Stimulated Raman Scattering and Two Plasmon Decay at laser intensities relevant for Shock Ignition in a hot plasma" High Power Laser Science and Engineering (2020)
7. D. Batani, L.Antonelli, S.Atzeni, J.Badziak, F.Baffigi, et al. "Generation of High Pressure Shocks relevant to the Shock-Ignition Intensity Regime" Physics of Plasmas, 21, 032710 (2014)