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Overview of some key achievements on the route to IFE

Peter A Norreys[1,2]

[1] Department of Physics, Atomic and Laser Physics sub-Department, Clarendon Laboratory, University of Oxford
[2]Central Laser Facility, STFC Rutherford Appleton Laboratory
peter.norreys@physics.ox.ac.uk; peter.norreys@stfc.ac.uk

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The ToIFE project hinges on (a) a program of experiments and numerical simulations to understand underlying obstacles to central hot-spot ignition on MJ-scale laser facilities and to reduce uncertainties that input into all inertial fusion ignition schemes [focusing on studies related to the radiative properties of the ablator dopants, to multi-speckle – plasma interaction, to foam induced imprint smoothing and hydrodynamic instabilities or to ion stopping in plasmas], (b) a program of experiments and numerical simulations towards demonstration of shock ignition [including the building of an integrated simulation platform], (c) a program of numerical simulations and experiments to test the viability of other alternative ignition schemes (electron- and ion-driven fast ignition or impact ignition) [with emphasis on magnetic collimation of electron beams, improvement of the laser-to- ion conversion efficiency thanks to advanced acceleration schemes and demonstration of laser-induced p-B fusion reactions] and (c) the conceptual design of an Inertial Fusion Energy (IFE) reactor based on the development of key technologies, such as high-repetition-rate laser drivers or innovative materials, for fusion targets or first walls.

In this presentation, I will show, for the first time, some of the work of my group at Oxford and RAL. It includes calculations indicating that it is possible to combine hydrodynamically stable, low convergence ratio "wetted foam" implosions, as demonstrated recently on the NIF [1], with the new concept of heating of the central hot spot by crossing relativistic electron beams [2], the latter being developed under the ToIFE grant over the past four years. It is shown that the ion temperature and fusion yield both increase when a few kilojoules of energy, deposited in the background electrons in the hot spot, equilibrates with the fusion fuel. In support of this approach, conclusive experimental evidence is provided for stable channel formation in the coronal plasma, by mitigation of the hosing instability associated with petawatt laser pulses, using the ORION laser facility at AWE plc [3] and the Vulcan laser facility at STFC Rutherford Appleton Laboratory.

Channeling experiments have also performed at the OMEGA EP facility using relativistic intensity ($>10^{18}$ W/cm^2) kilojoule laser pulses through large density scale length (~ 390-570 μm) laser-produced plasmas, demonstrating the effects of the pulse's focal location and intensity as well as the plasma's temperature on the resulting channel formation [4]. The results show deeper channeling when focused into hot plasmas and at lower densities as expected. However, contrary to previous large-scale length particle-in-cell studies, the results also indicate deeper penetration by short (10 ps), intense pulses compared to their longer duration equivalents. This new observation has many implications for future laser-plasma research in the relativistic regime.

To realize this "auxiliary heating" concept, and for fast ignition generally, multi-kJ petawatt ultra-violet laser pulses are required. The plasma Raman instability is an attractive candidate, in that it can efficiently compress a nanosecond long high power laser pulse to sub-picosecond duration. Although many authors envisaged a converging beam geometry for Raman amplification, here I will show, for the first time, that the exact opposite geometry works better; the amplification should start at the intense focus of the seed [5]. We have generalized the coupled laser envelope equations to include this non-collimated case. The new geometry completely eradicates the usual trailing secondary peaks of the output pulse, which typically lower the efficiency by half. The initial seed pulse energy required for efficient energy transfer is reduced by orders of magnitude. As in the collimated case, the evolution is self-similar, although the temporal pulse envelope is divergent. A two-dimensional particle-in-cell simulation demonstrates efficient amplification of a diverging seed with only 0:3mJ energy. The pulse has no secondary peaks and has constant intensity as it amplifies and diverges.

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