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High density plasmas formation in Inertial Confinement Fusion and Astrophysics

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1. Target design and fluid dynamic simulations

The new proposed design [1] contains the main ideas of fast ignition, while using a single energy drive that produces both fuel compression and ultra-fast energy deposition on it. The deposition of energy is produced by the impact of a hypervelocity jet onto the compressed core, converting therefore kinetic energy into thermal energy that produces a hot spot. That hypervelocity jet is produced simultaneously to the fuel compression, by the ablationally driven collapse of a conically shaped system, which absorbs energy from the same energy source that produces the fuel compression. Design (Fig 1) includes a spherical conventional target for fast ignition (not a full sphere) coupled to one or two cones pointing inwards such that can produce hypervelocity jets arriving at the center of the system in the very precise moment of highest compression and temperature. Between fuel and the conical system, there are conical shapes facing outwards, with the mission of preventing interaction between the two mentioned zones of the target.

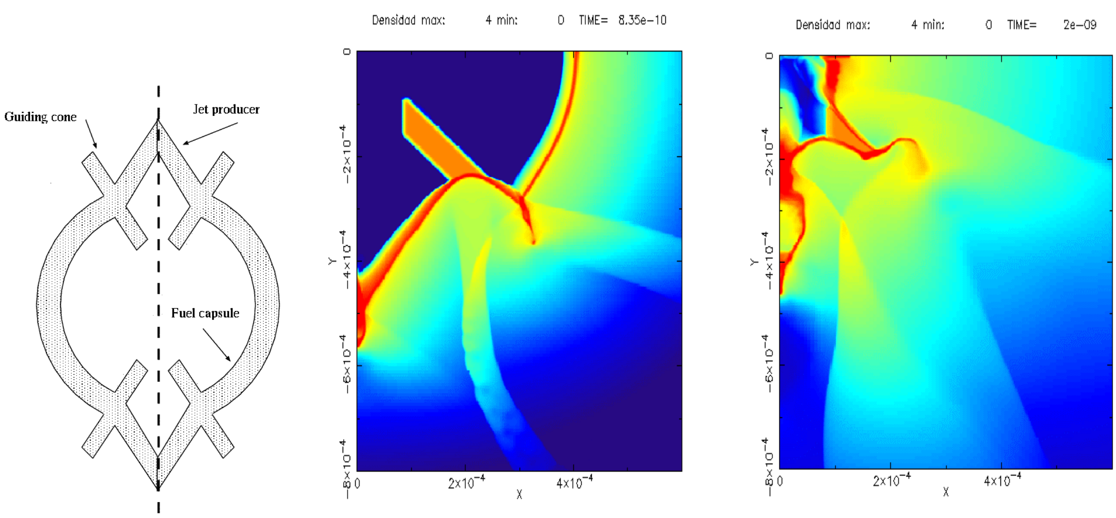

Figure 1:Schematics (a), and density plots at 835ps (b), 2000ps (c)

This design has been simulated using the ARWEN code [2] reaching to acceptable results [1]. Simulations have performed using one material for the whole system, showing an appreciable temperature rise in the collision zone of the fuel core. We are reaching conditions by the system in order to predict the propagation of the burning wave. ARWEN is being adapted to perform multimaterial calculations, which will show a better performance of the system. Other designs have been proposed [3] based on the idea of fast ignition by impact of high-speed matter. The system has been simulated to be in a hohlraum with an equivalent radiation temperature of 300 eV, thus using indirect radiation. An ablation process starts at the first phase, producing along the whole contour shock waves travelling inwards. These shock waves produce two different effects both in fuel shell and conical regions. On the spherical shell, due to the guiding effect of the outward-facing cones, matter is compressed in a uniform way, as was first shown in [4]. At the same time, the shock waves on the conical region produce a jet that grows in time on speed and mass (Figure 1b and 1c show a density map in log scale).

Under a precise design selecting angles and thickness, it was shown in [1] that an appropriate synchronisation could be achieved leading to a collision of the compressed fuel during the first stages of expansion while its core is in the most compressed state. The collision produces a hot spot in the lowest part of the compressed fuel (Figure 1c).

2. Inertial Fusion Features In Degenerate Plasmas

Very high plasma densities can be obtained at the end of the implosion phase in Inertial Fusion targets, particularly in the so-called fast-ignition scheme, where a central hot spark is not sought at all. By properly tailoring the fuel compression stage, degenerate states can be reached. In that case, most of the relevant energy transfers mechanisms involving electrons are affected. For instance, bremsstrahlung emission is highly suppressed [5]. In fact, a low ignition-temperature regime appears at very high plasma densities, due to radiation leakage reduction [6]. Stopping power and ion-electron coulomb collisions are also changed in this case, which are important mechanisms to trigger ignition by the incoming fast jet and to launch the fusion wave from the igniting region into the colder, degenerate plasma. All these points are reviewed in a recent paper [7]. Although degenerate states would not be easy to obtain by target implosion, they present a very interesting upper limit that deserves more attention in order to complete the understanding on the different domains for Inertial Confinement Fusion. A programme F.I.N.E. (fast ignition nodal energy) has been developed. In the programme, the equations defined are valid for the degenerate and classical region, taking into account the possibility that the plasmas pass from a degenerate state to a classical state during the heating process. The results of the programme are only valid to study the possibility of ignition of plasmas in the fast ignition concept, not the burn up phase of the target. Ions have been the choice for ignitor heating until ignition conditions are reached. The optimisation of the compression phase in fast ignition inertial fusion, to obtain low temperature and high-density plasmas, can lead to a degenerate plasma. The equations that governs these plasmas are different that the classical ones. The decrease in Bremsstrahlung emission permits the decrease in ignition temperature, for high-density plasmas. This assumption has been demonstrated. The high energy needed to obtain high density degenerate plasmas decrease the gain as compared to the results obtained in more moderated densities.

3. Atomic Physics

Optical properties of plasmas are a powerful tool for plasma diagnosis. As it is known, optical properties depend strongly on the level populations into the plasma, both for plasmas at LTE and NLTE conditions. Up to now the model proposed by us, ANALOP code [8], was only able to model optically thin plasmas, i.e. assuming that the self-absorption is negligible. For optically thick plasmas the rate equations and the radiation transfer equation are coupled and they should be resolved in a simultaneous way, since under these conditions the self-absorption of the radiation in the plasma influences considerably in the level populations.

Recently, we have proposed two different models in order to provide level populations for this kind of plasmas. The first one is based on the solution of the radiation transfer equation (LTNEP code) and the second one is based on the escape factor formalism (M3R-EF code).

In the LTNEP model, a 1D plasma divided into N cells is considered, having each cell different density and temperature. The profiles of density and temperature are provided by hydrodynamics calculations as input of the model. Then, the atomic kinetics and the radiation transfer equation are solved self-consistently for the whole plasma. The rates equations are solved in the Collisional-Radiative Steady State (CRSS) model and the atomic processes included are the following: spontaneous emission, resonant emission and stimulated emission, photoionization and radiative recombination, collisional excitation and dexexcitation, collisional ionization and 3-body recombination and dielectronic recombination.

The other model, M3R-EF code, introduces the reabsorption of the radiation through the escape factor formulism. The escape factor θ denotes the mean probability that a photon emitted anywhere in the source travels directly to the surface of the source in any direction and escapes. In this work we have assumed a uniform distribution of emitting atoms and isotropic emission and a slab geometry [9]. The rate equations are also solved in the CRSS model including the same atomic processes but the resonant emission and photoionization.

In both codes, the atomic data required for the calculations are provided as an input file and the Stark profile is calculated by the Code Pim Pam Poum [10]. Then, the source function is obtained from the calculated line opacity and the bound-free opacity is provided by hydrogenic formulas. Finally, the specific intensity is determined solving the transfer equation with the known source function. With these two models we have studied uniform aluminium plasmas, which length of 100 μm, for a fixed electronic density (10^{23} cm^{-3}) and several temperatures (from 200 to500 eV). It has been seen that for these plasmas the self-absorption must be included because it introduces relevant changes in the level populations. For example, for the Lyman series we obtain that the ratio of the level populations calculated assuming optically thick and thin plasma, P_{thick} / P_{thin}, is equal to 10 for the ground states and 10^2 for the excited states while for the Helium series is equal to 1 and 10, respectively. Taking into account the results of the ratios of populations shown before and according with the relations between the populations and the source function we obtain that source function for optically thick plasmas is ten times greater than for the optically thin ones. We have also verified that the escape factor formalism is a good alternative to those methods based on the resolution of the rate equations coupled to the radiation transport equation for uniform plasmas since LTNEP and M3R-EF codes provide similar results.

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