White Paper for *Frontiers of Plasma Science Panel*

Date of Submission:	***2015-07-15***

Indicate the primary area this white paper addresses by placing "P" in right column.
Indicate secondary area or areas by placing "S" in right column

	"P", "S"
• Plasma Atomic physics and the interface with chemistry and biology	
• Turbulence and transport	S
• Interactions of plasmas and waves	S
• Plasma self-organization	S
• Statistical mechanics of plasmas	P

Indicate type of presentation desired at Town Hall Meeting.

	"X"
Oral	
Poster	
Either Oral or Poster	
Will not attend	X

Title:	Plasmas rarely behave as perfect fluids or sets of collision-less particles : towards *calculating* an HED experiment
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**(Limit text to 3-pages including this form. Font Times Roman size 11.
1 page of references and 1 page of figures may also be included. *Submit in PDF format*.)**

- ***Describe the research frontier* and importance of the scientific challenge.**

Current modeling tools for HED experiments are based on a radiation-hydrodynamics framework that is more than 40-year-old. These tools have been immensely successful in designing and interpreting HED experiments, but they are reaching their limits of validity and accuracy when compared against current, more sophisticated and better diagnosed experiments. While more advanced physics codes and models have been developed recently (from molecular dynamics to detailed atomic physics to kinetic simulation of plasmas), they usually rely on plasma conditions input from the simpler "integrated simulation" describing the experiment as a whole (see [1] for example).
The grand challenge is to be able to *calculate* an HED experiment with enough details to match the current detailed measurements of plasma conditions. This would require merging the best available models/framework, leveraging modern computing power, and above all improving the degree to which we can constrain these models with dedicated experiments and diagnostics (i.e. developing a whole database of measured plasma "behavior" in the HED regime)

- ***Describe the approach to advancing the frontier and indicate if new research tools or capabilities are required.***

Over the next 5 years, this problem can be approached from two opposite sides. On large experimental facilities (Omega laser UR-LLE; NIF LLNL; Z Sandia;...), optical (Thomson scattering), x-ray (imaging;

spectroscopy; scattering) and particle-based (proton and neutron imaging) diagnostics are reaching a maturity level that allows for diagnosing detailed plasma conditions with unprecedented time and spatial resolution. At the 100 ps time scale and 100 µm spatial scale, dedicated HED experiments can provide constraining data to push our current modeling tools beyond the state-of-the-art radiation-hydrodynamics models (transport, kinetics, LPI...see [1] for an example). This requires a deliberate effort in adding and improving plasma diagnostics combined with a constant test of modeling tools against such data.
On smaller scale HED experiments, such as MEC@SLAC, plasma conditions can be diagnosed at the sub-picosecond/sub-micron scale over hundreds of shots. One can envision ab-initio modeling of the entire experiment with kinetic simulation (once they include radiation and atomic physics), testing our fundamental assumption for larger scale modeling (such as transport/mixing/...).

As a practical example there is a current renewed interest in laser driven plasma interpenetration/collision, driven by a desire to better understand the inside workings of NIF hohlraums. The expanding hohlraum wall can collide with the capsule ablator at a relative velocity of 1000 km/s, and density of 10^{20} cm^{-3}, a regime where the fluid approximation is questionable [4] and a kinetic treatment could be more appropriate [Fig. 1]. Our approach to resolve this problem combines a few integrated measurement on NIF experiments, a dedicated day (14 shots) at the Omega laser facilities with detailed (Thomson scattering; x-ray imaging) plasma parameters measurement (flows, temperatures, atomic composition) in a simplified system that can be modeled with kinetic codes (collisional/hybrid PIC [2]) and rad-hydrodynamics (fluid-based [3]) codes [Fig. 2]. The planned outcome is to improve plasma interpenetration [1] and transport models in the rad-hydrodynamics code to allow integrated modeling of the more complex situation on NIF, similar to what has already been done with diffusion [5]

- ***Describe the impact of this research on plasma science and related disciplines and any potential for societal benefit***.

The improvement of modeling capabilities for HED experiments, based on better models, modern computing capabilities and the possibility of acquiring large amounts of very accurate data on experimental plasma conditions in dedicated experiments, would benefit all subsequent HED experiments. The potential of being able to calculate the driver (i.e. hohlraum drive; ablation pressure; current/B-field; ...) in a HED/ICF experiment would remove a lot of uncertainties on the "what is exactly going on/how did we get here" part of an experiment and allow the focus to be moved from improving/understanding the driver to studying the driven part of the experiment.

References

[1] J. S. Ross, H.-S. Park, R. Berger, L. Divol, N. L. Kugland, W. Rozmus, D. Ryutov, and S. H. Glenzer "Collisionless Coupling of Ion and Electron Temperatures in Counterstreaming Plasma Flows", Phys. Rev. Lett. 110, 145005 (2013)

[2] Ruhl, 'Introduction to Computational Methods in Many Body Physics', Ed. M. Bonitz, Rinton (2005). Kemp et al. Phys. Plasmas 11, 5648 (2004)

[3] M. M. Marinak, G. D. Kerbel, N. A. Gentile, O. Jones, D. Munro, S. Pollaine, T. R. Dittrich, and S. W. Haan, Phys. Plasmas 8, 2275 (2001)

[4] Peter Amendt, Darwin D. Ho and Ogden S. Jones, "High-density carbon ablator ignition path with low-density gas-filled rugby hohlraum", Phys. Plasmas **22**, 040703 (2015)

[5] K. Molvig et al. , "Nonlinear Structure of the Diffusing Gas-Metal Interface in a Thermonuclear Plasma", Phys. Rev. Lett. 113, 145001 (2014))

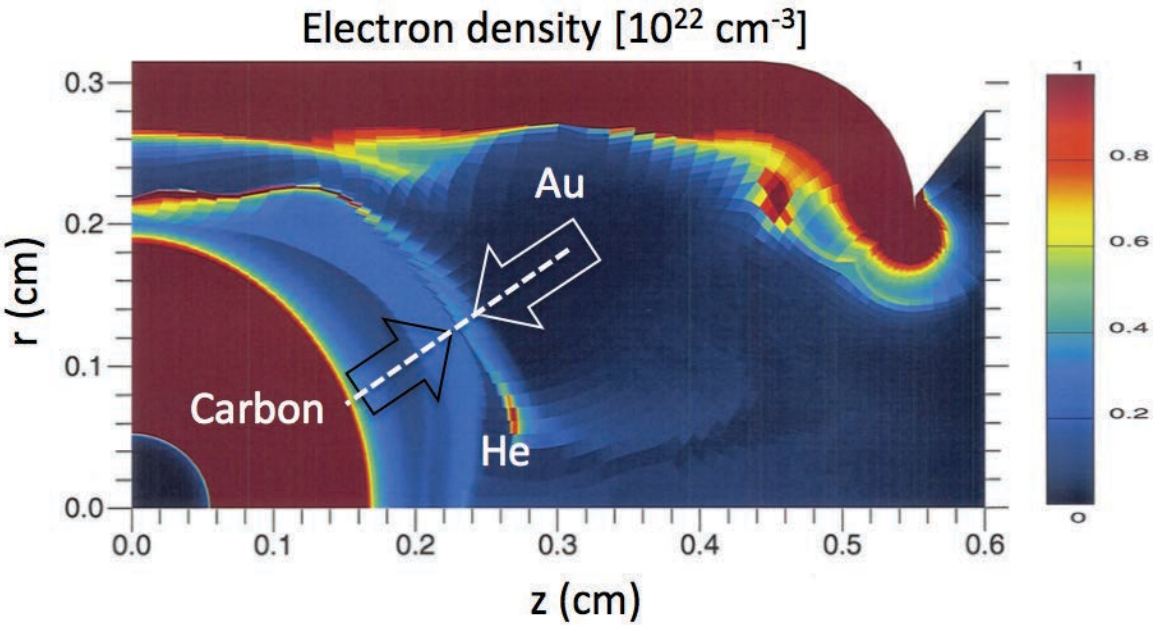

Figure 1 : in a NIF hohlraum, plasmas of different materials can collide at high relative velocity and densities low enough to question a fluid dynamics framework for simulations

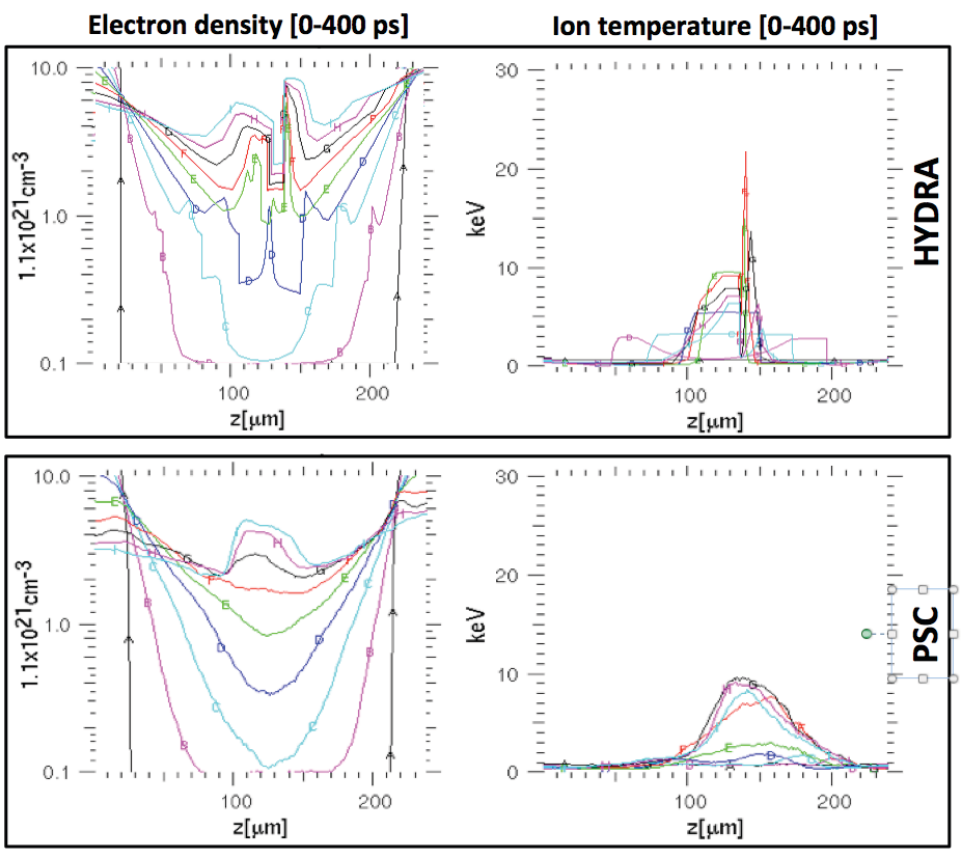

Figure 2: Collisional-kinetic simulations (PSC) predict a less violent stagnation than hydrodynamic simulations (HYDRA). This difference in density and temperature in the stagnation region can strongly affect the laser beams' propagation in the hohlraum and the symmetry of the capsule implosion