White Paper for *Frontiers of Plasma Science Panel*

Date of Submission:	***6/19/2015***

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	X
Poster	
Either Oral or Poster	
Will not attend	

Title:	Kinetic Plasma Simulation for Fusion Plasma
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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.**

The interaction of intense, nanosecond laser pulses with plasma has been the subject of intense international study over the last three decades, culminating in the recent successful completion of the Department of Energy funded *National Ignition Facility* (NIF) based at the Lawrence Livermore National Laboratory. The leading motivation for this has been the realization of inertial confinement fusion (ICF) schemes for both energy production and as part of the stockpile stewardship program. From a theoretical point of view the interactions of the NIF lasers with plasma are particularly interesting, as the strong heating leads to extremely non-thermal electron and ion distributions [2–4] and a number of plasma instabilities [5–8]. Energy transport near the walls of the hohlraum can be affected by the generation of strong magnetic fields [9], but the interplay between magnetic fields, non-locality and electron transport is not well understood. Under such conditions, an accurate representation of the physics is best achieved through kinetic modeling [16-23].

Laser pulses generally deliver highly localized, strong electric and magnetic fields with short temporal duration. Non-thermal distributions are not limited to laser plasma scenarios however, but also appear in fusion plasmas such as in tokamaks [13], industrial plasmas [14] and astrophysical situations [15], to name but a few. A non-thermal distribution means that a kinetic description is required, where the

velocity distribution of particles is not averaged as in a fluid model. An additional problem that arises in laser plasma interactions is that often the interaction is with higher density plasma, such as in the ablated plasma from a solid target interaction. Localization of the heating due to the small focal area means that there are areas of colder, denser plasma for which collisions are not negligible, as in the normal plasma approximation. To correctly model an ideal plasma we not only need to model the motion of particles in macroscopic electromagnetic fields, but also the collisional relaxation due to two-body interactions, particularly because of the relatively long timescales involved in, for example, an inertial fusion plasma. A good description of such interactions is the Maxwell– Vlasov–Fokker–Planck system of equations.

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

The Maxwell– Vlasov–Fokker–Planck description combines particle kinetics in smooth electromagnetic fields with momentum space dynamical friction and diffusion in 6+1D phase space. To finite difference the full phase space of the particle distribution is computationally difficult due to the rapid increase in calculations required with the number of grid-points used, which means for any realistic problem this brute force approach is currently unfeasible. However, for problems that are sufficiently collisional, the anisotropic part of the velocity dependence in the distribution be may considered a perturbation and the Vlasov-Fokker-Planck equation can then be decomposed in terms of basis functions, such as spherical harmonics, and truncated. This approach has been applied successfully to smaller physical systems [16-23] but hohlraum scale simulations are a little explored area. With current high power computing capabilities and the use of truncated basis function expanded distribution functions it should however be possible to construct new codes capable of performing full scale calculations in effectively 6+1D, which could ultimately be coupled with other physics models to achieve significantly more accurate modeling of the transport in inertial fusion plasma.

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

Inertial confinement fusion could potentially provide a CO2 free, baseload source of energy but so far experiments on the NIF have shown discrepancies with simulations, which are very difficult due to the complexity of the physical system. Although extensive hydrodynamic simulation support is offered for such experiments, kinetic codes have limited development. However, it is well known that hydrodynamic models do not capture all of the essential physics, for example due to non-local thermal transport. Better understanding of some of the poorly understood essential physics in hot, semi-collisional magnetized plasma will be of importance for research in inertial confinement fusion and elsewhere in fusion energy sciences.

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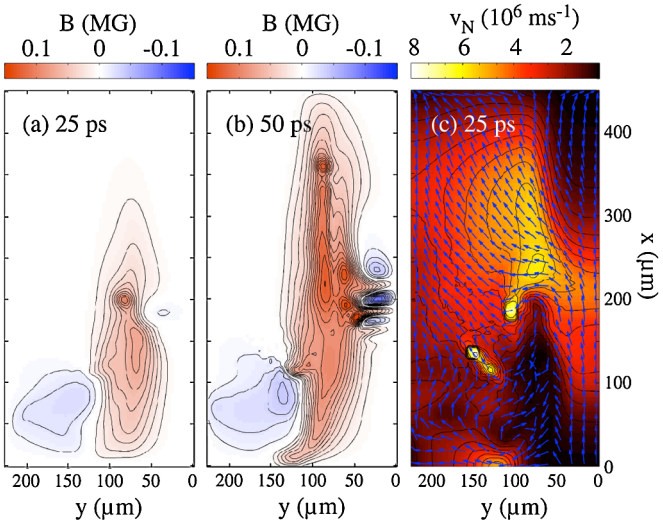
Figures (maximum 1 page)



Fast magnetic field convection calculated in 2D Vlasov-Fokker-Planck simulation (b) the magnetic field profile at 25 and 50 ps, respectively. (c) Nernst velocity, vN, at 25 ps, calculated directly from the distribution function [23].