

White Paper for *Frontiers of Plasma Science Panel*

Date of Submission:	18/JUN/2015
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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	P
• Plasma self-organization	
• Statistical mechanics of plasmas	

Indicate type of presentation desired at Town Hall Meeting.

	“X”
Oral	X
Poster	
Either Oral or Poster	

Title:	<i>LPSE</i> : A framework for modeling and predicting laser plasma instabilities driven by multiple overlapping laser beams in three dimensions.
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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 research frontier addressed here relates to the problem of modeling and predicting laser-plasma instabilities driven by multiple overlapping laser beams in laser fusion (Fig. 1). Problems caused by such instabilities are seen to be ubiquitous and persistent in laser-driven inertial confinement fusion (ICF) [1]. They degrade implosion performance, impose serious constraints designs and lead to difficulties in modeling and the interpretation of experiment. A clearer understanding of the effect of multiple beam instabilities as well as a tool that can be used to design and interpret experiments, and to develop mitigation strategies is therefore seen as essential for the ICF and HEDP communities. The threshold and nonlinear behavior of instabilities driven by multiple beams is essentially different from single beam instabilities, and this must be addressed in the theoretical and modeling work.

There are currently very few tools that are well suited to this task because multi-beam calculations, relevant to igniting plasmas, require large volumes of plasma to be simulated in three spatial dimensions and time. Particle-in-cell (PIC) techniques [2] are not well suited to these problems by themselves. While very impressive “grand challenge” scale calculations can be made on petascale facilities (e.g., L. Yin *et al.* [3]), most calculations must be performed in 2D. These are not sufficient to make progress in the field. We envisage making 3-D calculations routine, even with modest computational resources by tailoring the physics model based on the problem, using reduced models, while retaining the *essential* realism of

multiple-beam interactions [plasma scale length, laser-beam geometry and coherence properties (smoothing)]. The LPSE (Laser Plasma Simulation Environment) code system provides an efficient framework of physics packages that can be assembled quickly and efficiently for the task at hand. We have recently obtained success using this approach for the problem of multiple beam two-plasmon decay (TPD), which is an important problem for direct-drive ICF [4] (Fig. 2)..

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

It is proposed that the existing system of physics packages (contained within the LPSE framework) be significantly expanded. The recent successes obtained using this approach were achieved by combining an established model of TPD-driven electrostatic turbulence that uses wave-enveloping [5], with a reduced/hybrid model of kinetic saturation and hot electron generation. The latter was based on the integration of electron trajectories in the turbulent electrostatic fields using an algorithm that takes advantage of hardware (GPU) acceleration [4]. For TPD, these packages permitted large volume, long-time, simulations to be performed in three-dimensions with realistic multiple-beam irradiation. This physics was seen to be essential in order to reproduce experimental measurements [4]. This approach is intended to be viewed as being complementary to particle-in-cell techniques, providing a physics tool-box for problems such as cross-beam energy transfer [5], multiple beam stimulate Raman scattering, multiple beam stimulated Brillouin scattering, and possibly their nonlinear interaction.

A secondary part of the scientific challenge relates to computation in three-dimensions in general. After performing the calculation, the data must be visualized and analyzed. This step can be as challenging as making the calculations themselves. A significant part of the challenge addressed here is to design a practical 3-D data analysis and visualization platform using modest hardware. The authors intend to design a system that could be adopted by other users, at the many universities and smaller-scale facilities that do not have good and/or routine access to “petascale” computational facilities. The code system also provides a framework that enables others to contribute physics packages without the need to build new code from scratch. The requirement that LPSE be modular and extensible was a development criterion from the beginning.

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

Successful completion of this work may change the current view of laser plasma interaction (LPI) modeling. It is our opinion that such a viewpoint is necessary if LPI tools are to become more predictive in the context of ICF and HEDP. This has not been the case to date because of the lack of numerical tools emphasizing this important aspect. The intention is to develop LPSE as a supported, freely available, open-source tool for use by the community. This will provide a focal point for multiple beam studies enabling new research and the design of experiments.

The system, which currently is quite focused on a single application, may be extended to cover a wide class of nonlinear problems involving cooperative parametric instability between multiple waves and the resulting self-organization - perhaps in areas quite removed from laser-plasma physics.

Work on 3-D visualization might be transferable to vastly different areas, with potential for societal benefit. It is currently being used as a teaching [one of the authors (JM) uses it in his introductory plasma physics class] and research tool.

References (Maximum 1 page)

- 1) J. F. Myatt, J. Zhang, R. W. Short, A. V. Maximov, W. Seka, D. H. Froula, D. H. Edgell, D. T. Michel, I. V. Igumenshchev, D. E. Hinkel, P. Michel, and J. D. Moody, “*Multiple-beam laser-plasma interactions in inertial confinement fusion*”, Phys. Plasmas **21**, 055501 (2014).
- 2) J. M. Dawson, Rev. Mod. Phys. **55**, 403 (1983); C. K. Birdsall and A. B. Langdon, “Plasma Physics via Computer Simulation”, (McGraw-Hill, New York, 1985)
- 3) L. Yin, B. J. Albright, H. A. Rose, D. S. Montgomery, J. L. Kline, R. K. Kirkwood, P. Michel, K. J. Bowers, and B. Bergen, “*Self-organized coherent bursts of stimulated Raman scattering and speckle interaction in multi-speckled laser beams*”, Phys. Plasmas **20**, 012702 (2012).
- 4) R. K. Follett, D. H. Edgell, R. J. Henchen, S. X. Hu, J. Katz, D. T. Michel, J. F. Myatt, J. Shaw, and D. H. Froula, “*Direct observation of the two-plasmon decay common wave using ultraviolet Thomson scattering*”, Phys. Rev. E **91**, 031104 (2015); J. F. Myatt BAPS
- 5) Cross beam energy transfer references from Igumenshev (LLE) and P. Michel (LLNL).
- 6) P. A. Robinson, “*Nonlinear wave collapse and strong turbulence*”, Rev. Mod. Phys. **69**, 507 (1997); D. F. DuBois, D. A. Russell and H. A. Rose, “*Reduced description of strong Langmuir turbulence from kinetic theory*”, Phys. Plasmas **2**, 76 (1995); *ibid*, “*Saturation spectra of the two-plasmon decay instability*”, Phys. Rev. Lett. **74**, 3983 (1995); D. A. Russell and D. F. DuBois, “*3/2 omega radiation from the laser-driven two-plasmon decay instability in an inhomogeneous plasma*”, Phys. Rev. Lett. **86**, 428 (2001).
- 7) R. L. Follett, “*Zakharov modeling of Thomson scattering measurements of multiple-beam two-plasmon decay*”, Anomalous Absorption Conference 2015 (invited).

Figures (maximum 1 page)

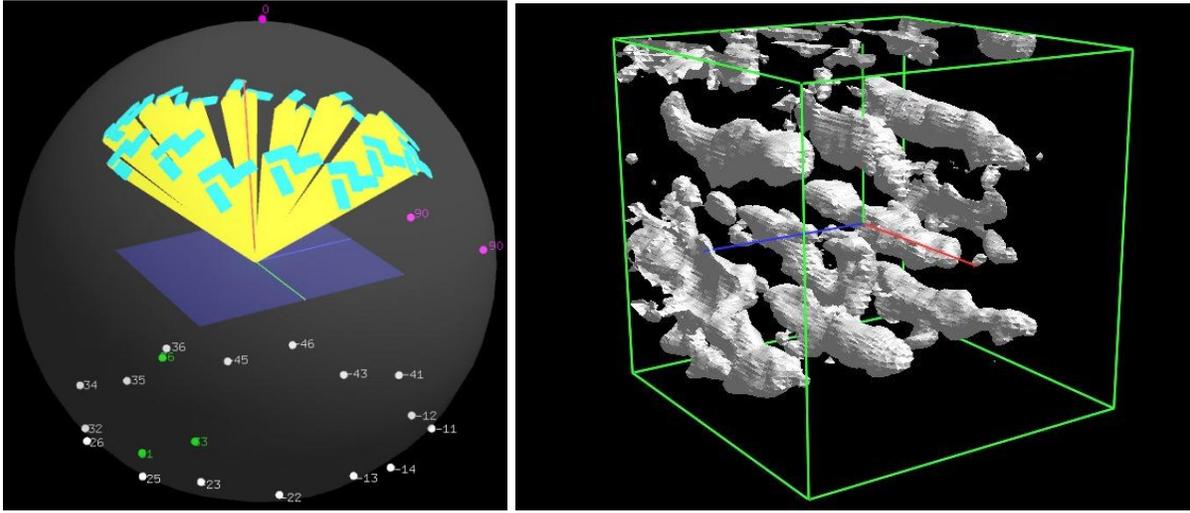


Fig. 1: Left: the beam geometry set up for a planar target experiment on the NIF shown in LpsePlotter. The yellow lines indicate the beam directions with polarization vectors shown in cyan. **Right:** iso-contours of plasma wave intensity taken from an LPSE simulation of TPD driven electrostatic turbulence. Plasma waves self-focus and collapse forming coherent structures. This process depends critically on the number of spatial dimensions – here shown in 3-D [6].

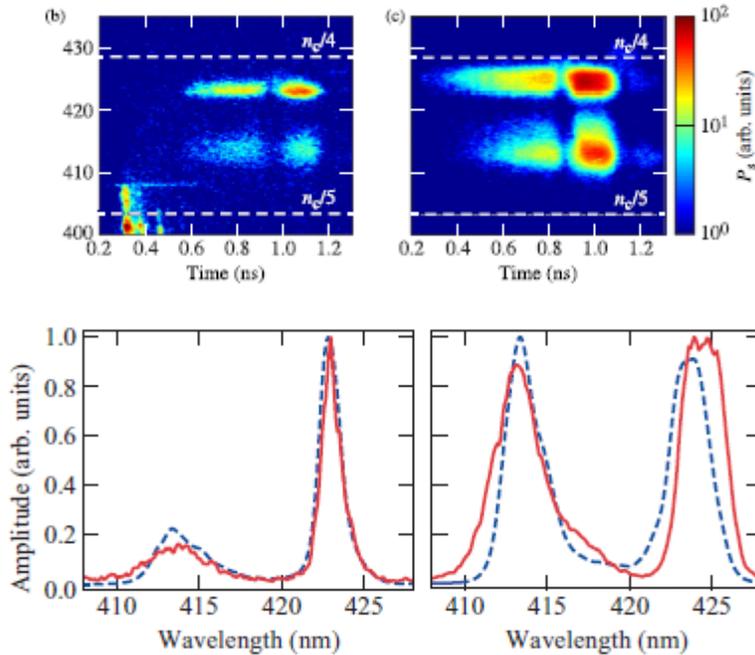


Fig. 2: Figure taken from Refs. [4,7] showing the importance of shared plasma waves in multiple beam two-plasmon decay and the good agreement between experiment (red curves, bottom) and LPSE simulations (blue dashed curve, bottom).