White Paper for *Frontiers of Plasma Science Panel*

Date of Submission:	**2015-06-19**

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	**P**
• Statistical mechanics of plasmas	

Indicate type of presentation desired at Town Hall Meeting.

	"X"
Oral	**X**
Poster	
Either Oral or Poster	

Title:	**Studying the physics of instabilities and mix at the fill-gas/wall-blowoff Interface and their potential roles in the hohlraum-drive deficit at the National Ignition Facility**
Corresponding Author:	Chikang Li
• Institution:	Massachusetts Institute of Technology
• email:	Li@psfc.mit.edu
Co-Authors:	Johan Frenje, Maria Gatu Johnson, Fredrick Seguin, Richard Petrasso, Sebastien Le Pape, Scott Wilks, Dan Sinars, Don Lamb, Mordy Rosen, Riccardo Betti, Stefano Atzeni

(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.**

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

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

Studying the physics of instabilities and mix at the fill-gas/wall-blowoff Interface and their potential roles in the hohlraum-drive deficit at the National Ignition Facility

An important issue in indirect-drive ICF [1-3] is to control and minimize the motion of the high-Z hohlraum wall blowoff [usually gold (Au) or uranium (U)] [2-5]. Such motion would lead to a change of the laser absorption region and alter the spatial distributions of x-ray energy sources and sinks, affecting drive dynamics [2-5]. To address this issue, hohlraums used at National Ignition Facility (NIF) [6] are typically filled with helium-4 gas (at a pressure ~ 0.4 atm [7-9]). But experiments [5] at the OMEGA laser facility [10], as shown in Figs. 1 and 2, have shown that the interface between hohlraum fill gas and Au wall blowoff is hydrodynamically unstable due to the classical Rayleigh-Taylor (RT) instability occurring at the interface as the lighter, decelerating, ionized gas plasma pushes against the heavier, expanding Au blow-off. In addition, recent theoretic modeling and numerical simulations [11], as shown in Fig. 3, indicate that a mix layer formed at the gold-gas interface due to ion diffusions would lead to the development of an ambipolar electric (E) field in the hohlraum radial direction. The consequence is a reduced benefit of the gas fill because the enhanced interpenetration and mixing between the Au blowoff and the gas plasma, resulting in significant changes in hohlraum drive dynamics and capsule implosion [5]. Systematic study of these effects is of fundamental importance to current indirect-drive experiments, and would contribute to our understanding of critical current issues with NIF experiments such as why the inner beams cannot reach the wall and how effective cross beam energy transfer is between inner and outer beams. Most importantly, such studies could shed on the critical question of why there is missing energy in NIF "ignition" experiments: more than ~ 0.2 MJ of energy has been unaccounted for in the high-energy, high-power, high-foot shots [9].

Our goal is to probe the dynamics of wall/gas interface in NIF ignition-relevant hohlraums with monoenergetic charged-particle radiography (Fig. 1), which we recently developed and used at the OMEGA laser facility for new types of studies of electromagnetic fields and plasma dynamics relevant to ICF physics and to HEDP [12,13]. This method has resulted in observation and measurement of the perturbation growth at the gas/Au interface and self-generated electromagnetic fields in hohlraums [5], and implosion dynamics in ICF implosions [14,15] at Omega. Its ability to quantify Rayleigh-Taylor instabilities, and to prove for the first time that they can result in generation of magnetic fields, has also been demonstrated in other kinds of laser-plasma experiments [16].

We are currently developing a similar imaging capability at the NIF, where it will enable quantitative analysis of NIF experiments for both programmatic projects and basic science. Monoenergetic charged-particle backlighting will be supplied by an exploding pusher [17] D^3He implosion based on an optimized design developed [18,19] by using the hydrodynamics simulation code *SAGE*; it will use 24 of the NIF's 192 beams (providing 20 kJ of energy) to implode a 210-μm-radius thin D^3He-filled glass shell, generating protons from the reaction $D + {}^3He \rightarrow \alpha + p$. Imaging CR-39 nuclear track detectors will be used for recording fluences of the resultant charged particles [12,13]. The spatial and temporal scales of this backlighter would be ~ 40 μm and ~ 80 ps.

This will allow us to systematically study the dynamics of the fill-gas/wall-blowoff interface, the interpenetration of two materials, the diffusion formed mix layer and an ambipolar E field, and the hohlraum drive evolution during long time intervals (up to ~25 ns, a time scale well beyond that of the OMEGA experiments) that is directly related to the unique, long hohlraum drives used for NIF indirect-drive implosions [2,4,6-9]. Charged-particle imaging could resolve ion diffusion, instability and mixing at the interface with spatial resolution ~30μm and temporal resolution ~ 100 ps, enough to distinguish between anomalous diffusion and instability driven mix [20].

The experiments would use the existing platform of NIF indirect-drive implosions (full/truncated hohlraums [21,22], driven non-yield shots) diagnosed primarily with end-on charged-particle radiography, as indicated in Fig. 1, using 15-MeV and 3-MeV protons; the backlighter timing will be adjusted relative to hohlraum drive to probe the implosion at different times. We will study the resultant fields and plasma flows as a function of time, and the effects of fill-gas on impeding plasma flows and on implosion dynamics and performance.

First experiments would measure the growth of RT instabilities at the interface and the structure, strength and evolution of the radial electric fields E (~ 10^8 V/m) developed in the mix/diffusion layer predicted by simulations with the inclusion of ion diffusions [11,23]. The experimental data, helped by the simulations, will provide insight into the effects of instabilities and fields on the interface structure and dynamics, and shed light on the missing energy in the NIF "ignition" experiments.

References

1. J. Nuckolls *et al.*, Nature **239**, 139 (1972).
2. J. D. Lindl, *Inertial Confinement Fusion* (Springer, NY 1999).
3. S. Atzeni and J. Meyer-Ter-Vehn, *The Physics of Inertial Fusion* (Clarendon, Oxford, 2004).
4. S. H. Glenzer *et al.*, Phys. Plasmas **6**, 2117 (1999).
5. C. K. Li *et al.*, Phys. Rev. Lett. **108,** 025001 (2012).
6. E. I. Moses, J. Phys.: Conf. Ser. **112**, 012003 (2008).
7. S. H. Glenzer *et al.*, Science **327**, 1228 (2010).
8. J. D. Lindl *et al.*, Phys. Plasmas **21**, 020501 (2014).
9. O. A. Hurricane *et al.*, Nature **506**, 343 (2014).
10. J. M. Soures *et al.*, Phys. Plasmas **3**, 2108 (1996).
11. S. C. Wilks *et al.*, to be submitted (2014).
12. C. K. Li *et al.*, Rev. Sci. Instrum. **74,** 10E725 (2006).
13. C. K. Li *et al*., Phys. Rev. Lett. **97,** 135003 (2006).
14. A. J. Mackinnon *et al*., Phys. Rev. Lett. **97,** 045001(2006).
15. C. K. Li *et al.*, Phys. Rev. Lett. **100**, 225001 (2008).
16. M. J.-E. Manuel *et al*., Phys. Rev. Lett. **108**, 225006 (2012).
17. M. D. Rosen and J. H. Nuckolls, Phys. Fluids **22**, 1393 (1979).
18. P.W. McKenty, Private Communication (2014).
19. Y. F. Kong *et al.*, OLUG annual Meeting (2014).
20. S. Le Pape, Private Communication (2014).
21. D. E. Hinkel, Nucl. Fusion **53,** 104027 (2013).
22. S. A. MacLaren *et al.*, Phys. Rev. Lett. **112**, 105003 (2014).
23. P. A. Amendt, Private Communication (2014).
24. C. K. Li *et al.*, Science **327**, 1231 (2010).

Figures

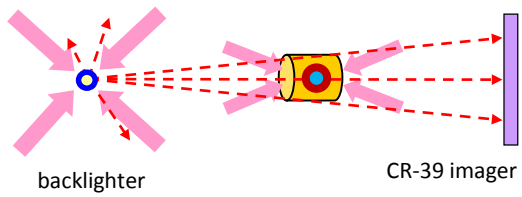

FIG. 1. Schematic of the experimental setup at Omega, with end-on backlighting of a holhraum for imaging electromagnetic fields and instabilities on the interface of the filled gas and Au wall blowoff in gas-filled hohlraums. The backlighter is an exploding pusher implosion of a D^3He-filled capsule that generates monoenergetic 3-MeV and 15-MeV fusion protons.

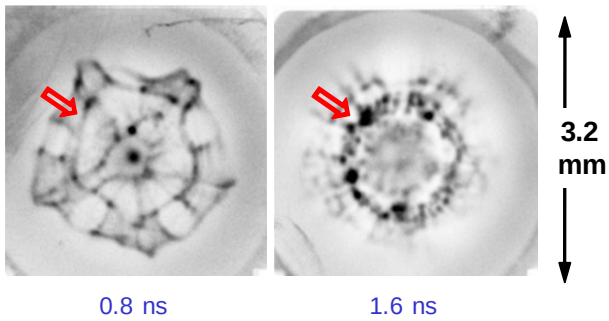

FIG. 2. Proton radiographs of capsule implosions in gas-filled hohlraums at Omega, recorded at different times. The open red arrows point to the interface between Au wall plasma blowoff and gas plasma. A relatively smooth interface appears between the expanding wall blowoff and the ionized fill gas at 0.8 ns, while chaotic spatial structure and interface interpenetration (mix) is evident at 1.6 ns. The fluence surplus inside the imploding capsule (0.8 ns) results from self-generated radial E fields [5].

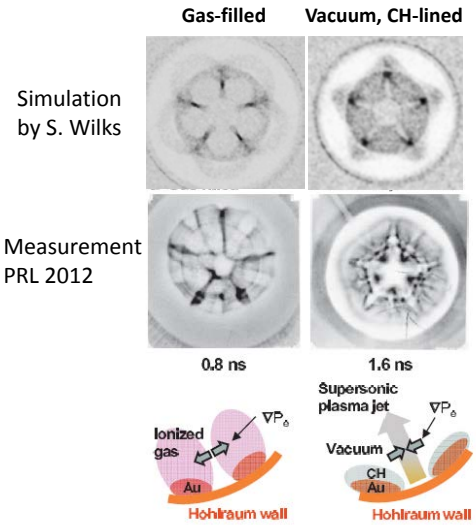

FIG. 3. Proton fluence distributions from numerical simulations (first row) [11] and from measurements (second row) for gas-filled and vacuum, CH-lined Au hohlraums [5,24] at Omega. The proton fluence surplus in the regions between the pairs of expanding plasma plumes in a gas-filled hohlraum, and the proton fluence deficit in the vacuum Au hohlraum, indicate opposing directions of the self-generated electric fields as illustrated schematically by the corresponding cartoons.

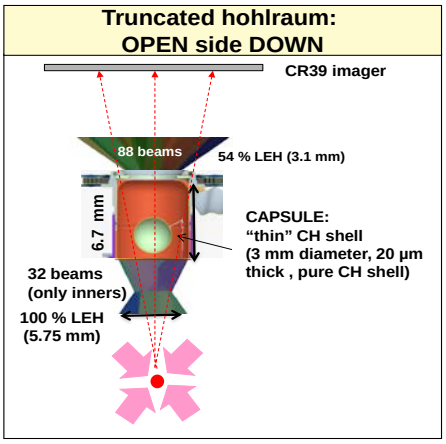

FIG. 4. Schematic for backlighting hohlraums in NIF ViewFactor experiments.