White Paper for *Frontiers of Plasma Science Panel*

Date of Submission:	19 June 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	P
• Interactions of plasmas and waves	S
• Plasma self-organization	
• Statistical mechanics of plasmas	

Indicate type of presentation desired at Town Hall Meeting.

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

Title:	Progress towards diagnosing hydrodynamic turbulence in plasmas
Corresponding Author:	Carolyn Kuranz
• Institution:	University of Michigan
• email:	ckuranz@umich.edu
Co-Authors:	

1.Describe the research frontier and importance of the scientific challenge,

Research frontier: Produce HED systems that evolve from initial instability into a state of hydrodynamic turbulence, and diagnose the resulting dynamics.

In the presence of density and pressure gradients hydrodynamic instabilities, Richtmyer–Meshkov (RM), Rayleigh–Taylor (RT) and Kelvin–Helmholtz (KH), will develop. In a high *Re* regime (above ~10000), these systems can transition to a turbulent mixing state where there will exist fluctuations on a wide range of scales. In plasmas, if the driving scale is about 1 mm, structures on the smallest turbulent length scale (Kolmogorov) can be 1 μm or even sub-micron. With the advent of high-energy, long-pulse lasers, such as NIF, we may be able to reach a truly turbulent plasma state. In order to diagnose these turbulent lengths scales we will need to develop higher quality images with better resolution and higher signal to noise ratios (SNRs).

There is a long history of successful plasma experiments studying hydrodynamic instabilities [1-3]. The current standard for diagnosing these processes is x-ray radiography, which produces a high-quality image using an x-ray source typically created with a UV laser. However, even at the National Ignition Facility, the resolution of these images is limited to ~20 μm [4] and, in some cases, this can reduced to ~10 μm [5]. Also, there is a limit to the brightness of the x-ray source, which, in turn, limits the signal-to-noise (SNR) ratio of the image. An example of an x-ray radiograph from a Richtmyer-Meshkov (RM) experiment is shown in Figure 1a [6]. In order to better understand the relevant structures produced by these unstable processes and in a turbulent state we must create better observation techniques.

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

In many hydrodynamics instability experiments using fluids and gasses, optical imaging techniques, such as planar laser-induced fluorescence (PLIF) and particle image velocimetry (PIV), are used to observe the evolution of these processes. These techniques are used to visualize flow fields and can create high-quality images [7]. An image obtained using the PLIF technique in an RM experiment is shown in Figure 1b [8]. Depending on how the imaging system is constructed, the resolution can be ~15 um, which is similar to the x-ray radiography technique. However, the amplitudes of these fluid systems are much larger, ranging from 1 to 10s of mm, whereas in plasmas, the amplitudes range from 1 to 10s of μm. Therefore, the ratio of amplitude to the size of a resolution element can be up to 2 orders of magnitude larger for techniques used by the fluids community.

Proof-of-principle experiments have demonstrated a similar technique in plasmas [9-11]. A bright x-ray source, such as an x-ray laser, coupled with the x-ray fluorescence imaging technique would be able to diagnose fine structures present in hydrodynamics instability experiments. This is an opportunity to develop techniques to diagnose turbulent states in plasmas.

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

Understanding the behavior of hydrodynamic instabilities and turbulent systems in plasmas has applications ranging from inertial confinement fusion experiments to astrophysical systems. Hydrodynamic instabilities are typically present in systems with density gradients and pressure gradients, which can be caused by strong shocks or shear flows. In inertially confined fusion capsules, hydrodynamic mixing of the ablator material and fuel can cool the center of the target, limiting gain and stymie fusion ignition [12]. Strong density and pressure gradients also occur in multiple stages in the lifecycle of supernovae. The evolution of these stars effects the ejection of heavy elements into the Universe [13].

References

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Figures.

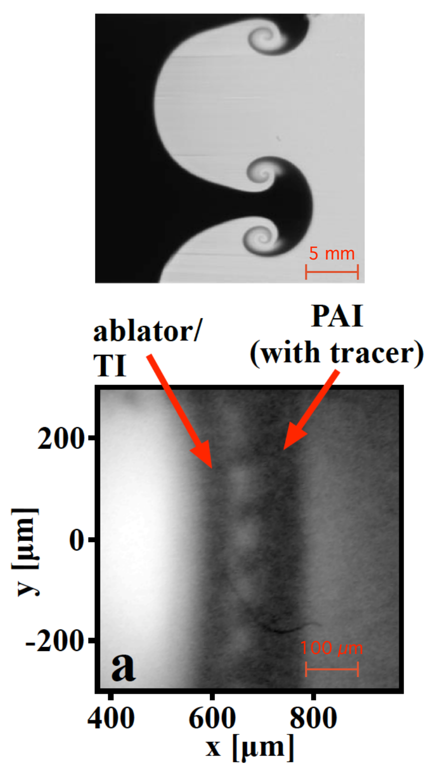

Figure 1. Images from RM experiments using the (a) PLIF technique [6] and (b) x-ray radiography [8] (b).