White Paper for *Frontiers of Plasma Science Panel*

Date of Submission:	***June 15, 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	S
• Turbulence and transport	S
• Interactions of plasmas and waves	P
• Plasma self-organization	S
• Statistical mechanics of plasmas	S

Indicate type of presentation desired at Town Hall Meeting.

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

Title:	**Radiation Hydrodynamics**
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- ***Describe the research frontier*** **and importance of the scientific challenge.**

Research Frontier: Develop a comprehensive understanding of hydrodynamic behavior that is affected by radiation.

In sufficiently hot and dense matter, broadband light waves distributed in direction can carry substantial energy within, and can at times exert substantial forces upon, the plasmas through which they propagate. The study of the fundamental behavior of systems in which radiation can affect the structure of the matter is known as *radiation hydrodynamics*. Radiation hydrodynamic effects become important in any plasma at a temperature of about 100,000 K or more, and dense and thick enough that the matter it contains radiates significant energy on the timescale of interest. The spatial scale can range from microns in hot plasmas near solid density to light years or more in astrophysical shocks. Our understanding of many astrophysical systems is limited by our understanding of, and ability to model, radiation hydrodynamic effects. They also affect the behavior of hot plasmas in thermal x-ray sources, which today are relevant for scientific imaging and for inertial confinement fusion, and ultimately also might play a role in manufacturing.

Radiation hydrodynamics is a subject area at least as challenging as the study of kinetic systems described by the Boltzmann equation. The impact of the radiation on the matter is represented by moments of the spectral intensity of the radiation, yet this spectral intensity is determined in detail by complex integrals involving the properties of the matter, and the properties of the matter involve the complex physics of

atoms in plasma. The approximations that enable simple solutions are extremely crude, yet full solutions for the behavior (including all the atomic details) are far beyond computational feasibility. As a result, the development of improved computational models, and testing the limits of present-day models, is a forefront and important area of research.

Radiation hydrodynamic experiments have likewise been limited to date. Radiative shocks have been studied the most, [1-3] but as yet explorations of their internal structure and their stability have been limited. Figure 1 shows a simulation in which complex structure is evident in a radiative shock. In this case, one also expects structure on a smaller scale that the simulation does not resolve, but that could be extended for study in a dedicated experiment. Studies of radiative jets have been very limited.[4] Diffusive heat waves (Marshak waves) have been observed,[5] but with very limited sets of diagnostics. The response of irradiated surfaces to radiation is likewise not well understood. The conversion of laser energy to thermal x-rays proved to be poorly understood in work using the National Ignition Facility,[6] and the recently discovered phenomenon called a double ablation front has not been examined by experiments.[7] Some known phenomena of interest, such as radiative acoustic waves and photoionization fronts, have not been studied at all in the laboratory. It is also likely that unanticipated phenomena remain to be discovered. An example of such a phenomenon that was discovered is Radiative Plasma Structures,[8,9] which can strongly modify the coupling of laser light to a target. Another example was the discovery that under some circumstances radiation is predicted to flow in an anti-diffusive direction.[10] Neither of these discoveries have been confirmed by experiment.

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

Continuing advances in theory and computations are clearly needed, and need to be supported. In particular, the development of practical models that span the range from freely escaping radiation to strongly trapped radiation is important.

Radiation hydrodynamic experiments can be performed at a wide range of experimental facilities. Past experiments have used facilities ranging from relative small lasers[11] all the way to the National Ignition Facility.[12] A bigger challenge lies in diagnostics. Measurement of the profiles in time and space of density, temperature, and ionization, along with the properties of the radiation, will remain a challenge and will require sustained innovation.

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

Progress in understanding radiation hydrodynamics in plasmas will improve our predictive understanding of plasma behavior. This fundamental advance will impact a wide range of plasma research and applications. The applications that will benefit include laboratory astrophysics at high energy density, x-ray sources for diagnostics and manufacturing, and inertial confinement fusion.

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Figures (maximum 1 page)

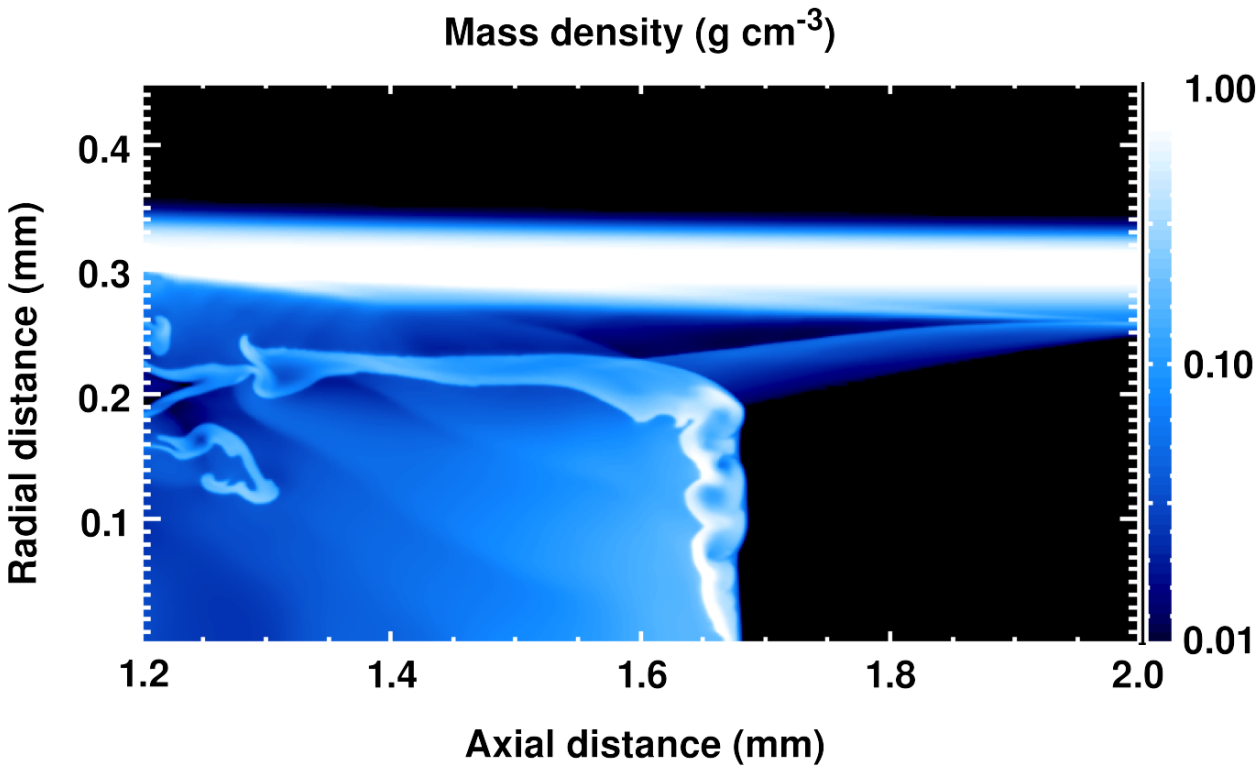

Figure 1. Density output from a simulation of a radiative shock wave in a xenon-filled tube. The shock is moving from left to right. The structure near the shock front results from a combination of instability and radiative effects. (Credit: Eric Myra)