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:	**Waves Behind Fronts**
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- ***Describe the research frontier*** **and importance of the scientific challenge.**

Research Frontier: Develop a comprehensive understanding of wave behavior in plasmas that is initiated by a front of some sort.

Plasmas can sustain many types of fronts – heat fronts, ionization fronts, and shock fronts of many types (radiative, collisional, collisionless, unmagnetized, magnetized, etc.). The behavior behind such fronts is commonly referred to as wave behavior, so that we have heat waves, ionization waves, shock waves, and so on. 20th Century plasma texts most often discuss waves only as modulations in a uniform, unbounded medium, perhaps with gradual changes in time and space. The most one is likely to find in classic plasma texts related to fronts is a brief chapter on shocks. Yet real plasmas often do contain fronts, with the leading edge of a coronal mass ejection (see Figure 1) being only one of many examples. Moreover, the structure of these fronts, the waves behind them, and the precursors ahead of them can be complex, involving variously the acceleration of ions and electrons, the transport of energy by radiation, and the generation and structuring of magnetic fields.

We understand some features of these fronts in plasmas, such as when they have a precursor and, in most cases, the relation between initial and final states for steady waves. But our understanding of their detailed structure is limited in most such cases. As one example, we understand the gross features of a coronal mass ejection (see Figure 1). It has a complicated structure, and it drives a magnetized, collisionless shock ahead of it through the Heliosphere. There is a precursor ahead of the shock. The wave behind the shock

is structured, and includes an unstable interface where the dense material from the mass ejection meets the less dense material from the solar wind. But we do not understand, and cannot predictively model, the detailed properties of any of the components of such an ejection.

- ***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 for the analysis or modeling of the three-dimensional behavior involved will be a key to understanding the detailed structures

Clever experiments are needed to become able to diagnose the details of the structures of such systems. These may involve a wide range of experimental facilities and diagnostics. Collisionless shock waves, for example, are now being explored using plasmas varying by several orders of magnitude in density and timescale.[1-6] However, one must view work on them to date as only first steps in coming to understand them. We are at the phase of "first observations", not at the stage of observing details or testing specific theories. The same can be said for radiative shocks[7] and heat fronts.[8] Photoionization fronts remain entirely unexplored in the laboratory (despite some potentially misleading paper titles). The experimental need in all these areas is for experiments that aim to acquire rigorous knowledge of the behavior of waves behind fronts. An intermediate scale laser facility that included a very large experimental chamber would be an optimum place to make progress on some of this research, as it would allow the study of systems that were spatially extended yet also large in an appropriate dimensionless sense (for example, many gyroradii in extent).

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

Progress in understanding fronts and the waves behind them 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, space science including the design of survivable space systems, and particle acceleration.

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Figures (maximum 1 page)

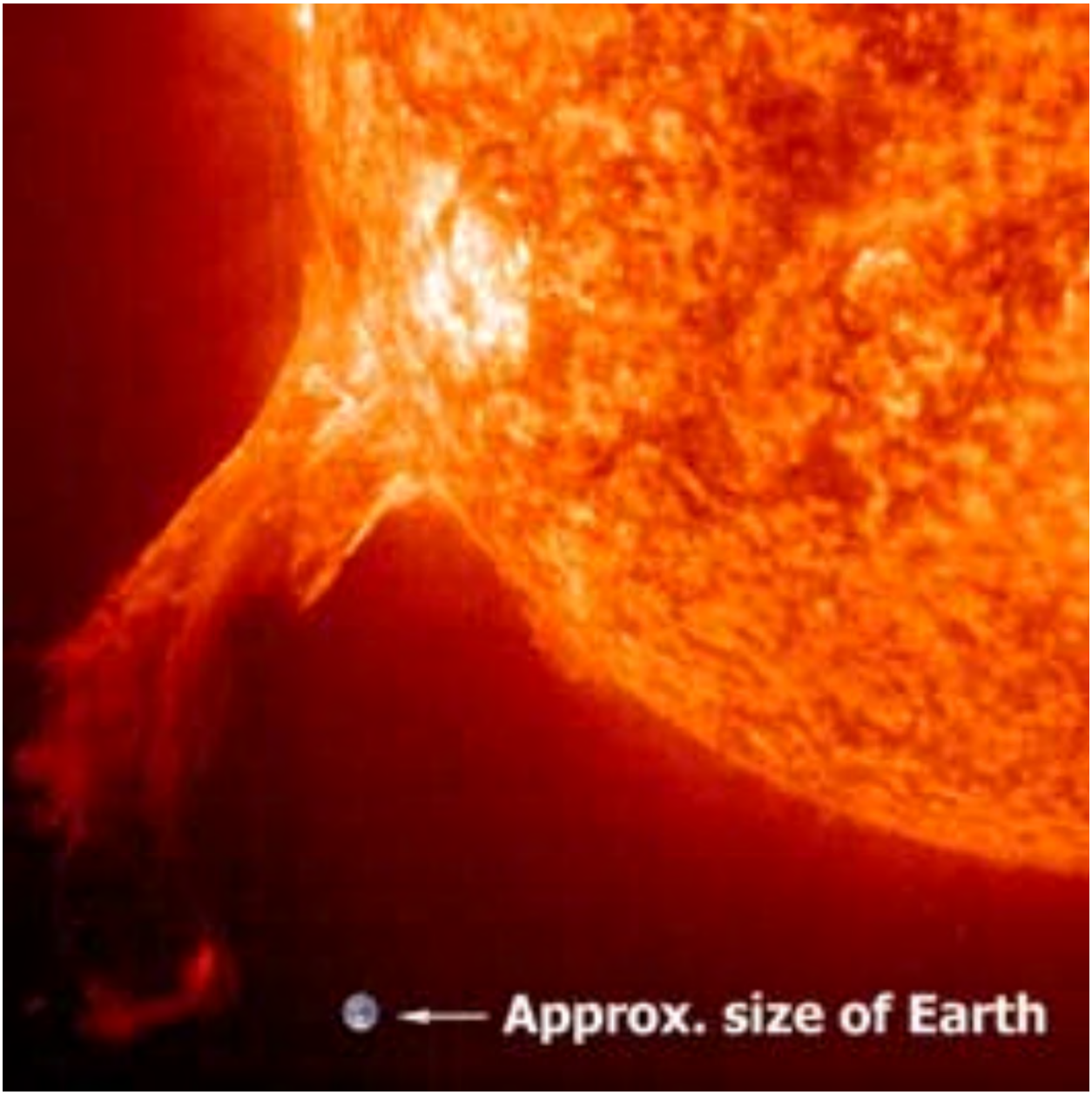

Figure 1. Density output from a simulation of a radiative shock wave in a xenon-filled tube. The shock is moving from left to right. The structure near the shock front results from a combination of instability and radiative effects. (Credit: http://www.daviddarling.info/images/coronal_mass_ejection)