White Paper for *Frontiers of Plasma Science Panel*

Date of Submission:	***6/19/2015***

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	
• Interactions of plasmas and waves	P
• Plasma self-organization	S
• 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:	Laser-plasma based particle accelerators
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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 past decade has witnessed the development of new capabilities for lasers to probe and control matter with unprecedented precision. Many national reports such as the recent ReNew report and several studies by National Academy committees have also recognized the revolutionary and transformational nature of the science enabled by the intensity, coherence and ultra-short pulse duration of these radiation sources. In particular, the criteria for relativistic motion of electrons in the laser focal region ($I \sim 10^{18}$ W/cm^2) is now being exceeded by many orders of magnitude through the development of ultra-fast Petawatt-class lasers which are opening new regimes in High Energy Density Physics (HEDP) – including relativistic plasma physics, non-linear QED, laboratory astrophysics, fast-ignition fusion and **compact plasma based particle accelerators.**

Plasma waves produced by high-power lasers have been studied intensively for their numerous applications. For example, laser wakefield acceleration of ultra-relativistic electron beams [1-9], has been a successful method for accelerating electrons to relativistic energies over a very short distance. In laser wakefield acceleration, an electron bunch 'surfs' on the electron plasma wave generated by an intense laser and gains a large amount of energy. The accelerating electric field strength that the plasma wave can

support can be many orders of magnitude higher than that of a conventional accelerator, which makes laser wakefield acceleration an exciting prospect as an advanced accelerator concept.

When an intense laser pulse interacts with a thin film target it instantaneously turns a thin front layer of the film into dense plasma. Interaction of the intense laser light with plasma at this surface produces highly energetic electrons with multi-MeV energies that are emitted forward and propagate through the foil. Hot electrons propagating all the way through a thin film can establish a very strong electrostatic field at the back of the target which can accelerate protons with maximum energy of tens of MeV and ion beams with energy of hundreds MeV [11-26]. In radiation pressure acceleration, circular polarization may inhibit the absorption of laser energy into thermal electrons, since jxB heating is absent, and consequently TNSA is suppressed. Momentum is imparted by the laser to the target material, either by the laser acting as a piston on a semi-infinite target (hole boring) or by the laser accelerating the plasma as an accelerating mirror (light sail) [13, 16,17,18].

Moreover, laser driven X-ray sources [27] have the potential to be genuinely compact, accessible and inexpensive. An advantage for the work proposed here is the easy synchronization of the x-ray pulse with other ultra-short pulse laser beams and the wide tunability in energy, permitting resonance measurements at the relevant absorption edges. The wakefields that accelerate the electrons can also wiggle them. Operating in the non-linear regime, this can yield a high quality X-ray beam, which is spatially coherent, emanates from a micron-sized source, has 1-100 keV photon energy, milliradian divergence, 10 femtosecond duration and high peak brightness. Recent experimental measurements using the Hercules laser system have measured x-ray photon fluxes with peak spectral brilliance exceeding 10^{22} photons/mm^2 mrad^{2}s/0.1% bandwidth from betatron oscillations of a 0.4 GeV electron beam [28].

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

The stability and response of the wakefield to laser conditions, such as phase front errors, is not well understood, but is crucial for the success of laser wakefield acceleration as a source of relativistic electrons and secondary radiation for applications. Applying coherent control to the transiently stable plasma wave structures [10] should result in a significantly improved understanding and control of the wakefield acceleration process with regard to stability, dark current reduction and beam emittance. This will be enabled by the **development of high repetition rate (>10Hz), high power laser systems (>10 TW).**

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

Subsequent development of laser wakefield accelerator technology for photon sources will be transformative since, unlike conventional synchrotron or free- electron-laser sources, these should be compact and relatively inexpensive. Such x-ray radiation sources could be used for applications across an incredibly broad range of scientific, engineering and technical fields. These sources will lead to improved availability and quality of diagnosis and measurement in these areas, and hence should benefit society as a whole.

Beams of highly energetic ions have a wide array of applications such as compact sources of radioactive isotopes and ion injector sources. Beams of energetic proton can be used to generate quasi-homogeneous warm dense matter by isochoric heating of solid density foils or can be used as a radiography source to detect and study the evolution of electric fields in laser-matter interaction. The possibilities have been discussed for using beams of laser driven ions for hadron radiation therapy, fast ignitor research and even for production of elementary particles.

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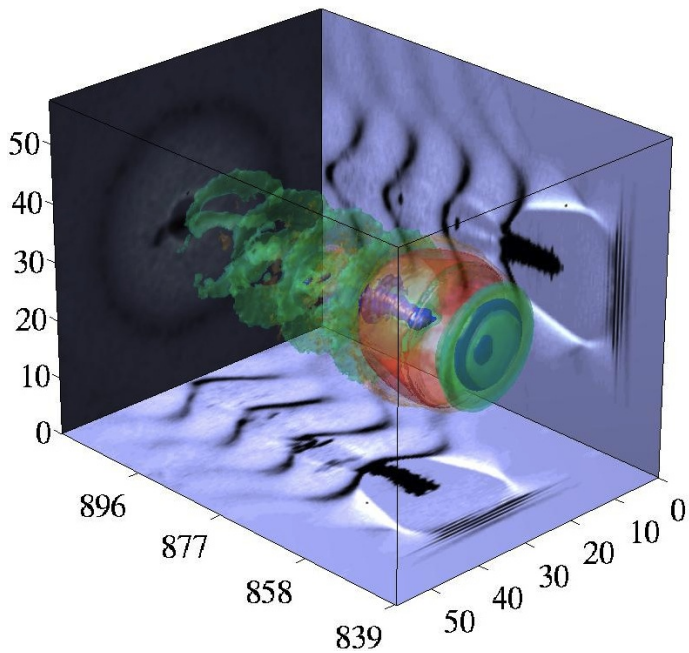
Figures (maximum 1 page)



Laser wakefield accelerator: Isocontours of longitudinal current density from an OSIRIS 2.0 simulation [29] in a moving window showing stable wakefield formation, electron trapping and acceleration [30].