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Title: Final Report on Institutional Computing Project s15_hilaserion, “Kinetic Modeling of Next-Generation High-Energy, High-Intensity Laser-Ion Accelerators as an Enabling Capability”

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Final Report on Institutional Computing Project s15_hilaserion, "Kinetic Modeling of Next-Generation High-Energy, High-Intensity Laser-Ion Accelerators as an Enabling Capability"

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15 Dec. 2016

Self-assessment:

This proposal sought of order 1M core-hours of Institutional Computing time intended to enable computing by a new LANL Postdoc (David Stark) working under LDRD ER project 20160472ER (PI: Lin Yin) on laser-ion acceleration. The project was "off-cycle," initiating in June of 2016 with a postdoc hire.

Laser-ion acceleration occurs through the interaction of ultra-intense ($I\lambda^2 > 10^{18}$ W $\mu m^2/cm^2$; λ is the laser wavelength) short-pulse lasers with thin, solid-density targets. Such accelerators are one of the most promising and active areas of plasma physics. In these accelerators, electric fields >10TV/m are achieved, leading to acceleration of ions to tens of MeV/nucleon over distances of 10s of μm. Novel, "next-generation" ion-acceleration mechanisms pioneered at LANL in computer simulations and validated experimentally are enabling several new applications, including isochoric heating, interrogation of nuclear material, ion fast ignition, hadron therapy of tumors, x-ray sources, and advanced diagnostics for MaRIE.

Unfortunately, the ion source literature is riddled with conflicting hypotheses and it's unclear which mechanisms dominate under which conditions. A recurring problem with modeling these systems on the computer is that the simulations typically do not resolve the essential length and time scales of the governing physics. This obscures understanding of the governing physics, a problem we seek to rectify in our work.

Our project sought to apply the best-in-class LANL VPIC explicit kinetic modeling capability on state-of-the-art LANL computing platforms to guide a comprehensive, theoretical study of nonlinear, relativistic, laser-plasma interaction physics. We had two specific computational physics goals with this project, both of which were accomplished successfully:

1. Perform and analyze large-scale 2D and 3D simulations that retain key plasma length and time scales in order to allow thermal effects to compete with light pressure. Retention of these plasma effects, including the plasma modes that appear to govern early time target expansion and ion acceleration, appears from our preliminary studies to be key to obtaining convergent results.

2. Test several physics hypotheses. Identify how 2D simulations depend upon, e.g., the direction of laser polarization, whether in the simulation plane (2D-"P polarized" or 2D-P) or out-of-plane (2D-S), and how best to mimic in 2D the essential physics occurring in 3D. As 3D simulations will remain "heroic" for the foreseeable future, determining how to effect this cost reduction is crucial to efficient computational design studies.

In order to conduct this work, the team developed, deployed, tested, and exercised new particle-tracking diagnostic capability in VPIC.

List of Publications and Presentations:

D. J. Stark, L. Yin, B. J. Albright, F. Guo, “Toward Extrapolating Two-Dimensional High-intensity Laser-Plasma Ion Acceleration Particle-in-Cell Simulations to Three Dimensions,” 58th Annual Meeting of the APS Division of Plasma Physics, October 31–November 4, San Jose, California (2016).

L. Yin, D. J. Stark, B. J. Albright, “Effects of dimensionality on computer simulations of laser-ion acceleration: When are three-dimensional simulations needed?” 58th Annual Meeting of the APS Division of Plasma Physics, October 31–November 4, San Jose, California (2016).

B. J. Albright, L. Yin, A. Favalli, “Neutron Generation from Laser-Accelerated Ion Beams: Use of Alternative Deuteron-Rich Targets for Improved Neutron Yield and Control of Neutron Spectra", 58th Annual Meeting of the APS Division of Plasma Physics, October 31-November 4, San Jose, California (2016).

B. J. Albright, L. Yin, and A. Favalli, “Neutron Generation from Laser-Accelerated Ion Beams: Use of Alternative Deuteron-Rich Targets for Improved Neutron Yield and Control of Neutron Spectra", submitted to *Physical Review Accelerators and Beams* (2016).

An additional journal article (to be submitted to *Physics of Plasmas)* is in preparation on these results.

Follow-on project/programmatic capabilities:

Institutional computing:
PI: Lin Yin
Co-PI: David Stark
Co-I: B. Albright
Project Title:
Kinetic Physics of High-Intensity Laser-Plasma Interaction
Award Amount and Period:
Wolf: Year 1: 213K hours, Year 2: 213K hours
Grizzly: Year 1: 13.5M hours, Year 2: 13.5M hours

Institutional Computing calculations supported the development of a novel class of high-intensity-laser-based radiation and particle sources presently under consideration for the MaRIE and ECSE/NDSE facilities (both of which are at the CD-0 stage). These decisions are anticipated in roughly the next twelve months (pending DOE and Congressional decisions).