TN

MI

TRANSFORMATIVE PETASCALE PARTICLE-IN-CELL SIMULATIONS

Allocation: NSF PRAC/3,200 Knh
PI: Warren B. Mori[1]
Co-PI: Frank S. Tsung[1]
Collaborators: L. O. Silva[2], R. A. Fonseca[3]

[1]University of California, Los Angeles
[2]Instituto Superior Técnico
[3]University Institute of Lisbon

EXECUTIVE SUMMARY

The NSF Leadership-class system at NCSA, Blue Waters, was used to study highly linear and kinetic processes that occurred in high-energy density plasmas, including plasma-based acceleration and laser fusion. These simulations have resulted in many high-impact publications in *Physical Review Letters*. In summary, Blue Waters resources allow the UCLA simulation group to perform high-impact research and train a new generation of plasma physicists capable of performing simulations on current and upcoming world-class supercomputers.

RESEARCH CHALLENGE

The research focused on three key areas with clearly developed science questions identified by the community [1–3]. This research, funded by both the National Science Foundation and the Department of Energy, addressed the following key questions:

- Can plasma-based acceleration be the basis of new compact accelerators for use at the energy frontier, in medicine, in probing materials, and in novel light sources?
- Can laser plasma instabilities be controlled or even harnessed in inertial fusion plasmas?
- What are the collective processes responsible for the formation of shocks in collisionless plasmas? Are collisionless shocks in plasmas responsible for the most energetic particles in the universe?

METHODS & CODES

Based on the highly nonlinear and kinetic processes occurring in high-intensity laser and beam-plasma interactions and in plasma based acceleration, we use PIC (particle-in-cell) codes [4,5], where Maxwell's equations are solved on a grid using currents and charge densities calculated by weighting particles onto the grid. For this project, we employ the PIC codes OSIRIS, QuickPIC, and UPIC. These codes are all developed locally by the UCLA simulation group (and in collaboration with Instituto Superior Técnico), share many of the same algorithms and data structures, and have been optimized for heterogeneous leadership class supercomputers such as Blue Waters. These codes are freely available and QuickPIC and UPIC are open source (on GitHub).

RESULTS & IMPACT

Large-scale particle-in-cell simulations have been performed that will impact the design of future experiments in plasma-based accelerators and inertial confinement fusion.

Blue Waters was used to study the generation of high-quality electron beams (with high brightness and low energy spread) using the density down-ramp injection scheme. By carefully choosing the parameters of the plasma and the driver, Blue Waters simulations show that electrons with 1GeV (gigaelectronvolt) energy, 0.2% relative projected energy spread, and >10kA (kilampere) current can be generated in nonlinear plasma wakes. This is suitable for X-ray FEL (free-electron laser) applications, which can provide a compact radiation source for nuclear science. Simulations were also run to study [6] the effects of ion motions on very-high-brightness beams such as those required for future collider design. In future colliders, which confine electrons within a radius of a few nanometers, the space charge forces around the beam can pull the plasma ions inward. This generates nonlinear focus force inside the wake, which can potentially lead to beam-emittance growth. The self-consistent simulation for this problem remains a big challenge because the simulation box has a transverse size of hundreds of microns. However, the cell size needs to be a few nanometers in order to resolve the electron beam, which results in a simulation box with 10^{11} cells. Blue Waters (because of its large memory size) is ideally suited to study this particularly demanding problem, and simulations performed on it showed that ion motion does not necessarily lead to catastrophic emittance growth.

In collaboration with colleagues at the Naval Research Laboratory, Blue Waters has been used to study the effects of temporal bandwidth (laser smoothing) on laser plasma interactions in laser fusion. In current inertial confinement fusion experiments, lasers can lose a large fraction of their energy to laser-plasma interactions where the laser decays into a backscattered light and a plasma wave. Large-scale 2D OSIRIS simulations showed that, given enough bandwidth (in the order of several terahertz), laser plasma instabilities can be suppressed. Blue Waters resources allow our group to simulate, for the first time, the interaction of many speckles in 2D over several picoseconds with beam smoothing. The additional realism provided by these simulations will lead to a better understanding of laser-plasma interactions in current and future experiments in inertial confinement fusion.

WHY BLUE WATERS

Blue Waters provides the largest, time-tested, and stable supercomputing platform in the world. It has a CPU side that is time tested and very stable, and has allowed us to perform large-scale simulations in a timely manner, and a GPU side that provides a testbed for code development. This combination suits almost all research supercomputing needs, and has provided a productive computational environment and a satisfactory experience since the very beginning of Blue Waters.