MODELING PHYSICAL PROCESSES IN THE SOLAR WIND AND LOCAL INTERSTELLAR MEDIUM WITH A MULTISCALE FLUID–KINETIC SIMULATION SUITE

Research Challenge
Investigation of physical phenomena that start on the solar surface and result in the solar wind (SW) acceleration and propagation through interplanetary space toward the boundary of the heliosphere, where the SW interacts with the local interstellar medium (LISM). The simulations are data-driven and help interpret observations from such space missions as IBEX, New Horizons, Ulysses, Voyager, and a fleet of near-Earth spacecraft. Vector magnetogram data and STEREO observations are used to study the propagation of coronal mass ejections toward Earth, where they affect space weather.

Methods & Codes
Solving the ideal magnetohydrodynamics (MHD) equations coupled with the kinetic Boltzmann equation describing the transport of neutral atoms. In a less strict approach, the flow of atoms is modeled with a few systems of the Euler gas dynamic equations. All these are components of a Multi-Scale Fluid-Kinetic Simulation Suite (MS-FLUKSS)—an adaptive mesh refinement code built on the Chombo framework from LBNL.

Why Blue Waters
First, neutral atoms are modeled kinetically, and the team needs of the order of $10^{12}$ particles in the Monte Carlo simulations. These simulations require particle splitting, multiple grids, and coupling with the MHD module. They also produce multiple data sets sometimes exceeding 1 terabyte, which require hybrid parallelization. Computational region sizes are very large, exceeding $7.5 \times 10^{11}$ cubed astronomical units, as in the case of long-heliotail simulations necessary to explain the observed anisotropy in multi-TeV cosmic ray flux. Finally, very deep adaptive mesh refinement is necessary near magnetic reconnection sites.

Results & Impact
By addressing the basic physical phenomena occurring at the SW-LISM interface, this research is of importance for solar and heliospheric physics, physics of the interstellar medium, and plasma physics in general. The collaboration with the Blue Waters team promotes the application of adaptive technologies to contemporary plasma physics problems through the development of publicly available packages suitable for multiple applications. This is of particular importance because of the Parker Solar Probe to be launched this summer and become the major Heliophysics mission for the decades to come.

Allocation: NSF PRAC/2,140 Knh
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Top: Simulated interplanetary magnetic field direction. Bottom: The distribution of simulated interstellar medium plasma density (left) along the Voyager 1 trajectory and its comparison with the plasma wave events detected by the spacecraft beyond the heliopause (right).
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Methods & Codes

Results & Impacts

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