

Submission in Response to NSF CI 2030 Request for Information

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Author Names & Affiliations

- James Drake - University of Maryland

Contact Email Address (for NSF use only)

(Hidden)

Research Domain, discipline, and sub-discipline

Plasma Physics

Title of Submission

Computational plasma physics

Abstract (maximum ~200 words).

Computation on massively parallel machines has transformed our ability to do research on the dynamics of plasmas. The focus of our group is on magnetic reconnection, which is the dominant mechanism for releasing magnetic energy in the universe. Magnetic reconnection typically takes place in explosive events which produce large numbers of very energetic particles. Such explosive energy releases have been documented in laboratory, space and astrophysical systems. Flares and coronal-mass-ejections from the sun are the drivers of space weather in the Earth space environment. This research area therefore has significant implications for protecting our infrastructure and the safety of astronauts during manned spaceflight. The exploration of the production of energetic particles during reconnection requires a kinetic description, which involves particle-in-cell codes. Recent theoretical advances suggest that understanding the dynamics of reconnection in three-dimensional rather than two-dimensional systems is critical for exploring particle energy gain. Carrying out three-dimensional simulations with the PIC model while adequately separating electron and ion kinetic scales is an enormous computational challenge that requires platforms with 100's of thousands of cores and runs involving 10s of millions of node-hours.

Question 1 Research Challenge(s) (maximum ~1200 words): Describe current or emerging science or engineering research challenge(s), providing context in terms of recent research activities and standing questions in the field.

The exploration of particle acceleration during magnetic reconnection requires the use of kinetic simulation approaches, with the most advanced being the use of particle-in-cell models. The challenge is the adequately separate electron (the electron skin depth and Larmor radius) and ion (the ion inertial and Larmor radius) kinetic scales from the macroscale size of a system. In 2D descriptions adequate separations of scale are possible. However, recent simulations have revealed that electron energy gain is greatly enhanced in a 3D system where the magnetic fields become chaotic. The consequence is that energetic electrons are no longer constrained in magnetic islands and can wander freely to access regions of space where magnetic energy release is taking place. The consequence is that electron energy gain

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is strongly enhanced. Thus, the exploration of electron energy gain during magnetic reconnection requires simulations in 3D systems with adequate separation of scales. This is an enormous computational challenge. The ultimate goal is to determine the mechanisms that lead to the ubiquitous power distributions of energetic particles seen in nature. What controls the spectral indices of these distributions? How do energetic particles escape from regions of space where magnetic energy is being released? It is the balance between the energetic particle drive and the loss of particles from the system that produces the spectrum of particles. This means that on top of the driver of energetic particles we need to understand the mechanisms that limit transport. There is now evidence from both observations and simulations that even in collisionless systems transport is suppressed below that expected from simple free-streaming models. The heat flux itself appears to be self-limiting in that a large heat flux drives turbulence, which then scatters particles and thereby reduces heat flux.

Question 2 Cyberinfrastructure Needed to Address the Research Challenge(s) (maximum ~1200 words): Describe any limitations or absence of existing cyberinfrastructure, and/or specific technical advancements in cyberinfrastructure (e.g. advanced computing, data infrastructure, software infrastructure, applications, networking, cybersecurity), that must be addressed to accomplish the identified research challenge(s).

Computational platforms with 100's of thousands of cores running for 10's of millions of core-hours are required to take the next steps for understanding particle acceleration and transport during magnetic reconnection.

Consent Statement

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