White Paper for *Frontiers of Plasma Science Panel*

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Title:	Exploring Space Plasma Reconnection-Driven Particle Acceleration
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1 page of references and 1 page of figures may also be included. *Submit in PDF format*.)

Exploring Space Plasma Reconnection-Driven Particle Acceleration

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Background

Energetic and violent events in the solar corona lead to solar storms (Figure 1) capable of destroying satellites, disrupting ground communication, and causing fluctuations in power grids on Earth[1,2]. The energy driver of these events is the sun's magnetic field. Oppositely directed magnetic fields annihilate each other, releasing magnetic energy in an explosive process called *magnetic reconnection*. In the astrophysical realm, magnetic reconnection also drives stellar flares and explosions in high magnetic field neutron stars – it is, in fact, the dominant process for dissipating magnetic energy in the universe. Explosive events on the sun have a direct and strong influence on the Earth's magnetosphere and ionosphere in the form of magnetic storms and intense auroras, creating serious risks for manned and unmanned space missions[3]. In laboratory thermonuclear fusion experiments, magnetic reconnection leads to the concentration of energy in small filaments that degrade confinement[4] and could potentially destroy the containers in which these plasmas are produced.

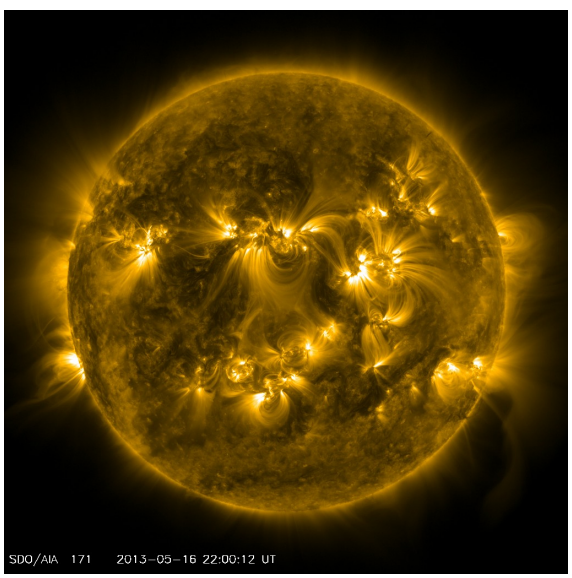

Figure 1: SDO x-ray imagery from the solar corona shows magnetized plasma loops on May 16, 2013. These loops interact, often times violently.

The Challenge

Observations indicate that magnetic reconnection is an extraordinarily efficient driver of energetic particles – in solar flares half of the released magnetic energy appears as energetic electrons and protons. In spite of the importance of this phenomenon of particle acceleration, the mechanisms for the production of energetic particles during magnetic reconnection remain poorly understood. The most energetic events are remote – on the sun and other astronomical bodies – and therefore not amenable to the detailed scientific exploration that is necessary to unravel the mystery of particle acceleration.

A number of theoretical models of particle acceleration during reconnection have been proposed over the past 50 years. Progress, however, has been hampered by the complexity of the problem – describing the interaction of particles with a turbulent spectrum of "magnetic islands" in a nearly collisionless, three-dimensional system pushes at the limits of modern computing power – and by the absence of direct observations for distinguishing between competing theories.

Significant progress has also been made to improve our understanding of plasma reconnection, thanks to dedicated laboratory reconnection experiments (Princeton[5], MIT[6], UCLA[7]). These have explored the processes that trigger reconnection and control how magnetic energy can be released so rapidly. However, none of these experiments has addressed the mechanisms that produce the most energetic particles.

The Approach

These knowledge and technical gaps call for the development of new laboratory reconnection experiments and theory designed to explore particle acceleration in the complex, multi-loop environment similar to that of the corona. The theory and experiments should build on collaborative expertise from plasma and fluid dynamics, pulsed-power systems, diagnostics and reconnection theory and modeling.

Specific design choices to maximize knowledge yield could include:

1. Simulate the space weather conditions that are created in the Sun-Earth space environment. For instance, a large vacuum vessel would allow for magnetized plasma loops to freely expand without interacting with the vessel walls (in the timescale of the experiment).

2. Flexible plasma gun arrangement to explore the interaction between two versus more than two plasma reconnection sites, and also the collision between expanding plasma flux ropes –resembling solar loops– and various objects (e.g., magnetized spheres that simulate collisions of solar eruptions with Earth's magnetosphere).

3. Multi-probe set-up designed to measure the time evolution of the flux ropes and associated energetic particle spectra. Potential probing could include: Rogowski coils and voltage dividers (to measure gun currents and voltages, respectively); miniature magnetic (B-dot) probes placed close to the plasma; charged particle energy analyzers; x-ray detectors; high speed imaging with different line filters in combination with different injected gases to visualize flows and mixing regions in the plasma; stereography; tomography.

Experiments should be paralleled with modeling efforts. In fact, the University of Maryland is already exploring the mechanisms that produce the most energetic electrons and ions, including multiple ion species, in complex 3-D magnetic systems. With solid modeling in place, new ideas could be directly tested and theory and modeling could act as the bridge between the experiment and the much larger physical environment of the solar corona.

The Impact

Magnetic reconnection and particle acceleration are universal processes of great scientific importance. NASA is building a $1B four-satellite constellation to study magnetic reconnection in the Earth's magnetosphere: MMS. The problem is also of great practical importance – solar storms and associated energetic particles pose a threat to manned and unmanned spacecraft. Results from particle acceleration-focused experiments are likely to be of interest to researchers from plasma physics, astrophysics, space physics, geophysics, and those working on plasma confinement for energy production. In addition, the results are highly visual and dynamic so may well be of interest to lay scientists and the general public, expanding the reach of plasma science.

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