**White Paper for *Frontiers of Science Panel***

| Date of Submission: | 15 June 2015 |
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Indicate the primary and secondary areas.

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|---|---|
| • Plasma Atomic physics and the interface with chemistry and biology | |
| • Turbulence and transport | P |
| • Interactions of plasmas and waves | S |
| • Plasma self-organization | S |
| • Statistical mechanics of plasmas | |

Indicate type of presentation desired at Town Hall Meeting.

| | |
|---|---|
| Title: Oral | |
| Poster: | |
| Either Oral or Poster: | |
| Will not attend: | X |

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|---|---|
| Title: | The Complex Interplay of Plasma Turbulence, Magnetic Reconnection, and Energetic Particle Acceleration |
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• ***Describe the research frontier and importance of the scientific challenge.***

It is widely acknowledged that three of the most fundamental outstanding plasma physics problems are plasma turbulence, magnetic reconnection, and particle acceleration. Distinct sub-disciplinary communities have arisen to address separately each one of these three grand challenge problems. Yet, these three phenomena rarely act in isolation, and accounting for the interaction among these processes may be necessary to understand fully their impact on any particular plasma environment of interest. For instance, does magnetic reconnection play a role in the dissipation of plasma turbulence? Does the evolution of a plasma undergoing magnetic reconnection differ qualitatively when the reconnecting plasma is turbulent compared to when it is not? Does the mechanism leading to particle acceleration require a background turbulent medium to operate effectively? It is the complicated interplay of turbulence, reconnection, and particle acceleration that represents a looming scientific challenge at the frontier of plasma physics.

To address the interplay of these three fundamental processes is made yet more challenging by the fact that the plasma collisionality is often weak on the length and time scales on which these mechanisms operate, necessitating a treatment using kinetic plasma physics. Although the turbulent cascade of energy in many space and astrophysical plasmas is driven at large scales that are strongly to moderately collisional, the dynamics is often weakly collisional on the small scales at which the turbulent fluctuations are damped and their energy is converted to plasma heat or some other form of particle energization. Magnetic reconnection in many laboratory, space, and astrophysical systems of interest occurs under weakly collisional conditions, requiring the complexity of kinetic theory to describe fully the evolution. And the acceleration of particles in the tail of the velocity distribution function to very high energies is inherently a collisionless process. A promising strategy that has been adopted by many groups hoping to illuminate the kinetic plasma physics of one of these grand challenge problems is to adopt a cross-cutting approach that coordinates laboratory experiments, *in situ* measurements by spacecraft, numerical simulations, and analytical theory. But to explore effectively the regimes of intersection among kinetic plasma turbulence, collisionless magnetic

reconnection, and particle acceleration will require unprecedented cooperation among established groups with expertise on each of these separate scientific topics.

***• Describe the approach to advancing the frontier and indicate if new research tools or capabilities are required.***

Although the broader community of plasma physicists, space physicists, and astrophysicists boasts the expertise needed to address the interplay of plasma turbulence, magnetic reconnection, and particle acceleration, establishing the cooperation necessary to ensure significant progress at their intersection is inhibited both by the difficulty of the individual problems alone and by the realities of the funding environment.

Although previous efforts have been made to address the interplay among turbulence, reconnection, and particle acceleration, in many cases the addition of a new phenomenon to an existing research program on one of the grand challenge problems involves the use an overly simplified, or even outdated, model for the new phenomenon. This is understandable since a group of experts in one of these very difficult grand challenge topics is unlikely to have an in-depth understanding of the most recent developments for the other grand challenge problems. For example, predicting the propagation of energetic particles throughout the heliosphere—particles that were accelerated in a violent event on the solar surface—requires a model of the turbulent magnetic field within the solar wind. But, with few exceptions, extremely outdated "slab" models of the turbulence have often been used, even though such simple models of turbulence have generally been abandoned by the turbulence community nearly two decades ago. In such a case, cooperation of the energetic particle experts with an expert on modern plasma turbulence theory would likely lead to a much more relevant, and possibly more successful, investigation.

But, under many of the existing funding programs, securing funding for such an unprecedented cooperative effort between leading experts on two distinct topics is unlikely. Notable exceptions include the NASA Heliophysics Science Centers, DOE Plasma Science Centers, and NSF Frontier Centers, but these opportunities are infrequently solicited and often dramatically over-subscribed. For focused topics of importance to plasma physics, heliophysics, and astrophysics, the solicitation of proposals targeted to one specific problem may help to promote this type of cooperation. For example, magnetic reconnection plays an important role at the dayside magnetopause and in the magnetotail, but both of these environments have pre-existing turbulence. By adjusting policy to encourage the development of collaborations between experts in both collisionless magnetic reconnection and kinetic plasma turbulence, the broader plasma physics, space physics, and astrophysics community may achieve new and important insights at the intersection of reconnection and turbulence. Within such collaborative efforts, it will be beneficial to maintain a strategy coordinating laboratory investigations, spacecraft measurements, numerical simulations, and analytical treatments. Thus, although funding levels for such a focused program need not be at the level of the NASA, DOE, or NSF Centers, it should provide significantly more resources than a typical, single-PI, three-year grant.

***• Describe the impact of this research on plasma science and related disciplines and any potential for societal benefit.***

The grand challenge problems of plasma turbulence, magnetic reconnection, and particle acceleration represent fundamental phenomena in plasma physics, cutting across traditional disciplinary boundaries, affecting the evolution of plasmas in the laboratory, in space, and throughout the universe. Indeed, the DOE Plasma Science Frontiers Workshop is organized in just such a cross-cutting manner to encourage discussion across traditionally distinct scientific sub-disciplines that have, at their core, similar fundamental plasma physics mechanisms. As each of the sub-panels develops its own view of the frontiers, they should consider also the important intersections among each of these broad categories of physics.

Plasma environments in which plasma turbulence, magnetic reconnection, and particle acceleration play an important role span the breadth of plasma physics, heliophysics, and astrophysics. Significant progress in any one of these topics will have a significant impact on the breadth of plasma science. The DOE, NSF,

and NASA will all benefit from progress in any of these fields, so collectively supporting these efforts, in a coordinated way, will likely reap significant rewards. Potential benefits to society include harnessing fusion energy as a power source and protecting communication and navigation satellites and astronauts from various forms of extreme space weather.