White Paper for *Frontiers of Plasma Science Panel*

Date of Submission:	***7/23/15***

Indicate the primary area this white paper addresses by placing "P" in right column.
Indicate secondary area or areas by placing "S" in right column

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

Indicate type of presentation desired at Town Hall Meeting.

	"X"
Oral	
Poster	
Either Oral or Poster	
Will not attend	

Title:	Geoplasma Physics – Fundamental Plasma Physics Issues of the Solar-Terrestrial Environment
Corresponding Author:	Tom Mehlhorn
• Institution:	Naval Research Laboratory
• email:	Tom.mehlhorn@nrl.navy.mil
Co-Authors:	Guru Ganguli, Bill Amatucci, Paul Bernhardt, Carl Siefring, Joe Huba, Jonathan Krall, and the US Geoplasma Physics Community

(Limit text to 3-pages including this form. Font Times Roman size 11.
1 page of references and 1 page of figures may also be included. *Submit in PDF format*.)

- ***Describe the research frontier* and importance of the scientific challenge.**

Geospace has been described as the region of the solar-terrestrial environment that includes the upper part of the atmosphere, the outer part of the geomagnetic field, and the solar emissions that affect them [1]. We use the term "geoplasma physics" to describe the ensemble of fundamental plasma physics issues that govern the dynamic processes in and the resultant structure of geospace - both during normal solar activity and during solar storms. It is important to note that many of the theoretical, computational, and experimental areas of particular interest in geoplasma physics are also relevant to other areas of plasma physics, most notably the science of magnetically confined fusion plasmas. These areas include (1) turbulence, (2) waves & instabilities, (3) wave-particle interactions, (4) plasma energization and transport, and (5) radiation belt dynamics (energetic particle-plasma wave interactions).

The Sun is the driver of the chain of events that facilitates the flow of solar mass, energy, and momentum into the near Earth region and defines the 'space weather'. Certain solar processes, such as eruptive events (coronal mass ejections (CME)) or the solar wind co-rotating interactive regions, are especially geoeffective. As the solar wind interacts with the Earth's dipolar magnetic field a unique interaction takes place, which couples the solar wind plasma, momentum, and energy into the geospace. At the largest scales the significant coupling process is magnetic reconnection between the interplanetary magnetic field

and the geomagnetic field. This coupling leads to the formation of boundary layers with scale sizes as small as a few ion gyro radii, which separates plasmas of different characteristics. Trapping of the energetic particles originating from the sun in the earth's dipolar field creates the deadly intermediate scale radiation belts. The orbital lifetime of satellites is inversely proportional to the population of the trapped energetic particles in the radiation belts. Between the reconnection scale and the boundary layers there is a huge disparity in both temporal and spatial scale, which provide an extraordinary challenge to both experimentalists and theorists. Experimental resolution of the smallest scale sizes in the geospace environment continues to be a challenge. The magnetospheric response to increasing solar wind activity leads to a remarkable chain of events, which can adversely affect the space based assets. This highly dynamic process involves the compression of the magnetotail, energization of particles, and dissipation of the energy, which ultimately results in the spectacular auroral emissions. Of particular interest are the consequences of the magnetospheric storms and the substorm process, which play a central role for the storage, conversion, and transport of solar wind energy inside the magnetosphere. After entering the magnetosphere and interacting with the Earth's magnetic field, an important fraction of the solar wind mass, energy, and momentum is deposited in the ionosphere. Among the prominent effects in the ionosphere is the convection of plasma in the Polar Regions and the heating and creation of winds in the thermosphere.

In many cases the global structure of the Earth's magnetosphere and the influence of the solar wind on it remains unknown, despite the heroic efforts of observational researchers using in-situ probes. This observational data has been used construct a number of empirical 'working' models; however, empirical models are limited in scope – we need to deepen our understanding of the underlying plasma physics and associated wave-particle interactions, and construct physics-based models. However, a true first principle based model for the entire geospace system is beyond our physics understanding as well as the severe limitations of our computational capabilities to encompass realistic cross-scale couplings and deal with nature's diversity in spatial and temporal scales. Relevant spatial scales vary from 1 AU down to an ion or electron gyroradius. Relevant temporal scales vary from days down to ion and electron gyrofrequencies, and possibly even plasma frequencies. The large temporal and spatial scale sizes involved with the solar wind tend to fragment towards smaller and smaller scales due to the solar wind-magnetosphere interactions and their nonlinear evolution. As the scale size becomes comparable to species gyroradii the MHD formulation becomes less reliable and makes a more general kinetic treatment necessary. In fact, the developing MHD conditions may seed the kinetic processes and this coupled system may self-consistently evolve towards a Self-Organized- Critical system.

Relevant micro instabilities and their meso- and macro-scale effects will have to be understood and parameterized. Space probes often observe waves. These collective plasma effects could be responses to the developing MHD conditions in which the shrinking scale sizes increase local gradients in the plasma parameters until they cross the threshold values. Therefore, waves are a valuable diagnostic of the local plasma conditions. Observations of linear and nonlinear waves in almost every region of geospace emphasize the importance of small-scale phenomenon as well. Both the large and small scales are relevant since the space plasma system is largely a collisionless system, and dissipation in a collisionless plasma is generally achieved via wave generation.

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

Advancing the frontier in understanding, modeling, and ultimately predicting the state of the geospace environment (e.g. space weather) will require substantial improvements in theory and simulation that address the plasma physics areas and challenges described in the previous section. These challenges include handling the multi-scale nature, both temporal and spatial of the geospace system. It also means understanding transitions from linear to non-linear interactions, fluid vice kinetic parameter regimes, and

the like. Experimental data will also play an important role in both uncovering the underlying geoplasma physics of the system, as well as helping to validate the computational models.

An impressive array of satellites and space probes, both domestic and international, are providing us with unprecedented data about the sun, the solar wind, magnetosphere, radiation belts, and the ionosphere. This data is available to the geoplasma physics community from NASA, NOAA, and other agencies and should be utilized to provide in-situ "space truth". The ionosphere has also traditionally been subject to ground-based investigation via radars, magnetometers, lidars, interferometers, photometers, and imaging. The NSF has developed a sophisticated network of these ground-based assets. The proximity of the ionosphere makes it a suitable outdoor plasma physics laboratory; however, it is difficult to determine initial and boundary conditions. Unique experimental facilities, such as the High power Active Auroral Research Program (HAARP) facility (now operated by the University of Alaska, Fairbanks), provide us with the ability to probe the ionosphere through high power wave-particle interactions that modify the ionosphere, create density structures, generate low frequency waves, and create super thermal electrons. Key to advancing the laboratory investigation of space plasma phenomena is the availability of facilities with sufficient flexibility in plasma parameters, magnetic field strength, and plasma species selection to allow proper scaling to important dimensionless parameters. Plasmas large enough to support the long transverse and magnetic-field-aligned wavelengths that characterize space plasma waves, while also allowing sufficient vacuum gap between the plasma and chamber walls to minimize boundary effects are required. Facilities such as the NRL Space Physics Simulation Chamber, the UCLA LArge Plasma Device (LAPD), and the West Virginia University Large Experiment on Instabilities and Anisotropy (LEIA) already exist that meet many of these requirements. For example, the micro-scale phenomenon involved in the collisionless dissipation described above is amenable to scaled laboratory studies under controlled and repeatable conditions. This offers the possibility of benchmarking and refining theoretical models that can then be applied to space relevant parameters with increased confidence.

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

Constant, reliable access to satellites has become a necessity for the critical commercial, communication, navigation, and intelligence needs of our modern society. Since the first in-situ measurements were made about half a century ago, our knowledge, and use, of the space environment has steadily grown. This had led to a concomitant demand to increase our understanding of geoplasma physics and improve our ability predict geoplasma dynamics in the Sun-Earth system to ensure the uninterrupted operation of a wide array of civilian, scientific, security, and military systems.

Our Society has become increasingly vulnerable to Space Weather events [2]. Our ever-growing fleet of expensive satellites are increasingly vulnerable to the extreme hazards the space environment. Highly energetic particles often penetrate to the electronic components of these satellites and cause electronic upsets, spurious signals, and system damage. Lower energy particles can contribute to satellite charging and dielectric discharges. Even on the Earth's surface, our increasing reliance on technology makes modern society vulnerable to space weather. Magnetic activity, with origin in space, is known to cause severe damage to power generation and distribution at higher latitudes, (e.g., 1989 Hydro Quebec incident [2]) as well as malfunction of long line telecommunication power circuits. Other societal vulnerabilities include disruptions in GPS, restrictions on commercial air traffic using polar routes, and disruptions in satellite telecommunication.

These space plasma effects are capable of causing substantial perturbations to economic activity and deep concerns to national security. It is therefore critical that we understand and predict the electromagnetic and plasma environment in the near-earth geospace environment, not just for science sake, but also for economic and national security.

References (Maximum 1 page)

[1] *The solar-terrestrial environment*, JK Hargreaves - 1992 - Published by the Press Syndicate of the University of Cambridge The Pitt Building, Trumpington Street, Cambridge CB2 1RP 40

[2] National Research Council (2008). **Severe Space Weather Events--Understanding Societal and Economic Impacts Workshop Report**. Committee on the Societal and Economic Impacts of Severe Space Weather Events:A Workshop, National Research Council, National Academy of Sciences**:** 131.

Figures (maximum 1 page)