White Paper for *Frontiers of Plasma Science Panel*

Date of Submission:	***6/19/2015***

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	P
• Interactions of plasmas and waves	P
• Plasma self-organization	P
• Statistical mechanics of plasmas	

Indicate type of presentation desired at Town Hall Meeting.

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

Title:	**Major Scientific Challenges and Opportunities in Plasma Astrophysics**
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(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*.)

I. Plasma Astrophysics

Plasma pervades the universe at all measurable scales. At the very small scale, coupled processes in plasmas determine the behavior of the solar system. The Sun rotates, generates magnetic fields, and ejects mass in part because of plasma processes. The ejected plasma expands as the solar wind toward the Earth, becoming turbulent as it travels. It then encounters and becomes trapped in the Earth's magnetic field, causes shocks, and produces magnetic substorms, aurora, and other plasma phenomena. This Sun-Earth system spans the short distance of 10^{-4} light years. Jumping ten orders of magnitude in size, extra-galactic jet systems are among the largest plasma structures in the universe. They begin with a rotating, accretion disk surrounding a supermassive black hole. Plasma transport processes determine the rate of accretion of matter onto the black hole, while producing the most luminous source of energy in the universe. The rotating plasma also launches a collimated jet that travels distances in the range of one million light years, ending in confined lobes of plasma. Dynamics of astrophysical systems at all scales between the solar system and jets are similarly regulated by plasma physics. Understanding these plasma behaviors, termed plasma astrophysics, represents the third important problem in the universe after revealing the nature of dark energy, which drives expansion of the universe, and the nature of dark matter, which dictates largest structure of the universe. Plasma astrophysics decides much of the rest of the visible universe.

II. 10 Major Questions or Challenges in Plasma Astrophysics

In 2010, a group of more than 100 scientists from three disciplines (laboratory plasma physics, heliophysics and astrophysics) undertook a grass-roots activity through a workshop called Workshop on Opportunities in Plasma Astrophysics, or WOPA (www.pppl.gov/conferences/2010/WOPA/index.html). 10 major scientific questions or challenges in plasma astrophysics have been identified:

1. How do magnetic explosions work?
2. How are cosmic rays accelerated to ultra-high energies?
3. What is the origin of coronae and winds in virtually all stars, including the Sun?
4. How are magnetic fields generated in stars, galaxies, and clusters?
5. What powers the most luminous sources in the universe?
6. How is star and planet formation impacted by plasma dynamics?
7. How do magnetic fields, radiation, and turbulence impact supernova explosions?
8. How are jets launched and collimated?
9. How is the plasma state altered by strong magnetic fields?
10. Can magnetic fields affect cosmic structure formation?

III. 10 Fundamental Topics in Plasma Astrophysics

To answer these questions, the WOPA team with their group members have identified 32 major scientific opportunities in plasma astrophysics on the following 10 fundamental plasma physics topics, each in a separate chapter:

1. Magnetic reconnection
2. Collisionless shocks and particle acceleration
3. Waves and turbulence
4. Magnetic dynamos
5. Interfacial and shear instabilities
6. Angular momentum transport
7. Magnetized dusty plasmas
8. Radiative hydrodynamics
9. Relativistic, Pair-dominated and Strongly Magnetized Plasmas
10. Jets and Outflows.

IV. 32 Major Scientific Opportunities in Plasma Astrophysics

The corresponding major opportunities are

1. Multi-island reconnection and particle acceleration
2. Reconnection under extreme conditions
3. Reconnection explosive onset
4. Cosmic Ray acceleration
5. Shocks in laboratory
6. Connection between shocks in astrophysics and heliophysics
7. Turbulent collisionless dissipation in laboratory
8. Advanced computing initiative for turbulence
9. Solar wind turbulence initiative
10. Systematic observation of B-field in lab and in astrophysics
11. Laboratory liquid metal and plasma experiments on dynamo

12. Modeling dynamo in larger parameter space bridging lab to astrophysics
13. Advanced diagnostics on B-field in flows
14. Solar wind interaction with Earth's magnetosphere
15. NIF initiative on shear instability study
16. Scaling of momentum transport for disks and stars
17. Coordinated effort on stellar momentum transport
18. Observation from Galactic black hole horizon
19. Coordinated effort on dust charging
20. Dust growth and breakup
21. Magnetic effects on dusts
22. Coordinated effort on radiative transfer in stars and during start formation
23. Radiative processes in supernova
24. Lab tests of radiative models of black hole accretion
25. Radiation on exoplanet atmosphere
26. Relativistic beam dissipation
27. Relativistic reconnection and turbulence
28. Magnetized HED experiments on relativistic jet
29. Strongly magnetized pair plasma
30. An interdisciplinary consortium on jet physics
31. Observation of jet launching and propagation
32. Coordinate effort on jet stability.

Many of these major opportunities have a significant lab component while others focus on theoretical and observational aspects.

V. Growing Excitements from Scientific Research Since 2010

There has been steady progress in all of these major scientific opportunities outlined by the WOPA report in the following fronts:

Laboratory experiments. Three intermediate-scale experiments have been built and being built through the NSF Major Research Instruments (MRI) program: Madison Plasma Dynamo Experiments, Magnetized Dusty Plasma Experiments, and Facility for Laboratory Reconnection Experiments. True pair-plasmas have been successfully generated in the laboratory. Z-pinch experiments have revealed nature of photoionization in astrophysics. Experiments on reconnection and shocks have been established using laser plasmas. SLAC Linac Coherent Light Source facility has begun its first operation to study processes like photoionization.

Theory and numerical modeling. Computational power continues to grow, expanding accessible parameter ranges, supplemented by analytic theory. Examples include identifications of new reconnection phases directly relevant to astrophysics.

Observation. New facilities such as the ground-based ALMA, EVLA, VLBA or space-borne IRIS become available to provide much needed observational capabilities suggested by the WOPA report. Examples include discovery of Crab nebular flares suggesting efficient particle acceleration through plasma processes such as magnetic reconnection. New observational evidence show astrophysical jets are driven magnetically.

VI. Summary

Major challenges and opportunities have been identified in plasma astrophysics by three communities (laboratory plasma physics, heliophysics, and astrophysics). We urge DoE to take a leadership role in forming partnership with NASA and NSF to support the research to advance the plasma frontiers in understanding our visible universe, with large impact on both broad scientific disciplines and as well as on general public.

Reference

WOPA Report: Research Opportunities in Plasma Astrophysics (2010): http://www.pppl.gov/conferences/2010/WOPA/index.html