Major Opportunities in Plasma Astrophysics

H. Ji for the WOPA* Team**

** Workshop for Opportunities in Plasma Astrophysics*

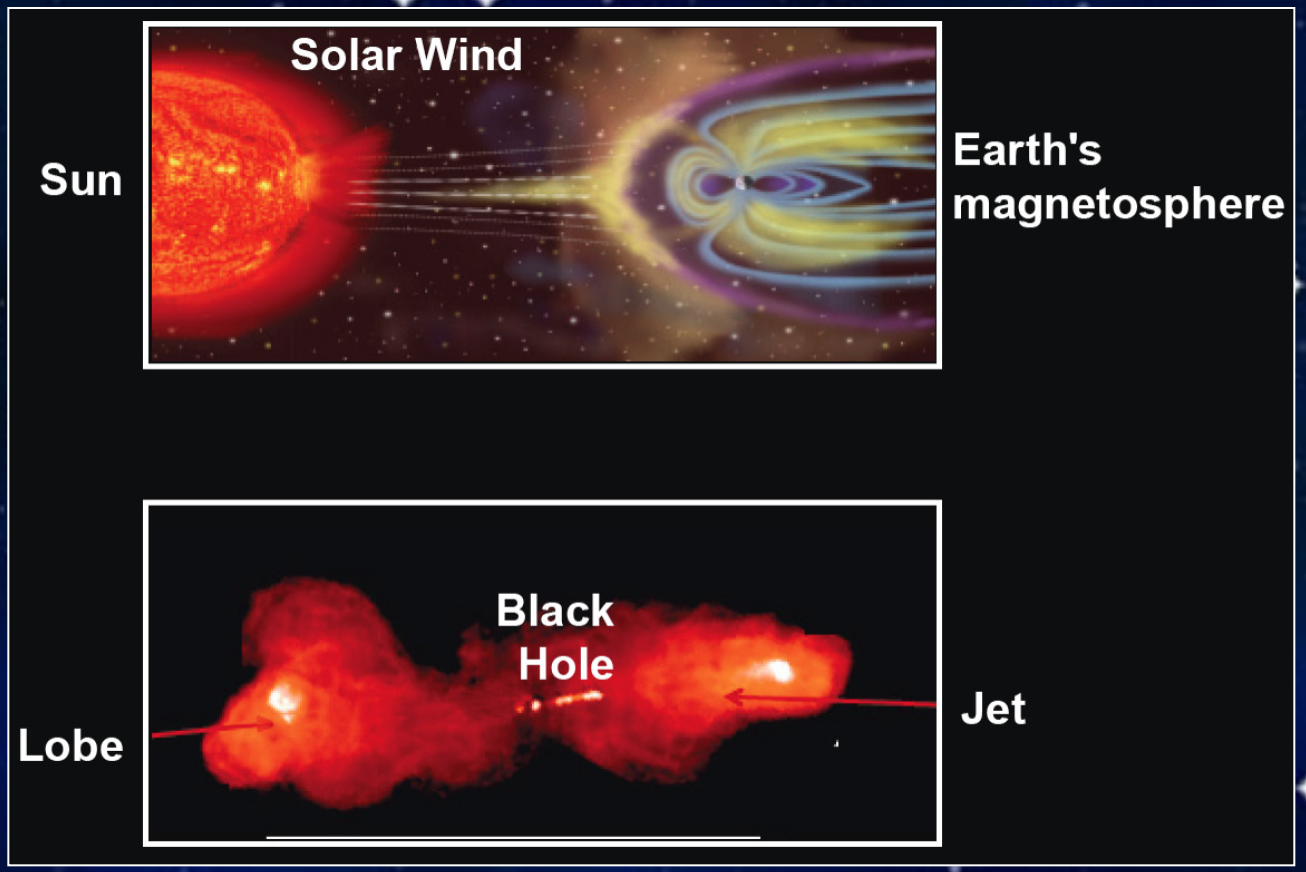
*** S. Bale, A. Bhattacharjee, F. Cattaneo, J. Drake, H. Ji, J. Kasper, M. Lee, H. Li, E. Liang, M. Pound, S. Prager, E. Quataert, B. Remington, R. Rosner, D. Ryutov, E. Thomas, E. Zweibel*

FESAC Strategic Planning Subcommittee
Public Input Meeting
June 4, 2014

Plasma pervades the universe at all scales

Heliophysics
($<10^{-4}$ light year)

Astrophysics
($>10^{6}$ light year)



Plasma astrophysics: understanding our visible universe via plasma physics
It addresses the third important question in the universe:

- Dark energy drives expansion of the universe
- Dark matter controls largest structures of the universe
- Plasma processes are key in deciding much of the rest

Workshop on Opportunities in Plasma Astrophysics (WOPA)

http://www.pppl.gov/conferences/2010/WOPA

- Motivated by extreme diversity of Plasma Astrophysics:
  - Theory and computation,
  - Observations from the magnetosphere to cosmological scales in clusters,
  - Magnetized basic experiments,
  - High energy density experiments,
  - Liquid metal experiments,
  - Aspects of fusion experiments.
- > 100 participants from 3 communities: lab plasma physics, heliophysics, and astrophysics
- Goal: to identify a unified set of major opportunities

Grass-root community activity supported by DoE, NASA, NSF, and APS

Topics Covered

1. Magnetic Reconnection (J. Drake, Maryland)
2. Collisionless Shocks and Particle Acceleration (M. Lee, New Hampshire)
3. Waves and Turbulence (A. Bhattacharjee, New Hampshire, S. Bale, Berkeley)
4. Magnetic Dynamo (E. Zweibel, Wisconsin, F. Cattaneo, Chicago)
5. Interface and Shear Instability (D. Ryutov, LLNL, M. Pound, Maryland)
6. Momentum Transport (E. Quataert, Berkeley)
7. Magnetized Dusty Plasma (E. Thomas, Auburn)
8. Radiative Hydrodynamics (B. Remington, LLNL)
9. Relativistic, Pair-Dominated, Strongly Magnetized Plasmas (E. Liang, Rice)
10. Jets and Outflows (H. Li, LANL)

Also generated 10 Major Plasma Astrophysics Questions

32 Major Opportunities (> Single PI Projects)

- Multi-island reconnection and particle acceleration
- Reconnection under extreme conditions
- Reconnection explosive onset
- Cosmic Ray acceleration
- Shocks in laboratory
- Connection between shocks in astrophysics and heliophysics
- Turbulent collisionless dissipation in laboratory
- Advanced computing initiative for turbulence
- Solar wind turbulence initiative
- Systematic observation of B-field in lab and in astrophysics
- Laboratory liquid metal and plasma experiments on dynamo
- Modeling dynamo in larger parameter space bridging lab to astrophysics
- Advanced diagnostics on B-field in flows
- Solar wind interaction with Earth's magnetosphere
- NIF initiative on shear instability study
- Scaling of momentum transport for disks and stars
- Coordinated effort on stellar momentum transport
- Observation from Galactic black hole horizon
- Coordinated effort on dust charging
- Dust growth and breakup
- Magnetic effects on dusts
- Coordinated effort on radiative transfer in stars and during start formation
- Radiative process in supernova
- Lab tests of radiative models of black hole accretion
- Radiation on exoplanet atmosphere
- Relativistic beam dissipation
- Relativistic reconnection and turbulence
- Magnetized HED experiments on relativistic jet
- Strongly magnetized pair plasma
- An interdisciplinary consortium on jet physics
- Observation of jet launching and propagation
- Coordinate effort on jet stability

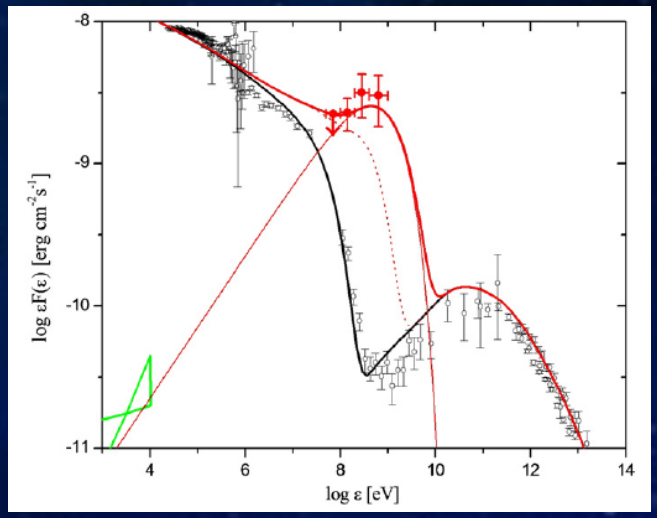
Funding magnitude is about $25-30M / year for 10 years

Major Opportunities with Significant Experimental Components

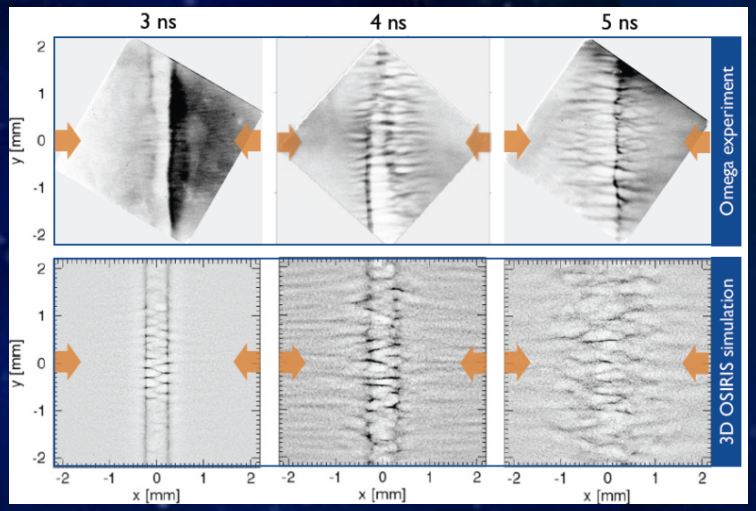
- Reconnection and Particle Acceleration: Magnetospheric observation, next-generation reconnection experiments, and large-scale computation.
- Shock in the Lab: Study of structure, formation, and particle acceleration in HED and non-HED experiments, supported by theory and simulation.
- Turbulence Initiative: Basic, magnetic/inertial fusion devices to study the transition to turbulence, dissipation and particle energization, supported by computation.
- Plasma Dynamo Experiments: Study of field generation in flow-dominated regimes, coordinated with experiments in magnetically dominated regimes and theory.
- Dusty Plasma Experiments: Exploration of new regimes of strong magnetization.
- Radiative Hydrodynamics Experiments: Understand radiative transfer in stars, in star-formation regions, and in accretion flows to compact objects
- Plasma Physics Under Extreme Conditions: To study fundamental physics of relativistic, strongly magnetized electron-ion or pair plasmas in HED experiments using advanced diagnostics and modeling.
- Jet Initiative: To study jet launching, collimation, and termination through a combination of observation, advanced computation, and laboratory experiment.

Growing Excitement in Plasma Astrophysics Since WOPA

Discovery of gamma-ray flare from Crab Nebula, attributed to reconnection



First detections of ion Weibel instability critical to collisionless shocks



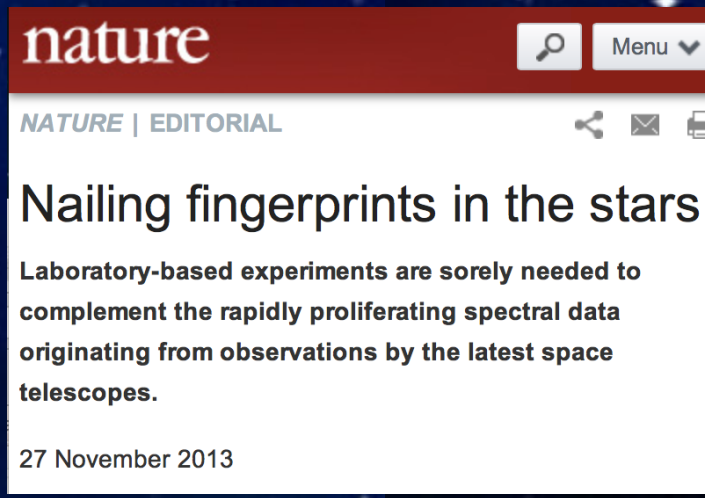
Exp

Sim

The Z Astrophysical Plasma Properties Collaboration: photoionization in astrophysics:

Three intermediate-scale experiments have been or being constructed by the NSF funds:

- Madison Plasma Dynamo Experiment
- Magnetized Dusty Plasma Experiment
- Facility for Laboratory Reconnection Experiments


nature

Menu

NATURE | EDITORIAL

Nailing fingerprints in the stars

Laboratory-based experiments are sorely needed to complement the rapidly proliferating spectral data originating from observations by the latest space telescopes.

27 November 2013

Positively Influenced Heliophysics Decadal Survey (2013-2022)

Recognition of contributions from the lab:
"*These advances were enabled by combining a wide array of observations in concert with theory, laboratory plasma experiments, and revolutionary computational models*."

Recognition of contributions to the lab:
"*The wealth of scientific insights that this recommended program will also provide direct benefits to other scientific fields, including astrophysics, planetary science, and laboratory plasma physics*."

Key Science Goal 4. Discover and characterize fundamental processes that occur both within the heliosphere and throughout the universe. …(T)he Sun, the heliosphere, and Earth's magnetosphere and ionosphere serve as cosmic laboratories for studying universal plasma phenomena, with applications to laboratory plasma physics, fusion research, and plasma astrophysics. Discoveries from these fields, of course, also contribute to the scientific progress in solar and space physics.

Recommendations from Heliophysics Decadal Survey

Dedicated Laboratory Experiments

Laboratory studies probe fundamental plasma physical processes and produce chemical and spectroscopic measurements that support satellite measurements and atmospheric models. They provide benchmarks for integrating theory and modeling with observation in solar and space physics (Box 4.4). Such laboratory experiments should be funded in a multiagency fashion.

Recommendation: NASA should join with NSF and DOE in a multiagency program on laboratory plasma astrophysics and spectroscopy, with an expected NASA contribution ramping from $2 million per year (plus increases for inflation), in order to obtain unique insights into fundamental physical processes.

Offers a significant partnership opportunity for FES

Studying Plasma Astrophysics Can Benefit Fusion Plasma Physics

- The concept of magnetic reconnection originates from solar flare
- The turbulent EMF dynamo effects were originally proposed to explain solar dynamo
- Radiative transfer modeling benefited from experiences and techniques of astrophysical modeling
- Astrophysical "Biermann Battery" mechanism explains magnetic field generation in laser plasmas
- Studies of zonal flows in stars and planets transplanted to the lab
- ….

For simulation:

- Largest simulations of magnetic reconnection and MHD turbulence
- Validated codes can contribute to fusion science research

WOPA Recommendations

- "…that the plasma astrophysics program in the U.S. be strengthened in structure and coordination across DOE , NSF, and NASA, to embrace the unity, coherence, and opportunities of the field.

- A strengthened program of plasma astrophysics greatly aids the missions of these agencies."

Input to the FESAC SP Panel

- To recommend FES take a leadership role to establish a dedicated program within Discovery Plasma Sciences, jointly with NASA (which is being recommended to establish a dedicated lab program) and NSF (which have just funded 3 intermediate-scale experiments for lab plasma astrophysics).