Plasma Science @ NSF

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on behalf of Div. of Physics, Div. of Astronomical Sciences, Div. of Atmospheric & Geospace Sciences,
and Div. of Chemical, Bioengineering, Environmental, and Transport Systems

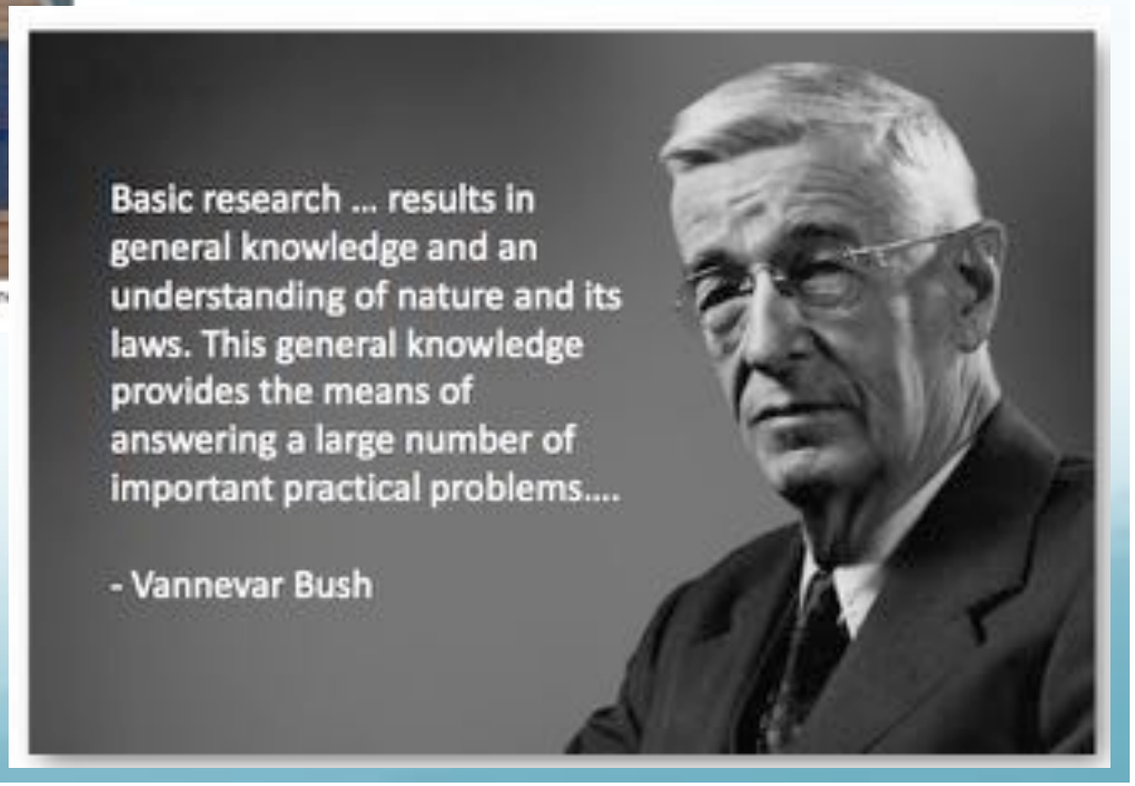
Plasma 2020 Decadal Committee Meeting

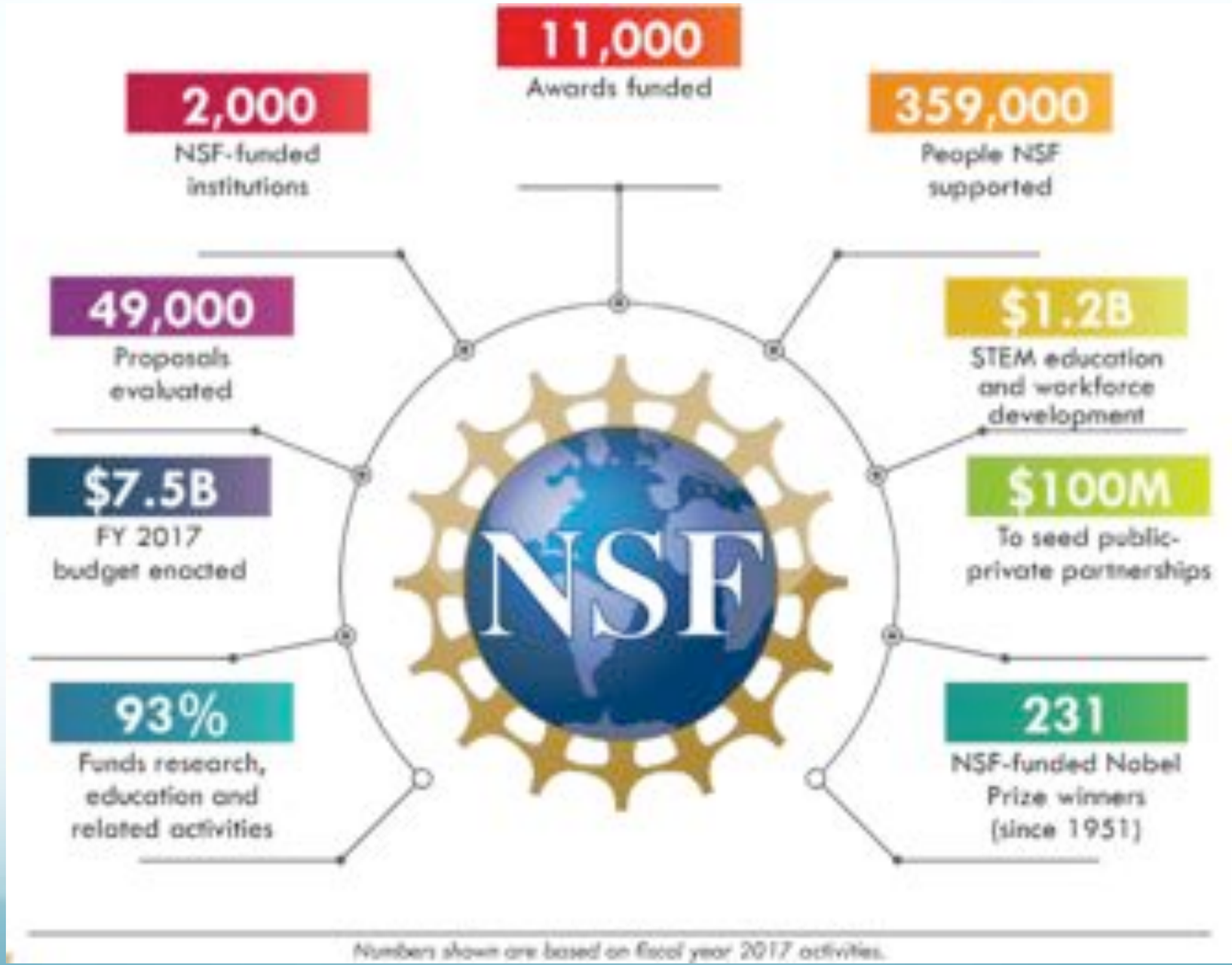
October 15, 2018

NSF Mission

Photo Credit: Maria Barry

Since 1950…




11,000
Awards funded
2,000
NSF-funded institutions
359,000
People NSF supported
49,000
Proposals evaluated
$1.2B
STEM education and workforce development
$7.5B
FY 2017 budget enacted
$100M
To seed public-private partnerships
93%
Funds research, education and related activities
231
NSF-funded Nobel Prize winners (since 1951)
NSF
Numbers shown are based on fiscal year 2017 activities.

NSF Funds All Fields of S&E

Biological Sciences

Computer & Information Science & Engineering

Education & Human Resources

Engineering

Geosciences (including Polar Programs)

Integrative Activities

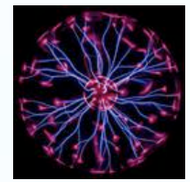
International Science and Engineering

Social, Behavioral & Economic Sciences

Mathematical & Physical Sciences

Continued Investment in NSF Research Infrastructure

Definition of Plasma Physics



Plasma Physics is a study of matter and physical systems whose intrinsic properties are governed by collective interactions of large ensembles of free charged particles.

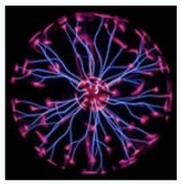
Such physical systems are thought to encompass 99.9% of the visible Universe, where the collective behavior in plasmas leads to phenomena as varied as magnetization from cosmic to planetary scales, particle energization throughout the Universe, and light shows from extragalactic gamma ray bursts to aurorae here on Earth.

Statistical mechanics of ultracold quantum plasmas, wave-particle interactions in ultra-intense electro-magnetic fields, and dusty plasma crystallization are just a few of the topics of current interest that exemplify the breadth of Plasma Physics.

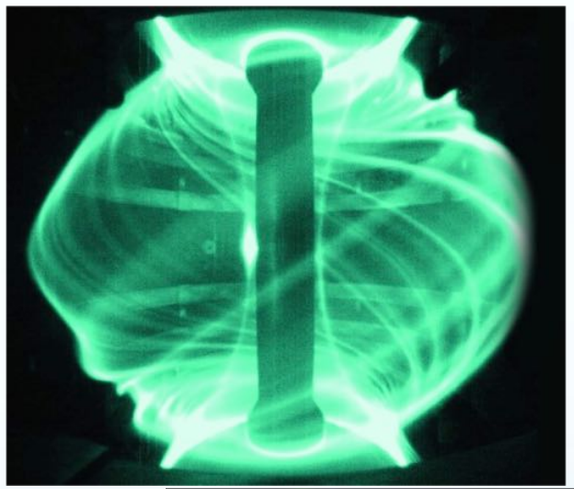
with input from many members of plasma physics community

slide from Dec 19, 2015 presentation to NRC/PLSC

Plasma Physics Applications



Plasma Physics has applications to Space Physics and Astrophysics, Materials Science, Fusion Science, Accelerator Science, Medicine, and many branches of Engineering.

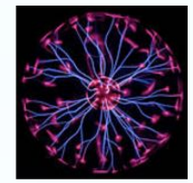


slide from Dec 19, 2015 presentation to NRC/PLSC

Many fundamental results in Plasma Physics have been inspired by these disciplines.

Plasma Science

= Plasma Physics + Applications



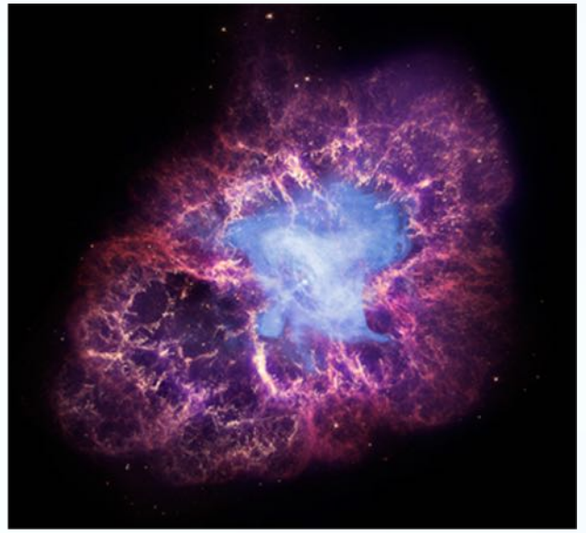
where:

Plasma Physics is a study of matter and physical systems whose intrinsic properties are governed by ***collective interactions*** *of large ensembles of free charged particles. 99.9% of the visible Universe is thought to consist of plasmas. The underlying physics of the collective behavior in plasmas has applications to space physics and astrophysics, materials science, fusion science, accelerator science, medicine, and many branches of engineering.*

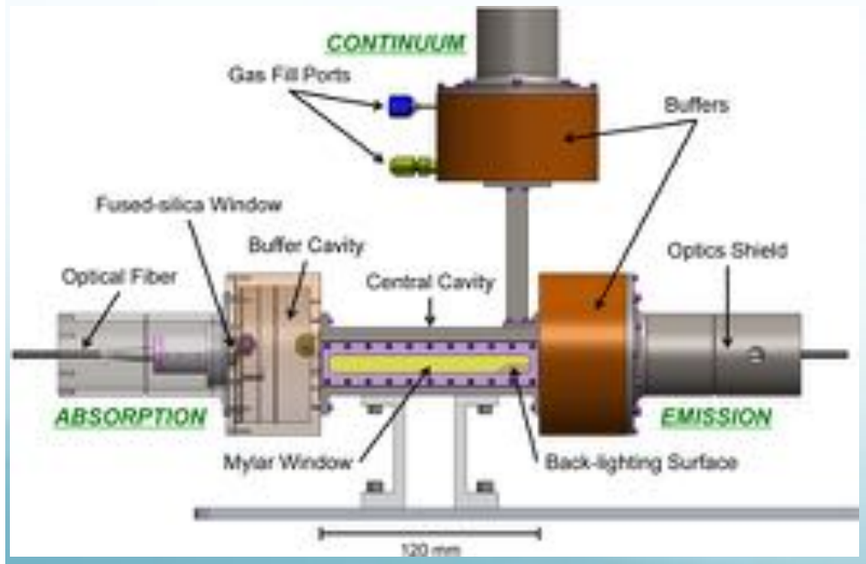
slide from Dec 19, 2015 presentation to NRC/PLSC

Corollary: A document intended to be a Plasma Science Decadal Survey should address plasma physics, the full set of its applications, and to the extent possible involve representatives of all of the stakeholder communities.

Astrophysical Plasmas

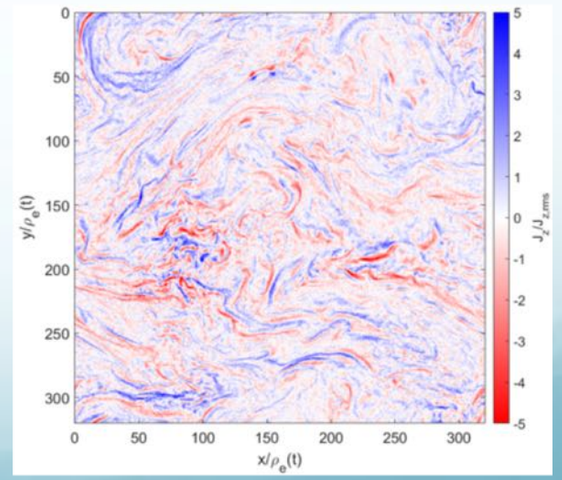


- Plasmas are common in astrophysical settings from extremely high densities in white dwarfs and neutron stars to very low densities in intergalactic space, all research supported by NSF's Division of Astronomical Sciences (AST).
- AST-supported plasma science includes:



- ➢ Laboratory astrophysics to measure hydrogen, helium, and carbon plasmas at the conditions characteristic of the atmospheres of white dwarf stars.
- ➢ Theoretical studies of the atmospheres of highly magnetized neutron stars.
- ➢ Observations of radio pulsars to understand the emission from relativistic plasma flux tubes at the poles.
- ➢ Simulations of the role of highly magnetized plasmas in non-thermal particle acceleration in astrophysics.

Crab Nebula (M1)
turbulent, magnetized, hot, dilute, relativistic pair plasma



Simulation: 200 billion particles in 1024^3 cells

Solar Plasmas and Research Facilities

- The Sun provides a nearby laboratory for Stellar Astrophysics
- The Sun is the driver of Space Weather
- The Sun provides a nearby laboratory for Plasma Physics

DKIST Science Questions

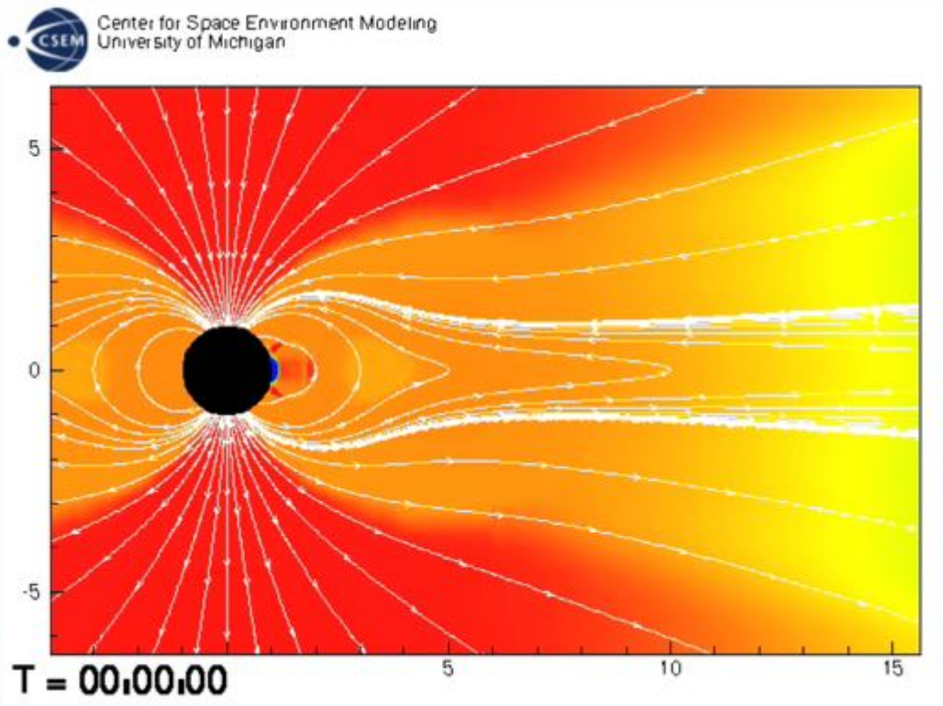
- How are cosmic magnetic fields generated and how are they destroyed?
- What role do cosmic magnetic fields play in the organization of plasma structures and the impulsive releases of energy seen ubiquitously in the universe?
- What are the mechanisms responsible for solar variability (that ultimately affects the Earth)?

NSF-AST supports:

- NSF's National Solar Observatory
- Construction of NSF's Daniel K. Inouye Solar Telescope (DKIST)

Geospace Sciences & Plasma Physics

Poker Flat Incoherent Scatter Radar



Space Weather Modeling Framework

$$\frac{\partial \rho}{\partial t} + \nabla \bullet \left[\rho \vec{u} \right] = 0$$

$$\frac{\partial \left(\rho \vec{u} \right)}{\partial t} + \nabla \bullet \left[\rho \vec{u}\vec{u} + \left(p + \frac{B^2}{8\pi} \right) \overleftrightarrow{I} + \frac{1}{4\pi} \vec{B}\vec{B} \right] = 0$$

$$\frac{\partial \vec{B}}{\partial t} + \nabla \bullet \left[\vec{u}\vec{B} - \vec{B}\vec{u} \right] = 0$$

$$\frac{\partial \left(\rho E \right)}{\partial t} + \nabla \bullet \left[\vec{u} \left(\rho E + p + \frac{B^2}{8\pi} \right) - \vec{B} \left(\vec{u} \bullet \vec{B} \right) \right] = 0$$

$$\nabla \bullet \vec{B} = 0$$

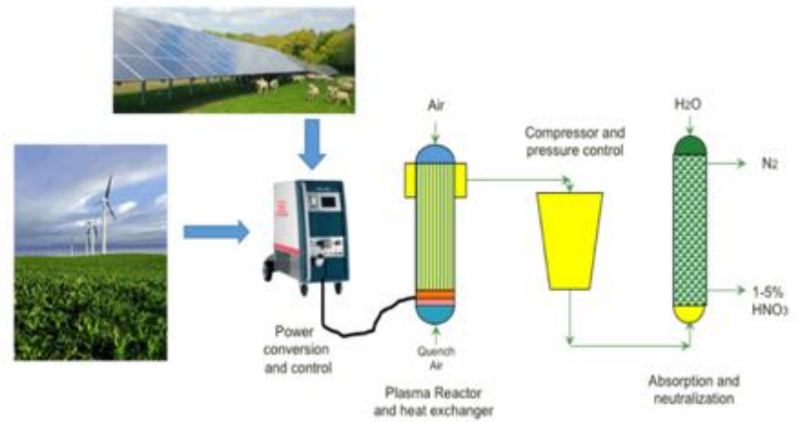
$$p = \left(\gamma - 1 \right) \left[E - \frac{1}{2} \rho u^2 - \frac{1}{2} B^2 \right]$$

Alfvén

- Support investigators using observations, modeling, and theory to advance fundamental understanding of space weather and related processes
  - 2012 – Solar & Space Physics Decadal Survey Goal – Discover and characterize fundamental processes that occur both within the heliosphere and throughout the universe

Low-Temperature Plasma (LTP) S&E

- Studies of LTPs continue to pose many basic physics questions, as well as serve an increasing number of applications via plasma chemistry and manipulation
- Division of Chemical, Bioengineering, Environmental, and Transport Systems (CBET) in the Engineering Directorate serves as the NSF lead in managing and supporting LTP research, with additional support provided by several other Divisions across NSF
- In 2016, CBET led in supporting an NSF Workshop on Science Challenges in Low Temperature Plasma S&E: Enabling a Future Based on Electricity through Non-Equilibrium Plasma Chemistry [http://mipse.umich.edu/nsfworkshop/index.html]
- As a result of the 2016 Workshop, the LTP community is back on the map in CBET programs (e.g., Process Systems, Reaction Engineering and Molecular Thermodynamics; Catalysis; Electrochemical Systems; Cellular and Biochemical Engineering; Environmental Engineering)
- CBET has set aside funds to support LTP-specific proposals in addition to core program funds invested in this area.



Graves (UC Berkeley): INFEWS N/P/H_2O: Fundamentals of N_2/O_2 Plasmas and Heterogeneous Catalysis
Major research challenge: Reduce power needed to produce HNO_3

Many Topically Broad Funding Opportunities

- Physics Frontier Centers (PFCs)
- Science and Technology Centers (STCs)
- Engineering Research Centers (ERCs)
- Major Research Instrumentation (MRI)
- International Research Experience for Students (IRES)
- Partnerships for International Research and Education (PIRE)
- Established Program to Stimulate Competitive Research (EPSCoR): Research Infrastructure Improvement Program
- Emerging Frontiers in Research and Innovation (EFRI)
- Computational and Data-Enabled Science and Engineering (CDS&E)
- Cyberinfrastructure for Sustained Scientific Innovation (CSSI)
- Windows on the Universe: The Era of Multi-Messenger Astrophysics (WoU-MMA)
- Faculty Early Career Development (CAREER)
- NSF Graduate Research Fellowship (GRFP)
- NSF Research Traineeship (NRT) Program
- Etc, etc…

Plasma Science @ NSF over the Past Decade

- The Plasma 2010 Decadal had little noticeable impact at NSF due, in large part, to the content of the document.
  - Plasma 2010 did not identify a unique leadership role for NSF to ”promote the progress of science” in the broad context of plasma science & engineering
- Nevertheless, over the past decade, NSF has acted to increase support for and recognition of plasma physics as a discipline:
  - Several mid-scale basic plasma physics experimental facilities across the spectrum of subfields (magnetized plasmas, dusty plasmas, laser-plasma interactions, high energy density plasmas) have been or are being built/upgraded via the NSF MRI program
  - NSF/Physics now has a full-time on-site program director for the Plasma Physics program. This has helped to strengthen Plasma S&E partnerships across and increase the visibility of Plasma Physics within NSF
  - Existing inter-agency partnerships (e.g., with DOE) have been strengthened and new ones (e.g., with NASA) established, with more inter-agency discussions taking place

2017 PLASMA Workshop at NSF

National Science Foundation – Department of Energy

PLASMA Partnership

Celebrating 20 years of Discovery and Innovation

Physics in

Laboratory,

Astrophysics,

Space, and

Manufacturing

20th **A**nniversary Workshop

NSF Headquarters

January 9th to January 11th, 2017

http://www.orau.gov/bpw2016

Opportunities, Challenges, and Best Practices for Basic Plasma Science User Facilities

- Workshop on **May 20-21, 2019 at U. Maryland** to be lead by Howard Milchberg (UMd) and Earl Scime (WVU)
- Workshop will aim to address the following questions:
  - *What are the science questions that require establishment and operation of plasma science user facilities and cannot be addressed on smaller scale single-PI experimental facilities? Are there compelling plasma science questions of such value and interest to the global scientific community that may warrant establishment of new user facilities? If so, what are they?*
  - *Under constrained resources, what are the upsides and the downsides of investing in the operation of user facilities in each of the relevant sub-fields?*
  - *What may be the limiting factors, e.g., the size of the community of potential users or the flexibility and ease of operation, in establishing an experimental facility as a user facility?*
  - *Are there particular challenges to transparent and effective operation of user facilities specific to plasma science or any of its sub-fields? If so, what are they and what modes of operation may be used to overcome such challenges?*
  - *What are the best practices for managing transparent and effective operation of mid-scale and major user facilities for plasma science?*

NSF Priorities for this Decadal Committee

- Fully address the Statement of Task
  - Identify and highlight *major scientific questions* in plasma physics & its applications
  - Discuss opportunities for *universities in the national landscape* of plasma science research
  - Assess whether *the demographic profile of* the plasma science workforce is commensurate with future workforce needs
  - Assess the *complementary nature* of support for plasma physics & applications across the federal agencies and the private sector
- Bring your expertise *to contribute* to the big picture, *not to defend* your own interests
- Get to know *the other* plasma science sub-communities
- Look for the next discovery, an emerging subfield of plasma science
- But remember: “It’s difficult to make predictions, especially about the future”