Plasma Physics @ NSF

Vyacheslav (Slava) Lukin

Program Director for

Plasma Physics & Accelerator Science

Division of Physics, National Science Foundation

Michigan Institute for Plasma Science and Engineering
University of Michigan – Ann Arbor, September 19, 2016

What is the mission and purpose of the National Science Foundation?

What is the mission and purpose of the National Science Foundation?

To promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense....

The National Science Foundation Act of 1950 authorized and directed NSF to initiate and support:

- basic scientific research and research fundamental to the engineering process,
- programs to strengthen scientific and engineering research potential,
- science and engineering education programs at all levels and in all the various fields of science and engineering,
- programs that provide a source of information for policy formulation.

What is the mission and purpose of the National Science Foundation?

To promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense….

NSF FY16 Budget: **$7.463 billion**, of which

- Research and Related Activities – $6,033 million
- Education and Human Resources – $880 million
- Agency Operations and Award Management – $330 million
- MREFC – $200 million

for comparison

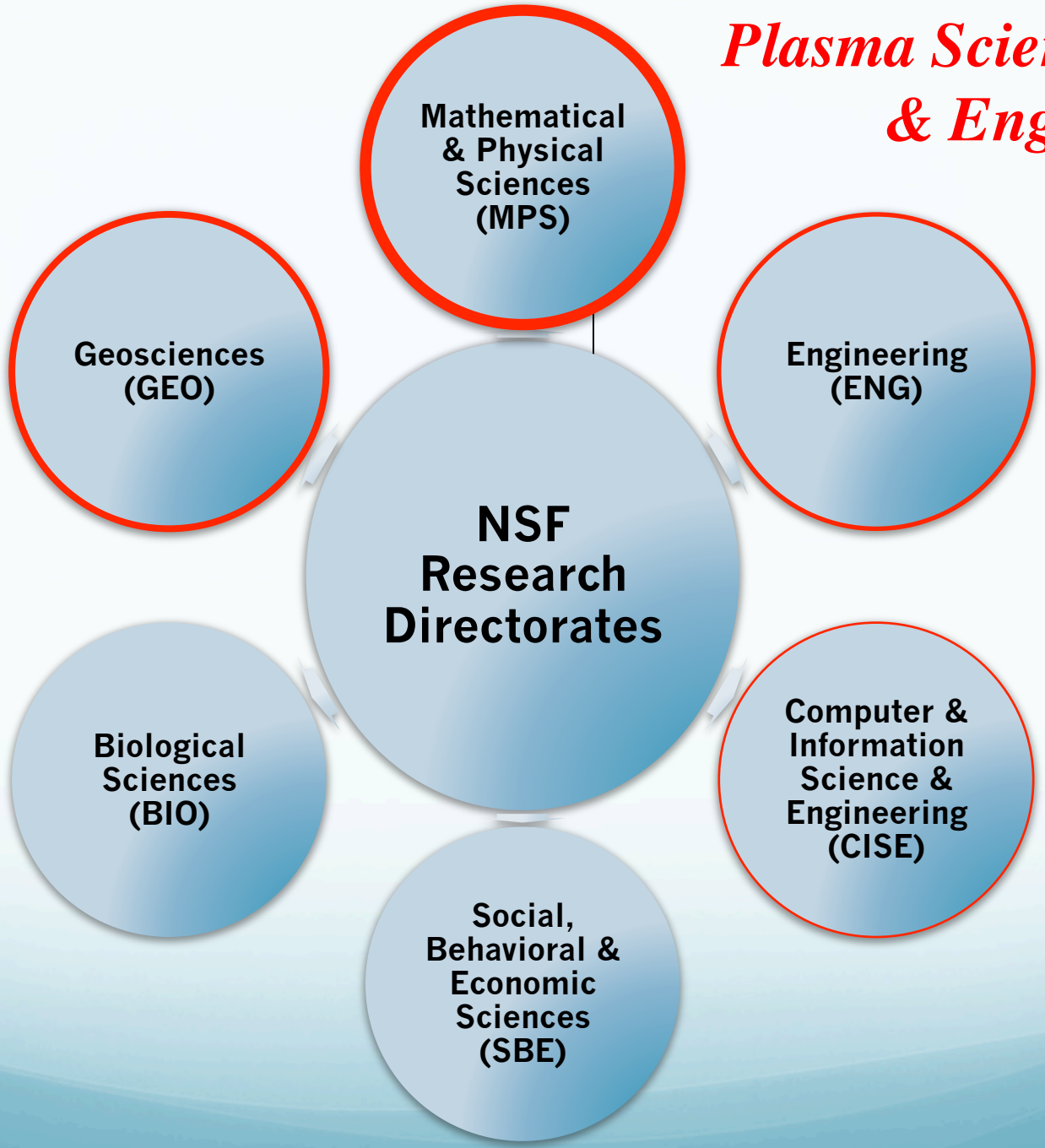
University of Michigan Operating Activities (from 2015 Annual Report): **Total revenue of $6.858 billion**

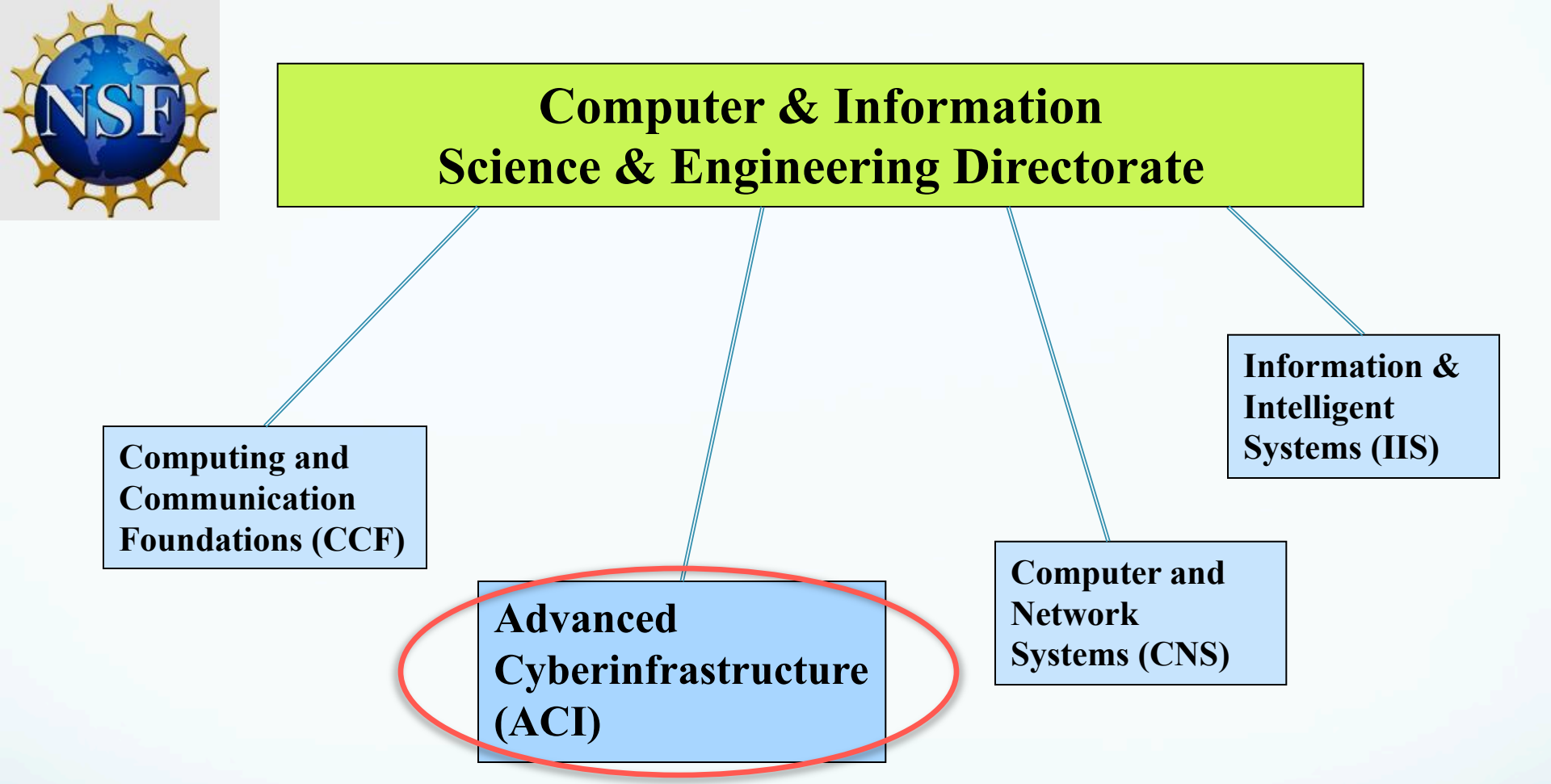
Expected total campaign contributions during 2016 election season (estimate by Wells Fargo Securities): **$7.5 billion**

What is the mission and purpose of the National Science Foundation?

To promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense….

Plasma Science & Engineering





- FY13 Software Infrastructure for Sustained Innovation – Scientific Software Integration award: “Particle-In-Cell and Kinetic Simulation Center” [PI: Mori (UCLA)]
- FY16 Data Infrastructure Building Blocks award: “Metadata Toolkits for Building Multi-faceted Data - relationship Models” [PI: Greenwald (MIT)]

Engineering Directorate

- Engineering Education and Centers (EEC)
- Chemical, Bioengineering, Environmental and Transport Systems (CBET)
- Electrical, Communications and Cyber Systems (ECCS)
- Industrial Innovation and Partnerships (IIP)
- Emerging Frontiers and Multidisciplinary Activities (EFMA)
- Civil, Mechanical and Manufacturing Innovation (CMMI)

Plasma Engineering

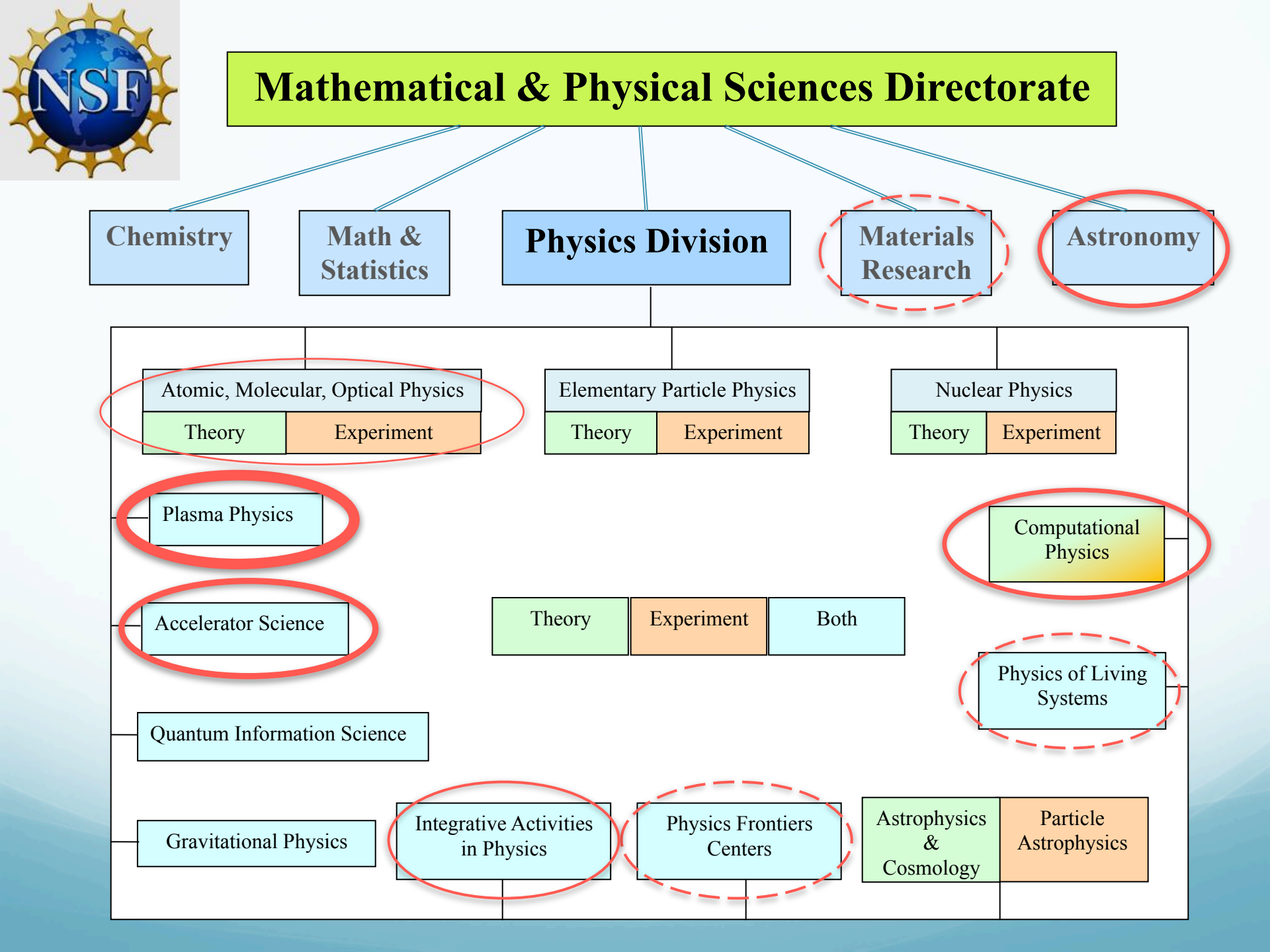
- No specific program dedicated to support of plasma physics applications; relevant ongoing plasma science & engineering research covers several areas of interest within ENG
- CBET has been most active in supporting work in the low temperature plasma domain: ~100 research awards since 2000 + support for numerous workshops and conferences
- ECCS also provides support for plasma science related awards: ~50 research awards since 2000 under all ECCS research programs, major research initiatives, and engineering research centers
- CMMI, IIP (GOALI), and EEC also, to a varying degree, provide support for plasma science & engineering on a one-off basis

Geosciences Directorate

- Earth Sciences (EAR)
- Atmospheric and Geospace Sciences (AGS): Geospace Section
- Polar Programs (PLR)
- Ocean Sciences (OCE)

Geospace Plasma Science
(FY15 $ estimates)

- Aeronomy: mesosphere, thermosphere, ionosphere, effects of high-power radio wave modification on these regions – $9.3M
- Magnetospheric Physics: geomagnetic disturbances, waves and instabilities in the natural plasma, ground-based observational programs, laboratory experiments related to geospace – $6.8M
- Solar-Terrestial Research: processes by which energy is generated by the Sun, transported to Earth, and ultimately deposited in geospace – $7.3M
- Space Weather Research: cubesats – $5.7M
- Upper Atmosphere Facilities: four large incoherent-scatter radar and the SuperDARN coherent scatter radar systems – $14M
- **Plasma physics of phenomena manifested in the coupled Sun-Earth system**
- Interagency Collaboration: NSF/NASA Space Weather Modeling


Mathematical & Physical Sciences Directorate
Chemistry
Math & Statistics
Physics Division
Materials Research
Astronomy
Atomic, Molecular, Optical Physics
Theory
Experiment
Elementary Particle Physics
Theory
Experiment
Nuclear Physics
Theory
Experiment
Plasma Physics
Computational Physics
Accelerator Science
Theory
Experiment
Both
Physics of Living Systems
Quantum Information Science
Gravitational Physics
Integrative Activities in Physics
Physics Frontiers Centers
Astrophysics & Cosmology
Particle Astrophysics

THE CORE – THE HEART OF WHAT WE DO

Major Sub-Areas of Physics (Experiment and Theory)

Gravitational Physics

Atomic, Molecular, and Optical Physics (Includes QIS)

Nuclear Physics

Particle Physics (EPP and PA)

Physics of Living Systems

Plasma Physics (NSF/DOE Partnership in Basic Plasma Science and Engineering)

Accelerator Science

(Note that Condensed Matter Physics is NOT included)

From presentation by Denise Caldwell at March 31, 2016 HEPAP meeting

Physics Division Portfolio

The portfolio of awards made through the Physics Division has as primary goal "to promote the progress of science", as expressed in the NSF act. Awards in the portfolio support the research needed to address a scientific question that is at the frontier of knowledge as it is currently known, while at the same time extending and redefining that frontier. Inherent in the implementation of this portfolio, which includes significant support for students and junior scientists, is the preparation of the next generation of the advanced high tech workforce and the development of innovative new technologies that arise in the quest to answer some of the hardest questions that Nature can pose.

From presentation by Denise Caldwell at March 31, 2016 HEPAP meeting

Questions Cut Across Disciplinary Programs

Controlling the Quantum World: Optical Physics; Quantum Information Science

Complex Systems and Collective Behavior: Physics of Living Systems; Atomic and Molecular Dynamics; Nuclear Physics; Plasma Physics

Neutrinos and Beyond the Higgs: Particle Astrophysics; Gravitational Physics; Nuclear Physics; Precision Measurements; Elementary Particle Physics

Origin and Structure of the Universe: Gravitational Physics; Cosmology; Nuclear Physics; Particle Astrophysics; Plasma Physics

Strongly-Interacting Systems: Nuclear Physics; Gravitational Physics; Plasma Physics

From presentation by Denise Caldwell at March 31, 2016 HEPAP meeting

Progress of Science

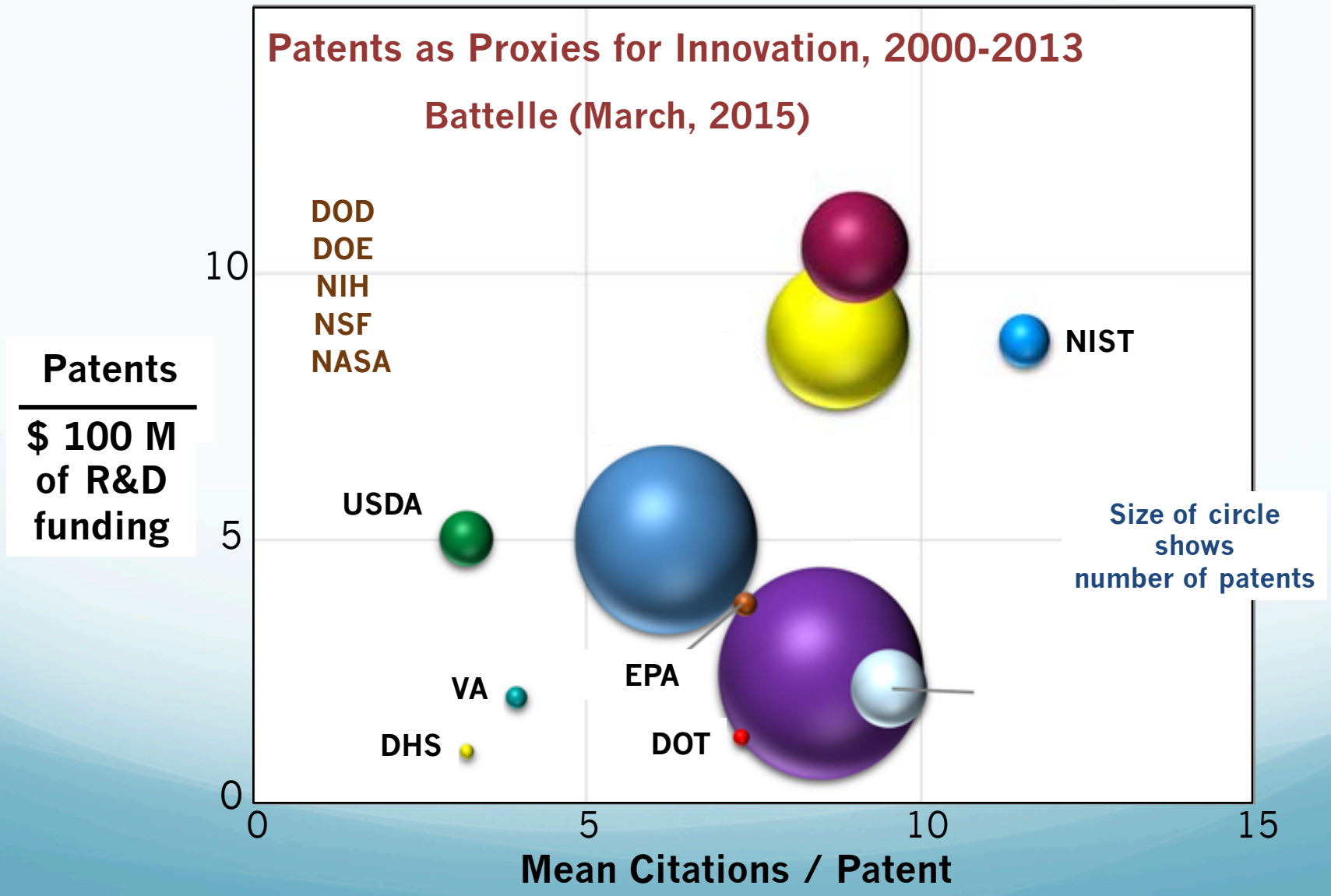
"…**does science, or knowledge, really need a justification?** It is hard to imagine that any man or woman since the dawn of intelligent life has not gazed out at the sky on a moonless night, wondering how it came to be and what is our place in this vast and wondrous firmament. And each time science has advanced our understanding of those countless dots of light, it has uncovered more mysteries, more questions. **The curiosity of our species knows no bounds**; more remarkably, neither does our capacity for satisfying it. **And that is truly wonderful in itself, even if it doesn't lead to a better toaster.**"

Progress of Science

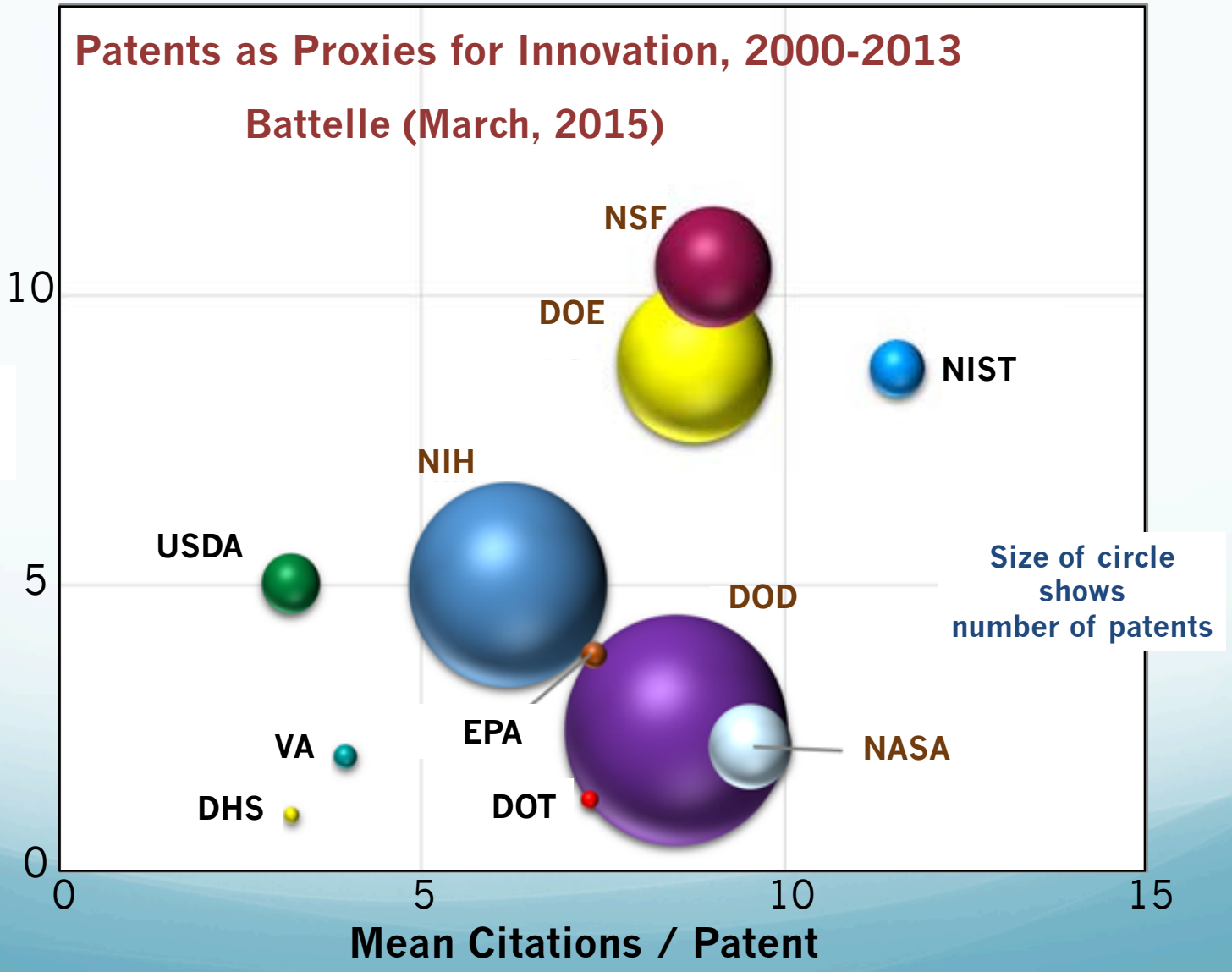
"…**does science, or knowledge, really need a justification?** It is hard to imagine that any man or woman since the dawn of intelligent life has not gazed out at the sky on a moonless night, wondering how it came to be and what is our place in this vast and wondrous firmament. And each time science has advanced our understanding of those countless dots of light, it has uncovered more mysteries, more questions. **The curiosity of our species knows no bounds**; more remarkably, neither does our capacity for satisfying it. **And that is truly wonderful in itself, even if it doesn't lead to a better toaster.**"

By NYT Editorial Board [Feb 16, 2016] commenting on the press coverage of LIGO detection of gravitational waves

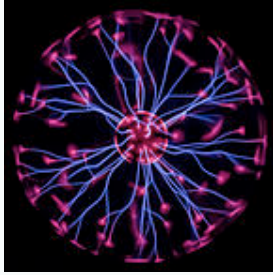
Progress of Science



Progress of Science



Frontier of Knowledge: Plasma Physics



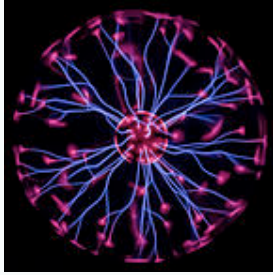
Plasma Physics is a study of matter and physical systems whose intrinsic properties are governed by collective interactions of large ensembles of free charged particles.

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

Plasma Physics in Context



Many-body equilibrium physics

- Classical Statistical Mechanics
- Boltzmann Equation

Few-body quantum interactions

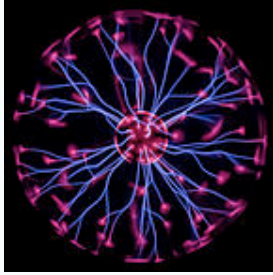
- Quantum Mechanics
- Schrödinger Equation

Collective interactions in equilibrium and non-equilibrium many-state systems

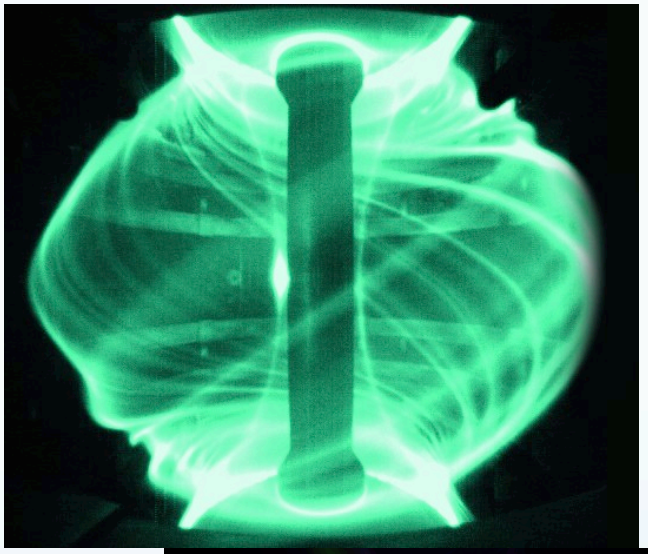
- Condensed Matter Physics
- Atomic Physics: Cold atoms
- Nuclear Physics: Nuclear matter
- High Energy Physics: Quark-gluon plasma
- **Plasma Physics**

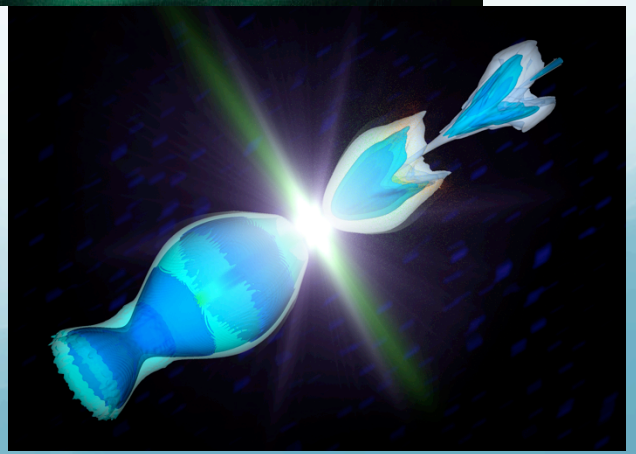
Seeking underlying concepts to understand collective behavior

Plasma Applications

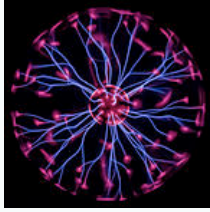


Plasma Physics has applications to Space Physics and Astrophysics, Materials Science, Fusion Science, Accelerator Science, Medicine, and many branches of Engineering.





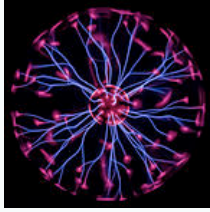
Many fundamental results in Plasma Physics have been inspired by these disciplines.



Plasma Physics Program

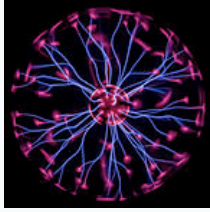
- NSF/DOE Partnership in Basic Plasma Science & Engineering, first MOU signed Dec 1996
  - *renewed in Nov, 2015 for another 6 years, through Dec, 2021*
  - NSF: MPS (Physics & Astronomy), GEO (Geospace), ENG (Chemical, Bioengineering, Environmental & Transport Systems and Electrical, Communications & Cyber Systems); DOE/FES (Plasma Science Frontiers)
  - formal & informal co-funding with AFOSR & NASA
- CAREER Awards
  - 10 awarded since 2005; no FY16 CAREER awards: potential awardee Louise Willingale (U. Michigan) withdrew the proposal due to moving abroad
- Conference/Workshop grants; REU supplements
- NSF-wide and cross-directorate funding opportunities
  - INSPIRE, MRI, CDS&E, SI2, DIBBs, EPSCoR, GOALI, etc.

NSF/DOE Plasma Partnership



- NSF/DOE Partnership funds basic plasma physics projects covering areas roughly categorized as
  - Low temperature plasmas & plasma material interactions
  - High energy density plasmas & laser-plasma interactions
  - Turbulence, waves, magnetic reconnection and other magnetized plasma phenomena
  - *Projects focused on fusion energy studies are not considered*
- Joint support for the BaPSF mid-scale user facility at UCLA was renewed in FY16 for another 5 years
- NSF/DOE Partnership encourages proposals from university PI's to perform basic plasma physics research at user facilities (including DOE facilities) designed to serve the needs of the broader physics community.

NSF/DOE Plasma Partnership



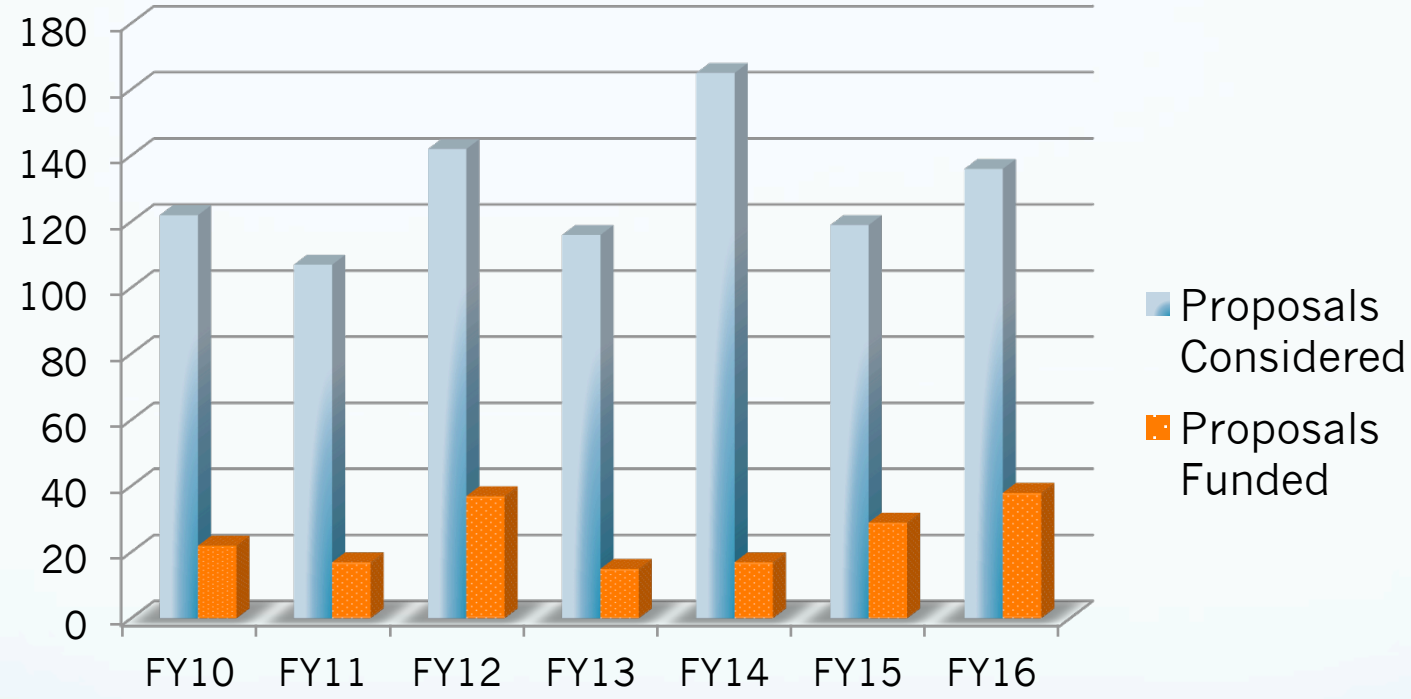
- From the FY17 NSF/DOE Partnership in Basic Plasma Science and Engineering solicitation (minor updates relative to the FY16 solicitation):

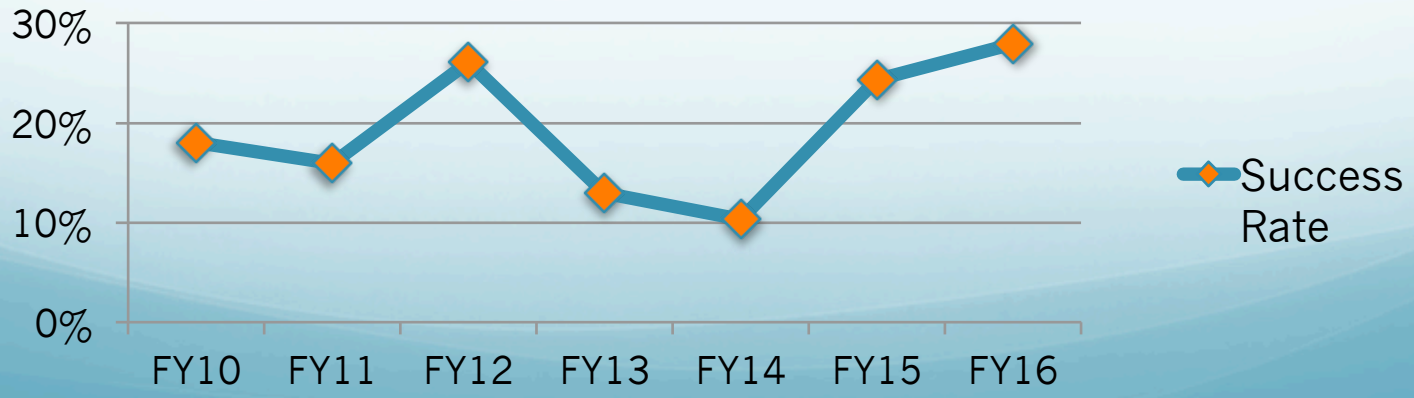
"Plasma Physics is a study of matter and physical systems whose intrinsic properties are governed by collective interactions of large ensembles of free charged particles. 99.9% of the visible Universe is thought to consist of plasmas. The underlying physics of the collective behavior in plasmas has applications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

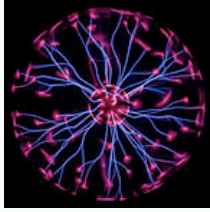
...

The foci of the initiative are to generate an understanding of the fundamental physics principles governing the collective interactions of large ensembles of free charged particles, as well as to improve the basic understanding of the plasma state as needed for other areas or disciplines of science and engineering."

NSF/DOE Plasma Partnership:
Recent History



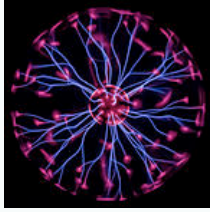




NSF/DOE Plasma Partnership: Review and Decision Process

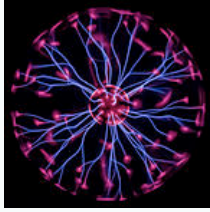
1. NSF receives the proposals and, with DOE's assistance, manages and is responsible for the review process.
2. Review panels are organized by and held at NSF. The outcome of each review panel is a ranked list of proposals considered by the panel. These rankings are FACA advise to the NSF Program Directors and DOE Program Managers.
3. A discussion between NSF PDs and DOE PMs results in a list of proposals to be recommended for awards
   - The goal is to make as many awards for highest quality proposals as possible while maintaining a balanced portfolio and satisfying programmatic priorities
   - Neither NSF nor DOE dictates to the other what awards to make
   - NSF may make awards that, due to the proposal having low DOE/FES programmatic priority, DOE would not make
   - DOE may make awards that, due to the proposal having lower relative ranking than others, NSF would not make

FY16 NSF/DOE Competition



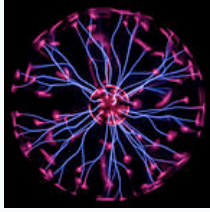
- 118 distinct projects (136 proposals) considered by three NSF/DOE review panels – requested amount over 3 years $68M (FY15: $54.7M)
- 14 projects (17 proposals) Returned Without Review; 8 projects (12 proposals) transferred out of the Plasma Physics program to be reviewed by more appropriate panels in other programs
- ~1/3 of the proposals received shared consideration with other programs within NSF.
- **34 out of 118 projects** (38 of 136 proposals) considered by the NSF/DOE Plasma Partnership panels were funded in full or in part. Together, NSF & DOE made up to 3-year commitments for **$19.0M** (NSF: $5.3M; DOE: $13.7M) **out of $68.0M** requested.
- Awards to **27 out of 83 applying institutions** (26 of 77 colleges & universities). 98.8% of funds went to colleges and universities.

FY16 NSF/DOE Awards - I



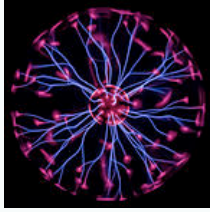
Title	Principal Investigator	Institution	Total Committed
Nanosecond Pulse Discharges at a Liquid-Vapor Interface and in Liquids: Discharge Dynamics and Plasma Chemistry	Igor V Adamovich	Ohio State U.	$384,000
Laboratory Plasma Investigations and Associated Theoretical Models Relevant to Understanding Space and Astrophysical Plasmas	Paul M. Bellan	Caltech	$700,000
Kinetic characterization of 3D magnetic reconnection: A transformative step	Li-Jen Chen	U. Maryland - College Park	$595,000
Laboratory studies of avalanche transport in magnetized plasmas	Bart G Van Compernolle	UCLA	$257,000
Experimental Investigation of Nanosecond and Subnanosecond Pulsed DBD in Atmospheric Air: Fast Imaging and Spectroscopy	Danil Dobrynin	Drexel U.	$300,000
Spatio-temporal control of ionization and electron dynamics in laser plasmas	Charles G Durfee	Colorado School of Mines	$405,000
Magnetic Reconnection in Strongly-Magnetized, Weakly-Collisional Plasmas: Onset, Turbulence and Energy-Partition in 3D, Plasmoid-Dominated Regimes	Nuno F Gomes Loureiro	MIT	$450,000
The equation of state of warm dense matter generated by pulsed-power generators	Pierre A Gourdain	U. Rochester	$625,000
Experimental Study of the Fundamental Properties of Warm Dense Mixtures	James Hawreliak	Washington State U.	$400,000
RUI: Plasma Response to a Variable Electric Multipole Configuration	Nathaniel Hicks	U. Alaska - Anchorage	$100,000
Laser plasma interaction in the MG magnetic field	Vladimir Ivanov	U. Nevada - Reno	$650,001
The Plasma Science and Innovation Center (PSI-Center) at Washington, Wisconsin, and Utah State	Thomas R Jarboe	U. Washington	$2,400,000
	Jeong-Young Ji	Utah State U.	
	Carl R Sovinec	U. Wisconsin - Madison	
Helicity Injected Torus (HIT) Program: Sustainment of stable equilibria through Self-Organization	Thomas R Jarboe	U. Washington	$1,350,000

FY16 NSF/DOE Awards - II



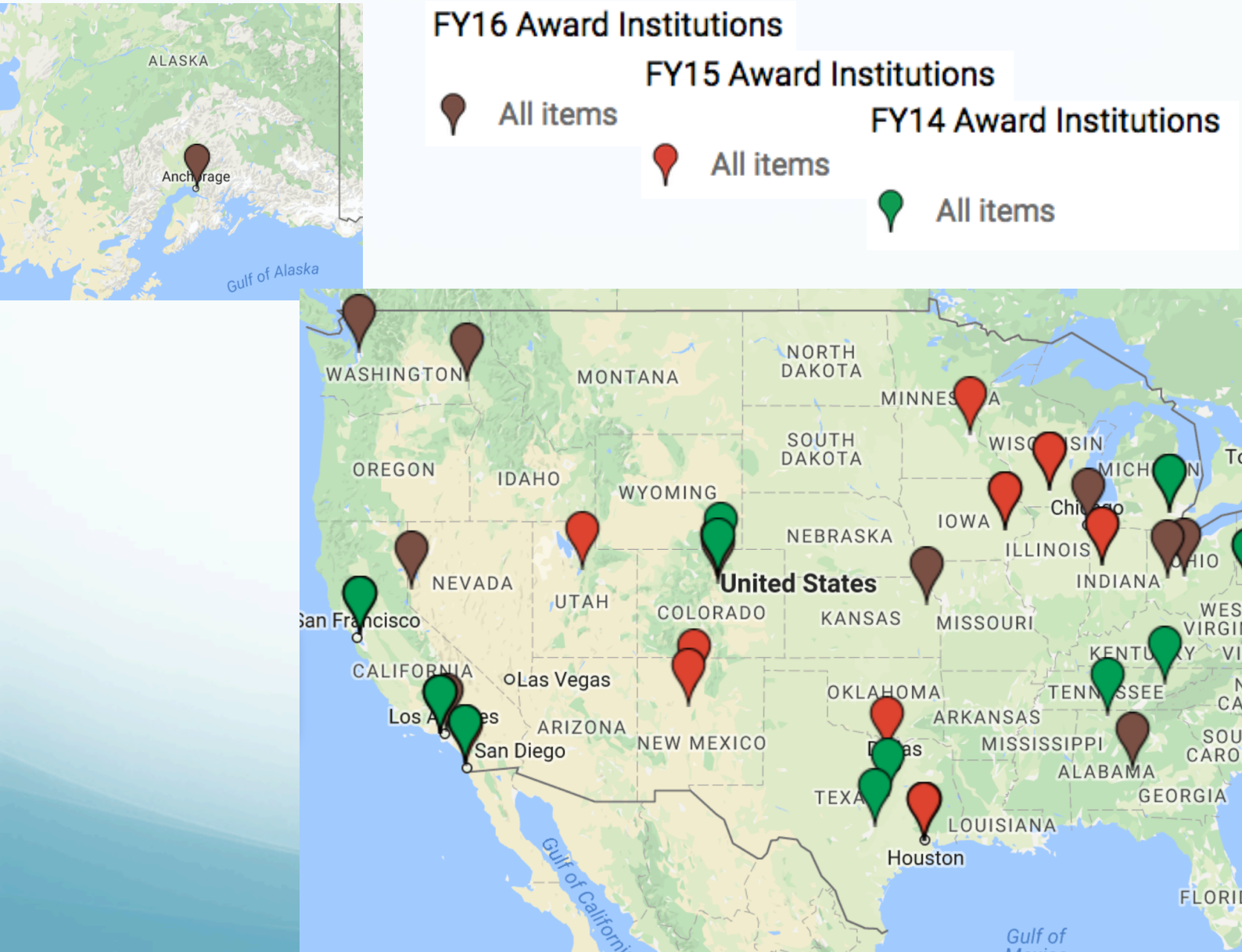
Title	Principal Investigator	Institution	Total Committed
Dense Pair and Gamma-Ray Creation Using Ultra-intense Lasers	Edison P Liang	William Marsh Rice U.	$375,000
Explosive reconnection in relativistic magnetically-dominated plasmas	Maxim Y Lyutikov	Purdue U.	$239,988
	Lorenzo Sironi	Columbia U.	$147,000
Understanding and Controlling Turbulent Mixing in a Laboratory Magnetosphere	Michael E Mauel	Columbia U.	$610,000
Interdisciplinary study of chemical and transport processes at a plasma-liquid interface	Selma Mededovic	Clarkson U.	$450,000
Study of quasi-collisional effects in laboratory and astrophysical plasmas	Mikhail V Medvedev	U. Kansas	$400,000
Intense sub-femtosecond optical radiation from relativistic plasmas	Howard M Milchberg	U. Maryland - College Park	$460,000
Path Integral Monte Carlo Simulations of Iron Plasmas	Burkhard Militzer	UC Berkeley	$710,000
The Evolution of Magnetic Skeletons During 3D Reconnection	Nicholas A Murphy	SAO - CfA	$235,000
	Yi-Min Huang	Princeton U.	$119,000
Plasmas for Low Noise Reconfigurable RF Systems	Dimitrios Peroulis	Purdue U.	$360,000
Fundamental Studies in Basic Plasma Science: Experimental Investigations of Alfven Wave Damping Processes Relevant to the Solar Corona	Daniel Wolf Savin	Columbia U.	$450,000
Realistic treatment of plasma-surface interactions in simulations of low temperature plasmas: From a new diagnostic for y-coefficients to optimization of process control	Felix J. Schulze	West Virginia U.	$435,000
GOALI: OPTIMIZATION OF ION BEAM EXTRACTION - ENABLING TECHNOLOGY FOR ADVANCED SEMICONDUCTOR FABRICATION	Earl E Scime	West Virginia U.	$425,000
New Physics in the Hot Electron Furnace	Gerald Seidler	U. Washington	$600,000
Fluctuations and Self-Organization in Plasma Boundary Layers	Frederick N Skiff	U. Iowa	$655,000

FY16 NSF/DOE Awards - III

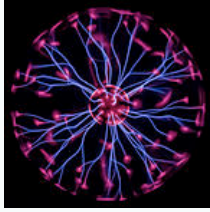


Title	Principal Investigator	Institution	Total Committed
2D Vortex Dynamics in Externally Imposed Flows Studied Using Electron Plasmas	Cliff Surko	UCSD	$500,000
Advancing the Physics of Magnetized Dusty Plasmas	Edward E Thomas	Auburn U.	$865,000
	Marlene C Rosenberg	UCSD	$165,000
	Robert L Merlino	U. Iowa	$175,000
Laboratory investigation of arched magnetoplasma eruptions on the Sun	Shreekrishna Tripathi	UCLA	$360,000
Simulations of Laser Experiments to Study the Origin of Cosmic Magnetic Fields	Petros Tzeferacos	U. Chicago	$465,000
The dynamics of thin current sheets and the triggering of fast reconnection in different plasma environments	Marco C Velli	UCLA	$366,000
Non-invasive diagnostics of molecular gas plasmas with quantitative optical emission spectroscopy	Amy E Wendt	U. Wisconsin - Madison	$525,000
RUI: Experimental study of the thermal state of weakly-coupled dusty plasmas and nonlinear properties of the dust acoustic wave	Jeremiah D Williams	Wittenberg U.	$300,000

FY14-16 NSF/DOE Awards

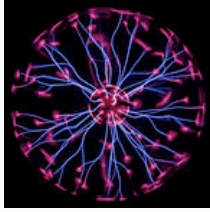


FY16 Plasma Physics Program



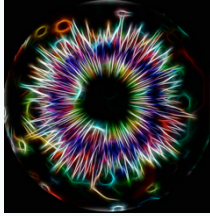
- FY16 program core allocation – $3,921k; a 0.8% increase over the FY15 core allocation
- Funded or co-funded 15 awards in response to the NSF/DOE Plasma Partnership solicitation proposals
- Renewed BaPSF facility (UCLA) for another 5 years of operations
- INSPIRE award co-funded with PHY/AMO & BIO: “Compact X-Ray Laser in "Water Window" and Microscopy of Cell Membranes” [PI: Suckewer (Princeton U.)]
- Data Infrastructure Building Blocks (DIBBs) award co-funded with PHY/Comp Phys, CISE, and GEO: “Metadata Toolkits for Building Multi-faceted Data - relationship Models” [PI: Greenwald (MIT)]
- HBCU award “Overcoming the Saturation Limit of High Intensity, Fully Coherent Raman Backscattering Laser” [PI: Jun Ren (Delaware State U.)] funded by the MPS/Office of Multidisciplinary Activities
- 5 Conference/Workshop and 2 REU Supplement awards

Plasma Program Outlook



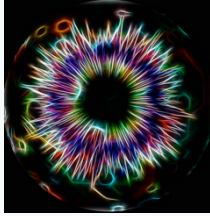
- Proposals submitted in response to solicitation "NASA/NSF Partnership on Science of Dusty Plasmas: Utilizing the PK-4 Facility on board the International Space Station" are under review.
- NSF/ENG sponsored (with Plasma Physics Program co-funding), "Workshop on Science Challenges in Low Temperature Plasma Science and Engineering" was held at NSF on August 22-23, 2016 led by Mark Kushner, Selma Mededovic, and Mohan Sankaran. We are waiting for the workshop report.
- The last NRC Plasma Science Decadal Survey was completed in 2007. The next one has not yet been initiated and is thus already behind schedule.
- Follow developments and prepare for opportunities for the plasma science community offered by two recent OSTP initiatives:
  - National Strategic Computing Initiative [July, 2015]
  - National Space Weather Strategy & Action Plan [October, 2015]

Accelerator Science Program



- A 3-year old program. Crosses multiple areas of science (plasma physics, materials science, etc.)
- Focus on fundamental science best done at colleges & universities
  - High risk, transformational, cross-cutting with other academic disciplines
  - Research work itself can take place on campus or off campus (national lab, etc.)
- Goal is to attract the best students/postdocs by tackling hard and interesting problems
- This program is **NOT** intended to be
  - Directed R&D towards or an incremental improvement of a foreseen project or facility
  - “Supplement” to an existing DOE award

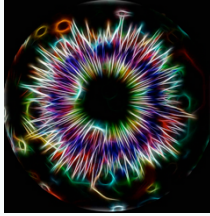
Accelerator Science Program



from the Program Description:

"The Accelerator Science program supports and fosters research that exploits the **educational and discovery potential of basic accelerator physics research** at academic institutions. A key goal of the program is to **seed and develop research efforts** in fundamental accelerator science **at colleges and universities** that will **enable transformational discoveries** in this crosscutting academic discipline. In particular, this program seeks to support **research with the potential to disrupt existing paradigms** and advance accelerator science at a fundamental level, such as enabling discoveries that lead to novel, compact, powerful, and/or cost-effective accelerators..."

Accelerator Science Program

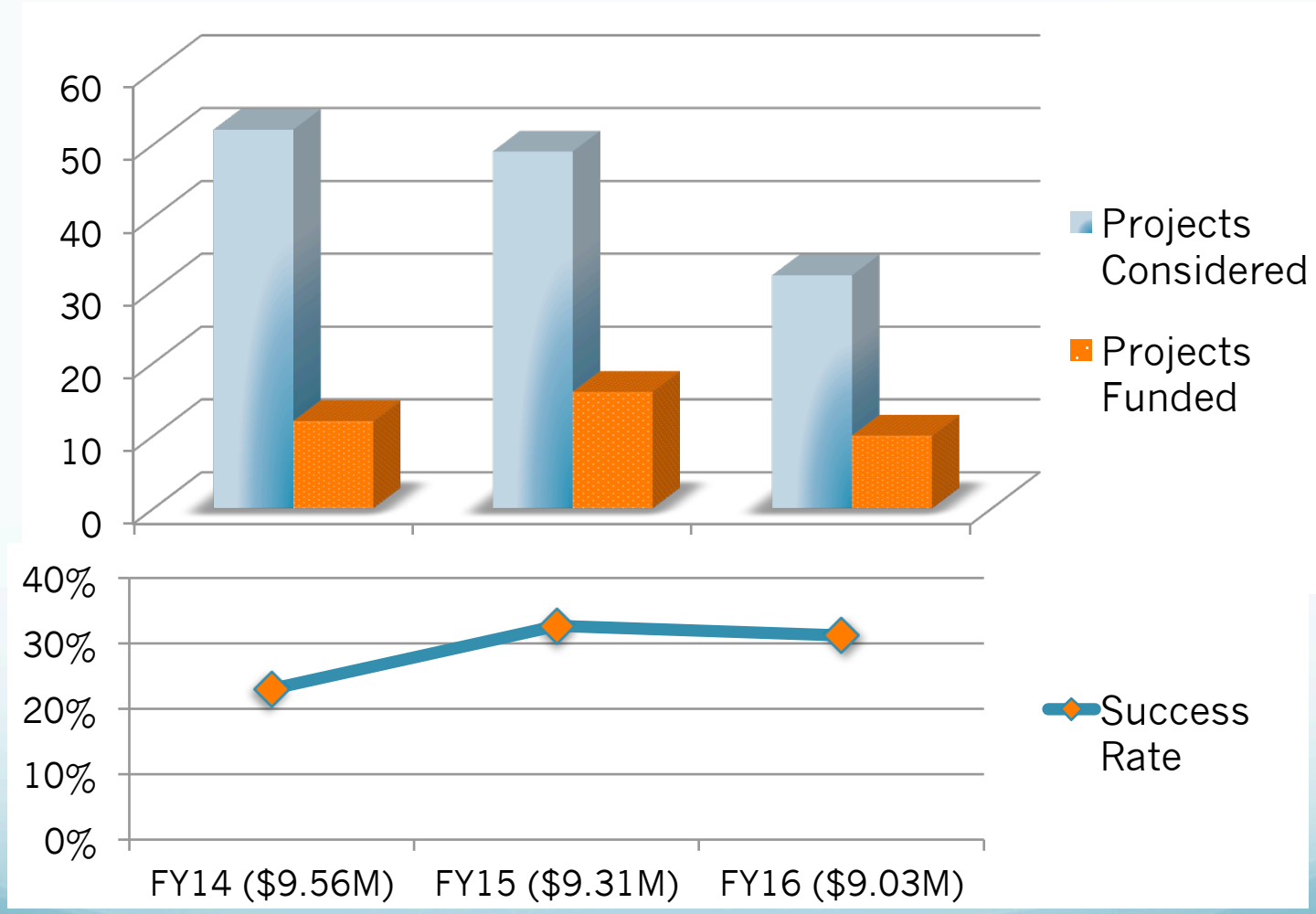


more from the Program Description:

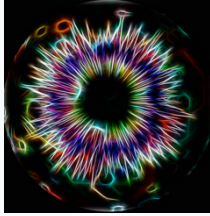
"This program aims to provide the **foundation in knowledge and workforce** upon which major advances in accelerator-driven technologies will be based. An important component of the program is the **support and training of the next generation of accelerator scientists**, including students, postdoctoral researchers, and junior faculty, **who will lead innovations in the field** and will form the backbone of the nation's highly trained accelerator workforce.

... **Priority will be given to those proposals that** enable the discovery science supported by the MPS Division of Physics and **do not augment ongoing work supported by other agencies.**"

Accelerator Science: 3-Year Funding History

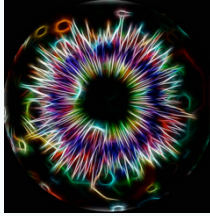


Program budget includes funding for conferences, REU supplements, etc.



FY16 Accelerator Science Program

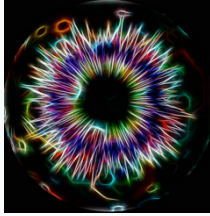
- 32 distinct projects considered by the FY16 Accelerator Science review panel: $29,867k requested over 3 years
- 5 proposals Returned Without Review; 1 Withdrawn
- 4 of 32 proposals received shared consideration with other programs within NSF
- **10 out of 32 proposals** considered by the panel were funded in full or in part. NSF made up to 3-year commitments for **$4,458k out of $29,867k** requested
- Awards made to **10 out of 20 applying institutions** (all colleges and universities)
- In addition, co-funded one Plasma Physics award and one DMR MRI award
- Funded or co-funded 6 Conference/Workshop awards and 1 REU Supplement award



FY16 Accelerator Science Awards

Title	Principal Investigator	Institution
New frontiers of direct laser acceleration in Megatesla magnetic fields	Arefiev, Alexey	UT - Austin
Magnetic Field Mapping of Vortex Hotspots and Identifying the Sources of Losses in Superconducting Accelerating Cavities	Ciovati, Gianluigi	Old Dominion U.
Accurate Electron Spin Optical Polarimetry (AESOP)	Gay, Timothy J.	U. Nebraska-Lincoln
High-energy laser-proton acceleration from cryogenic hydrogen	Glenzer, Siegfried	Stanford U.
Nanopatterned Electron Beams for Coherent Radiation Emission	Graves, William S.	Arizona State U.
Beam-Driven Accelerator Studies	Jiang, Yong	Yale U.
From phase space manipulation to first light from a laser plasma accelerator powered free electron laser	Leemans, Wim	UC-Berkeley
Graduate Research at Michigan State University to Push the Intensity Frontier and Support Accelerator Science	Lund, Steven	Michigan State U.
Intense sub-femtosecond optical radiation from relativistic plasmas	Milchberg, Howard M.	U. Maryland - College Park
Modeling Ion Extraction from first Toroidal Electron-Cyclotron-Resonance Ion Source	Volpe, Francesco	Columbia U.

FY14-16 Accelerator Science Awards



Accelerator Science Program Outlook

- The program is at a critical point in FY17. The first batch of awards is completing their three-year award period and one can begin to evaluate the program outcomes.
- It is absolutely imperative that the NSF Accelerator Science program acquires its own distinct identity. It **will not survive** as just another funding source for projects that are declined by DOE for one reason or another.
- **We are looking for many more proposals with new ideas** that the PI's wouldn't even consider sending to DOE (as opposed to proposals DOE wouldn't fund). We are NOT looking for more proposals that are not responsive to the spirit of the solicitation.
- The NSF/PHY Committee of Visitors in FY18 is certain to be taking a long hard look at the Accelerator Science program and its fate very much depends on what happens over the coming year.

Other NSF Opportunities

- **Partnerships for International Research and Education (PIRE)**
- **Science and Technology Centers (STCs)**
- **Major Research Instrumentation (MRI)** (next deadline in January, 2017)
- **Software Infrastructure for Sustained Innovation (SI^2)** (multiple deadlines: September 19, 2016; February 21, 2017)
- **Emerging Frontiers in Research and Innovation (EFRI)** (FY18 topics being solicited now)
- **GOALI, CDS&E, and INSPIRE programs**
- **Faculty Early Career Development (CAREER)** (next deadline in July 2017)
- **NSF Graduate Research Fellowship (GRFP)** (late October 2016**)**
- **See 'Dear Colleague Letters' on:**
  - **Optics & Photonics**
  - **Midscale Level Instrumentation in Division of Physics**
  - **Graduate Research Supplements for Veterans and for AGEP Institutions**