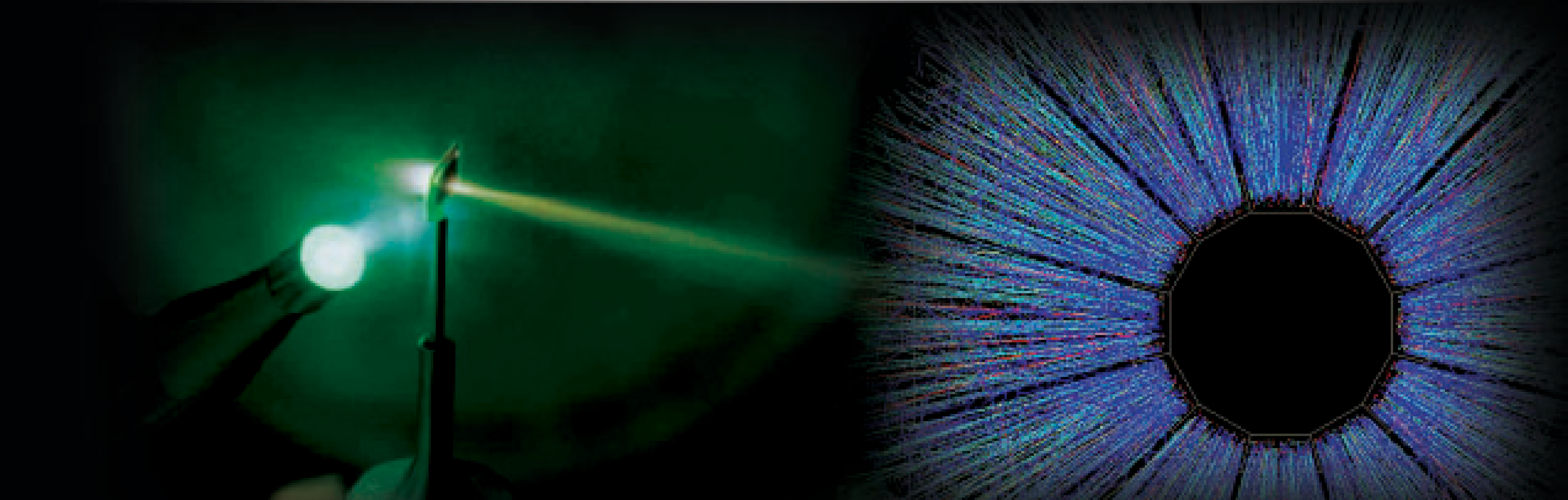
Report of the Interagency Task Force on High Energy Density Physics

National Science and Technology Council
Committee on Science
Interagency Working Group on the Physics of the Universe

AUGUST 2007



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About this Report

This report, prepared by the interagency Task Force on High Energy Density Physics under the auspices of the Interagency Working Group on the Physics of the Universe, identifies the needs for improving Federal stewardship of specific aspects of high energy density physics, particularly the study of high energy density plasmas in the laboratory, and strengthening university activities in this latter discipline. The report articulates how HEDP fits into the portfolio of federally funded missions and includes agency actions to be taken that are necessary to further this area of study consistent with Federal priorities and plans, while being responsive to the needs of the scientific community.

Acknowledgements

The task force would like to thank Cris Barnes, Julie Carruthers, Peter Lincoln, Uday Varadarajan, and Yolanda White for their assistance in the preparation of this report.

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EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20502

August 24, 2007

Dear Colleague,

The study of matter under extreme conditions of temperature and density – high energy density physics (HEDP) – is an emerging multidisciplinary field with potentially broad benefits to our society. HEDP is an area of science where theory and technology intersect to extend our conceptual framework of the universe. Discoveries in HEDP will enrich our understanding of important phenomena and stimulate future technology development.

Recent reports, including two by the National Research Council, have outlined exciting new research areas and strategic approaches for advancing this emerging field. They all concur that research activities in intellectually diverse fields should be coordinated to enhance the benefits of HEDP research beyond those attainable by each separate discipline. Intertwining traditional particle physics, materials science, and laser science will generate new tools and techniques for studying the interactions of matter and energy at extreme physical conditions, with potential applications ranging from understanding exotic cosmic sources to fusion energy.

The accompanying report provides a Federal cross-agency strategic plan for scientific discovery in the broad HEDP field. This plan was developed by the Task Force on High Energy Density Physics under the auspices of the National Science and Technology Council's Interagency Working Group on the Physics of the Universe. The activities described in the Task Force report chart a new path for coordinating high-priority HEDP research programs across the government, which will help ensure that these programs can achieve the maximum possible benefits, and provide the science community with access to state-of-the-art facilities.

Sincerely,

John H. Marburger III
Director, Office of Science and Technology Policy

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Executive Summary

High energy density physics (HEDP) – the study of matter subject to extreme conditions of temperature and density – cuts across many traditional fields of physical science, including astrophysics, cosmology, nuclear physics, and plasma science. Research in HEDP is necessary to accomplish specific scientific and national security missions of several Federal agencies. The broad range of phenomena relevant to HEDP and the corresponding degree to which HEDP touches established fields of science – such as atomic physics, nuclear physics, plasma physics, high energy physics, astrophysics, materials science, and laser science – requires that these numerous interconnections to existing fields of science be maintained and nurtured. Most of these fields of science have well-established scientific communities in academe and the national laboratories, peer-review mechanisms for funding, open facility access, and technical reporting, but their HEDP connections require greater Federal coordination and management.

Technical advances relevant to HEDP, emerging scientific opportunities, and recommendations for enabling further progress have been presented in a number of reports sponsored by the Federal government in recent years. The current interagency Task Force on HEDP (TF-HEDP) was chartered by the Interagency Working Group on the Physics of the Universe (IWG-POU) under the Committee on Science of the National Science and Technology Council to respond to a community-based report (*Frontiers for Discovery in HEDP*) previously commissioned by the IWG-POU and to recommend specific steps needed to advance scientific opportunities in HEDP.

Because of its interdisciplinary nature, support for HEDP crosses Federal agency boundaries. Current HEDP-related activities are supported by the Department of Energy (DOE), the National Aeronautics and Space Administration (NASA), the Department of Commerce's National Institute of Standards and Technology (NIST), the National Science Foundation (NSF), and the Department of Defense (DOD). The scientific opportunities for HEDP have arisen from frontier technologies developed for mission-critical needs in these Federal programs, so the exploitation of these opportunities is best pursued in the context of primary agency missions. Enhanced coordination among the agencies is appropriate, however, in order to foster relationships among the range of scientific disciplines relevant to HEDP. *No single Federal agency can or should be the steward for this highly diverse area of research.* HEDP must also cultivate the diverse education and research activities in universities that are vital both for advancing the intellectual frontiers of HEDP and for recruiting and training the next generation of HEDP professionals.

This discussion of the Federal management of HEDP-related activities is organized along the lines of current agency missions into four Federal Research Categories: *Astrophysics, High Energy Density Nuclear Physics, High Energy Density Laboratory Plasmas (HED-LP), and Ultrafast, Ultraintense Laser Science*. The mechanisms for planning, managing and stewarding three of the four research categories – *Astrophysics, High Energy Density Nuclear Physics, and Ultrafast, Ultraintense Laser Science* – already exist and these opportunities should be exploited in the context of agency missions. Competitive processes to support research in *Astrophysics* exist within NASA and NSF. *High Energy Density Nuclear Physics* is a well-defined area of research that is stewarded by DOE/Office of Science/Office of Nuclear Physics (DOE/NP). Likewise, research thrusts related to *Ultrafast, Ultraintense Laser Science* are supported by the DOE, DOD, and NSF.

However, the Federal government would be well served by the establishment of strategic planning, management and merit-based, science-driven stewardship for *High Energy Density Laboratory Plasmas (HED-LP*). Significant investments are presently being expended in applied studies of HED-LP, but the Federal mechanisms for stewarding fundamental research in HED-LP are poorly defined or do not exist. DOE facility usage policies and practices, support and scientific evaluation infrastructure, and user communities are not in place to take advantage of research capabilities.

To ensure stewardship of fundamental HED-LP science, and advance this area of research consistent with Federal priorities and plans, while being responsive to the needs of the scientific community, the TF-HEDP agencies will take the following actions:

- The Office of Science (SC) and the National Nuclear Security Administration (NNSA) within DOE will establish a joint program in HED-LP responsible for stewarding fundamental high energy density laboratory plasma science within the Department of Energy.

- The DOE will ensure that the joint program solicits advice from the scientific community regarding opportunities and priorities in fundamental HED-LP science.

- The joint program, in consultation with NSF, will develop a coordinated strategic plan for a national program in HED-LP and will support peer-reviewed research through normal agency planning processes and joint solicitations for research to be performed at universities and at national facilities.

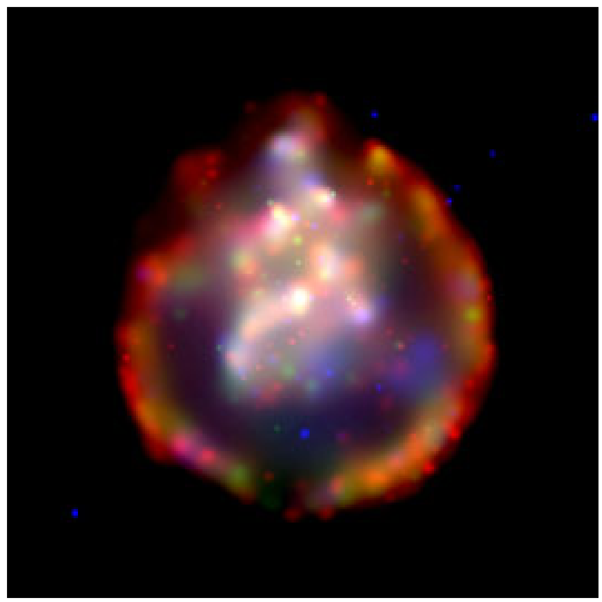
- As the primary Federal steward of research capabilities in HED-LP within DOE, NNSA will develop management processes to provide access to its major facilities by researchers external to the NNSA national laboratories.

More broadly, actions led by the appropriate Federal agencies will be taken to encourage and nurture interactions among the diverse range of scientific disciplines and associated enabling technologies that encompass HEDP. An interagency website will be established to provide information regarding the various Federal programs and their connection to HEDP with links to information on HEDP research activities, funding mechanisms, user facilities, workshops, and interagency coordinating activities. Interdisciplinary, international meetings on HEDP will be organized, supported by all relevant agencies, to strengthen the collaboration among the wide-ranging subfields of HEDP and to facilitate cross-fertilization among groups at universities and national facilities. Further workshops will be organized as needed to focus on specific areas that cut across the subfields of HEDP.

I. Introduction

High energy density physics (HEDP) is the study of matter subject to conditions leading to energy densities exceeding 10^{11} Joules/m^3. Examples of such extreme conditions include pressures greater than a million times that of our atmosphere, laser intensities more than twenty-five quadrillion times as intense as sunlight, ultra-strong magnetic fields more than five million times that of the Earth, and energy densities at the very limit of what can be studied in the laboratory (~2 x 10^{30} Joules/m^3) where ordinary nuclear matter melts into its fundamental constituents, quarks and gluons. The study of high energy density physics and related phenomena could enable significant advancements in astrophysics, cosmology, high energy physics, nuclear physics and plasma science, and is necessary to accomplish specific scientific and national security missions of the Federal agencies.

Over the last few years, a number of reports sponsored by the Federal government have identified an array of scientific opportunities in HEDP. These opportunities often cut across scientific disciplines and have arisen from research supported by several Federal programs. For example, some of the earliest theoretical work on matter in the HEDP regime was driven by observations of astrophysical phenomena, such as the death of a star, in which matter can be subject to extreme pressures, temperatures, and densities. Over the last few decades, analogous physical conditions have been reproduced in laboratories conducting research driven by starkly different missions. For instance, nuclear physics experiments aimed at studying new phases of nuclear matter through the collision of heavy ions accelerated to high energies produce fireballs with energy densities so extreme as to mimic the conditions of the first microseconds after the Big Bang. Likewise, temperatures and densities that rival those in the interior of the sun can be produced in high-energy/high-intensity laser and pulsed-power experimental facilities used in inertial confinement fusion research and nuclear stockpile stewardship. While pursuing their distinct mission-driven goals, these facilities have nevertheless opened up new opportunities for research in laboratory-based astrophysics.



The striking Chandra image of supernova remnant, SNR 0103-72.6, reveals a nearly perfect ring about 150 light years in diameter surrounding a cloud of gas enriched in oxygen and heated to millions of degrees Celsius by a shock wave produced by the supernova explosion.

Credit: NASA/CXO/Penn. State/S.Park et al.

There are now a number of complementary techniques used in the study of physics at high energy densities – astrophysical observations, particle accelerators, magnetically confined plasmas, pulsed-power facilities, high-energy lasers and high-intensity lasers, often in combination with one another. These approaches cut across a number of scientific disciplines: atomic and molecular physics, astrophysics, plasma physics, material science, laser science, nuclear physics and particle physics. The broad range of phenomena relevant to HEDP and the corresponding degree to which HEDP touches on established fields of science immediately highlights the strong interdisciplinary nature of this research and the need for Federal coordination where appropriate. Federally sponsored studies examining HEDP have identified many of these scientific links, but as yet no coherent framework for Federal oversight of this area of research has been defined.

This report, prepared by the interagency Task Force on High Energy Density Physics (TF-HEDP) under the auspices of the Interagency Working Group on the Physics of the Universe (IWG-POU), identifies the needs for improving Federal stewardship of specific aspects of high energy density physics, particularly the study of high energy density plasmas in the laboratory and university activities in this discipline. The report articulates how HEDP fits into the portfolio of Federally funded missions and includes agency actions to be taken to further this area of study consistent with Federal priorities and plans, while being responsive to the needs of the scientific community. The actions contained in the report, along with other activities currently underway within individual agencies, will foster the evolution of this emerging multidisciplinary scientific area.

The report is organized as follows: Section II reviews previous reports relating to HEDP and summarizes the key issues relevant to Federal management. Section III summarizes the key points of the 2004 report (*Frontiers for Discovery in HEDP*) of the National Task Force on High Energy Density Physics (NTF-HEDP) and lays the groundwork for the findings of this interagency TF-HEDP. Section IV outlines how HEDP, as categorized by this task force, fits within the spectrum of Federal missions. Section V outlines the Federal plan for managing HEDP activities, including specific agency actions to strengthen the Nation's research programs in high energy density physics. Appendix A and B contain the charter and membership of the TF-HEDP. Appendix C describes Federal research and development capabilities relevant to HEDP by agency. Appendix D describes how the major scientific thrusts in HEDP, as identified by the NTF-HEDP, cut across various agency missions. Finally, Appendix E describes the current and planned user policies for the National Nuclear Security Administration's facilities.

II. Summary of Previous Reports

The rapid worldwide progress in fields of research tied to high energy density physics has received extensive recognition within the scientific community. Technical advances in the field, emerging scientific opportunities, and recommendations to enable further progress have been presented in a number of reports authored or sponsored by the Federal government in recent years. These reports, which have been central to defining the science of high energy density physics and future directions for research, are listed below:

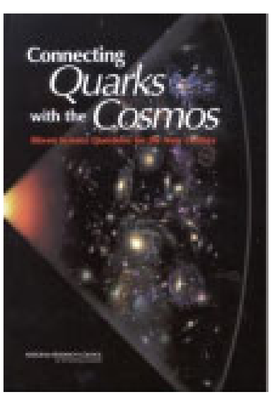
1. National Research Council, *Connecting Quarks with the Cosmos: Eleven Science Questions for the New Century (Quarks to Cosmos)*, National Academies Press, Washington, DC, 2003.

2. *The Science and Applications of Ultrafast, Ultraintense Lasers (SAUUL): Opportunities in Science and Technology Using the Brightest Light Known to Man*, Report on the *SAUUL* workshop sponsored by DOE and the National Science Foundation (NSF), 2002.

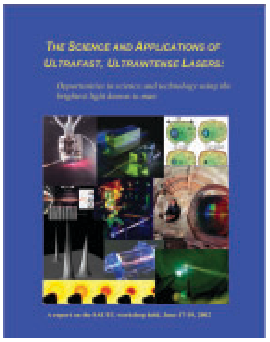
3. National Research Council, *High Energy Density Physics: The X-Games of Contemporary Science (HEDP/X-Games)*, National Academies Press, Washington, DC, 2003.

4. National Science and Technology Council Committee on Science, *A 21st Century Frontier of Discovery: The Physics of the Universe (2004-POU)*, Office of Science and Technology Policy, Washington, DC, 2004.

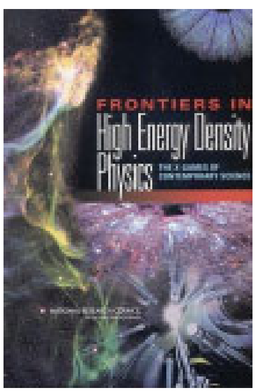
5. National Task Force on High Energy Density Physics, *Frontiers for Discovery in High Energy Density Physics (Frontiers for Discovery in HEDP)*, Office of Science and Technology Policy, Washington DC, 2004.



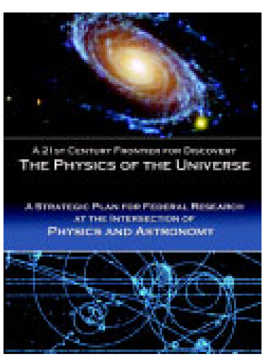
The *Quarks to Cosmos* report has played a major role in organizing the scientific thinking and effort within the Nation towards answering fundamental questions at the intersection of physics and astronomy. High energy density physics is highlighted in the report as rapidly evolving and key to developing an understanding of the physics of extreme astrophysical environments. The report noted that unique laser, accelerator, and plasma confinement devices could be used to "understand some of the most interesting objects in the universe." The report strongly endorses enhanced exploration of laboratory high energy density plasmas and recommends Federal interagency cooperation to fully exploit the available scientific opportunities. This strong endorsement has catalyzed extensive interagency discussions on HEDP as part of a broader discussion on interagency coordination of research on the physics of the universe.



The *SAUUL* report discussed scientific applications of ultrafast, ultraintense lasers relevant to HEDP studies. The report was motivated by opportunities arising from the impressive advances in laser technology over the previous ten years. Laser pulses shorter in duration than a trillionth of a second, and with irradiance exceeding those available in very large inertial fusion facilities, are now available at modest size and cost to university researchers. These lasers allow many HEDP questions to be investigated by university research groups. The *SAUUL* report also made recommendations for organizing the ultrafast, ultraintense laser research community across the U.S. Many of the HEDP opportunities made available by short-pulse lasers were also described in the *HEDP/X-Games* report.



The *HEDP/X-Games* report serves as a valuable survey of the science of high energy density physics. This report defined key scientific questions in this area of research and united a number of disparate activities into an overall framework. The report also pointed out the interdisciplinary (and interagency) nature of the field and provided specific recommendations to strengthen the field.



In order to formulate an interagency Federal response to the *Quarks to Cosmos* report, the Interagency Working Group on the Physics of the Universe (IWG-POU) was chartered under the Committee on Science of the National Science and Technology Council. The IWG-POU examined the investments required in physics and astronomy research relevant to the fundamental scientific questions raised by the *Quarks to Cosmos* report and developed priorities for further Federal action. The IWG-POU report (*2004-POU*) recommended giving priority to three areas ready for investment: Dark Energy; Dark Matter, Neutrinos and Proton Decay; and Gravity. The report also formulated the next steps for the agencies to take in three additional areas: Origin of the Elements; Birth of the Universe Using the Cosmic Microwave Background; and High Density and Temperature Physics. The *2004-POU* report contained thirteen recommendations aimed at prioritizing and implementing the recommended actions in all six areas. The IWG-POU considered the *HEDP/X-Games* and *SAUUL* reports and other input in formulating its recommendations regarding High Density and Temperature Physics.

The *2004-POU* report contained three recommendations for High Density and Temperature Physics:

1. In order to develop a balanced, comprehensive program, NSF will work with DOE, NIST and NASA to develop a science driven roadmap that lays out the major components of a national HEDP program, including major scientific objectives and milestones and recommended facility modifications and upgrades.

2. NNSA will add a high-energy, high-intensity laser capability to at least one of its major compression facilities in order to observe and characterize the dynamic behavior of high energy density matter.

3. DOE and NSF will develop a scientific roadmap for the luminosity upgrade of the Relativistic Heavy Ion Collider (RHIC) in order to maximize the scientific impact of RHIC on High Energy Density (HED) physics.

All action items have been addressed:

1. The IWG-POU commissioned a community-based National Task Force on High Energy Density Physics (NTF-HEDP) to determine the principal science thrust areas as a "roadmap" for the field. The task force successfully completed its work and submitted its report (*Frontiers for Discovery in HEDP*) to the Federal government in 2004.

2. NNSA has implemented a high-energy, high-intensity laser capability at the Omega EP facility located at the Laboratory for Laser Energetics at the University of Rochester. A Congressionally-directed high intensity petawatt laser capability is also under construction at Sandia National Laboratories. Appendix E provides a summary of user policies for these and other NNSA facilities.

3. DOE and NSF charged the jointly chartered Nuclear Science Advisory Committee (NSAC) to develop a scientific roadmap for the RHIC program. This roadmap forms the basis for DOE and NSF planning. The RHIC accelerator and detector upgrades are now essential elements in the DOE Office of Science/Office of Nuclear Physics 5-year budget plan.

III. Frontiers for Discovery in HEDP Report

As discussed above, the IWG-POU chartered the scientific community to develop a roadmap for high energy density physics; a National Task Force on HEDP (NTF-HEDP) was convened with Professor Ronald C. Davidson (Princeton University) as chairperson. Professor Davidson had also chaired the *HEDP/X-Games* study. The NTF-HEDP organized a community workshop to generate a science-driven roadmap and submitted its report (*Frontiers for Discoveries in HEDP)* to the IWG-POU in 2004.

The *Frontiers for Discovery in HEDP* report identified fifteen scientific thrust areas of high intellectual value for HEDP research, shown in Table 1. Research opportunities, scientific objectives and milestones, resource requirements and opportunities for interagency cooperation in the fifteen scientific thrust areas were identified. The report also contained recommendations, some explicit and many implicit, for addressing obstacles to progress in HEDP research.

The *Frontiers for Discovery in HEDP* report raised a number of specific issues, such as the lack of access to appropriate computing facilities for many of the individual research areas described. The need for continuing interagency coordination including facility access programs was also noted. The report identified a variety of facility needs, including open access to present kilojoule (kJ)-class lasers or a new kJ-class facility, and the need for investment in kilowatt (kW), 1-10 millijoule femtosecond lasers and centers.

The current interagency task force on HEDP (TF-HEDP) was chartered by the IWG-POU to respond to the findings in the *Frontiers for Discovery in HEDP* report and to determine specific steps needed to move forward on scientific opportunities in HEDP. The charter and members of the TF-HEDP are documented in Appendix A and B of this report. The findings from the TF-HEDP are presented and discussed in the next section. Key actions to be pursued by the Federal agencies are described in Section V. The emphasis in these findings and agency actions is on defining roles and responsibilities for Federal stewardship of HEDP as defined by the fifteen thrust areas in the *Frontiers for Discovery in HEDP* report. Consideration of other specific actions in areas such as computing will be delegated to the agency or agencies involved.

***Table 1:** The fifteen research thrust areas contained in the Frontiers for Discovery in HEDP report.*

Research Thrust Areas from Frontiers for Discovery in HEDP Report
1. Astrophysical phenomena: What is the nature of matter and energy observed under extraordinary conditions in highly evolved stars and in their immediate surroundings, and how do matter and energy interact in such systems to produce the most energetic transient events in the universe?
2. Fundamental physics of HED astrophysical phenomena: What are the fundamental material properties of matter, and what is the nature of the fundamental interactions between matter and energy, under the extreme conditions encountered in high energy density astrophysics?
3. Laboratory astrophysics: What are the limits to our ability to test astrophysical models and fundamental physics in the laboratory, and how can we use laboratory experiments to elucidate either fundamental physics or phenomenology of astrophysical systems that are as yet inaccessible to either theory or simulations?
4. Heavy ion driven HEDP and fusion: How can heavy ion beams be compressed to the high intensities required for creating high energy density matter and fusion ignition conditions?
5. HED physics with ultrarelativistic electron beams: How can the ultra high electric fields in a beam-driven plasma wake field be harnessed and sufficiently controlled to accelerate and focus high-quality, high-energy beams in compact devices?
6. Characterization of quark-gluon plasmas: What is the nature of matter at exceedingly high density and temperature characteristic of the Early Universe? Does the Quark Gluon Plasma exhibit any of the properties of classical plasma?
7. Materials properties: What are the fundamental properties of matter at extreme states of temperature and/or density?
8. Compressible dynamics: How do compressible, nonlinear flows evolve into the turbulent regime?
9. Radiative hydrodynamics: Can high energy density experiments answer enduring questions about nonlinear radiative hydrodynamics and the dynamics of powerful astrophysical phenomena?
10. Inertial confinement fusion: Can inertial fusion ignition be achieved in the laboratory and developed as a research tool?
11. Laser excitation of matter at the relativistic extreme: How do many-body systems evolve in a light field under extreme relativistic conditions where an electron is accelerated to relativistic energies and particle production becomes possible in one optical cycle?
12. Attosecond physics: Can physical and chemical processes be controlled with light pulses created in the laboratory that possess both the intrinsic time- (attoseconds, 1 as=10^{-18}s) and length- (x-rays, 1 Å) scales of all atomic matter?
13. Ultrafast, high peak-power x-rays: Can intense, ultra-fast x-rays become a routine tool for imaging the structure and motion of "single" complex bio-molecules that are the constituents of all living things? Can nonlinear optics be applied as a powerful, routine probe of matter in the XUV/x-ray regime?
14. Compact high energy particle acceleration: How can ultra-intense ultra-short pulse lasers be used to develop compact GeV to TeV class electron and or proton/ion accelerators?
15. Inertial fusion fast ignition: Is it possible to make controlled nuclear fusion useful and efficient by heating plasmas with an intense, short pulse laser?

IV. Findings

The TF-HEDP examined the *Frontiers for Discovery in HEDP* report and other inputs and generated a series of findings and proposed Federal actions. In taking on this task, the major problem encountered by the TF-HEDP was developing a sensible way to categorize and discuss HEDP consistent with existing Federal missions. As described previously, HEDP studies span a range of physics and are highly interdisciplinary. Advancing HEDP requires that the numerous interconnections to existing major fields of science such as plasma physics, atomic physics, nuclear physics, high energy physics, astrophysics, materials science, and laser science be maintained and nurtured. The specific findings of the TF-HEDP include:

1. The opportunities for HEDP arise from frontier technologies developed for mission-critical needs in several high-priority Federal programs, as illustrated in Table 2. Exploitation of these opportunities supports, and needs to be pursued in the context of, these primary missions. This crucial point is key to understanding the interdisciplinary nature of HEDP. In particular:

- DOE/NNSA and DOE/SC/Office of Fusion Energy Sciences (DOE/FES) have developed capabilities for their stockpile stewardship and fusion energy missions, respectively, that enable studies of high energy density laboratory and astrophysical plasmas.

- DOE/SC/Office of Nuclear Physics (DOE/NP) has developed capabilities for studies of matter at extreme density and temperature that are integral to the Nuclear Physics mission.

- NASA, NSF and DOE/SC/Office of High Energy Physics (DOE/HEP) have developed capabilities for mission-related astrophysical studies that will increase fundamental knowledge about high energy density plasmas and ultimately elucidate novel HEDP phenomena in the cosmos.

- DOE/HEP is examining both high power laser and electron-beam-driven plasma wake fields as possible advanced accelerator mechanisms.

- DOE/SC/Office of Basic Energy Science (DOE/BES) and NSF support work in ultrafast, ultraintense laser science to study fundamental interactions in atoms, molecules, and materials; to advance basic plasma physics; and to develop new tools such as ultrafast x-ray sources for investigation of matter. This work also enables and advances the study of high energy density plasmas.

- The Department of Defense (DOD) supports research in intense laser and particle beam generation, pulsed power, as well as the generation of x-rays and neutrons for weapons applications and effects studies.

- The National Institute of Standards and Technology (NIST) supplies fundamental atomic data and advances the study of atomic processes in high energy density plasmas.

Table 2: *Agencies, their missions, and the capabilities developed in support of those agency missions that are relevant to HEDP studies.*

Agency	Mission	Capabilities relevant to HEDP
DOE/NNSA	Stockpile Stewardship	Major facilities, modeling capabilities, and technologies; fundamental physics of matter at extreme conditions; physics of ultraintense laser-matter and beam-matter interactions
DOE/FES	Fusion Energy; Basic Plasma Science	Heavy ion beam science; physics of laser-matter, beam-matter interactions, plasma jets, and dense plasmas in ultrahigh magnetic fields
DOE/NP	Nuclear Physics	Major facility for studies of fundamental knowledge of quark-gluon plasmas
NASA	Astrophysics	Space-based astrophysics observatories
DOE/HEP	High Energy Physics	Relativistic laser-matter and intense beam-matter interactions
NSF	Basic Research and Education	Basic plasma physics; basic atomic and molecular physics (ultrafast, ultraintense lasers); ground-based astrophysics observatories
DOE/BES	Basic Energy Sciences	Ultrafast, ultraintense lasers and x-ray sources capable of producing HED matter; x-ray and neutron sources capable of probing HED matter
DOD	National Defense	Intense laser and particle beam generation and interaction with matter; x-ray and neutron generation; pulsed power technologies
NIST	Measurement Science, Standards, and Technology	Atomic data; atomic physics in high temperature plasmas; x-ray diagnostic instrumentation; laser science; metrology

2. High energy density physics as articulated in the *Frontiers for Discovery in HEDP* report (i.e., the fifteen thrust areas) cuts across many traditional fields of physical science.

- The fields of science relevant to the advancement of HEDP include atomic and molecular physics, astrophysics, materials science, nuclear physics, particle physics, plasma physics, and laser science. Most of these fields are already well-established in terms of the infrastructure required to support university research, including established scientific communities, peer-review mechanisms for funding, and open facility access policies.

- Since HEDP involves multiple disciplines, its support crosses agency boundaries. Current HEDP-related activities are supported by the DOE, NASA, NIST, NSF, and the DOD.

- Moreover, the common usage of "HEDP" within the scientific community, nationally and internationally, generally refers only to studies of high energy density plasmas in the laboratory.

- The fifteen thrust areas include both the development of fundamental knowledge regarding matter at extreme conditions and the use of that knowledge to enable research advances in other areas such as astrophysical phenomena, development of advanced accelerators, and materials science studies.

3. The list of fifteen research thrusts identified by the *Frontiers for Discovery in HEDP* report should not be regarded as comprehensive. There are additional cross-cutting areas of HEDP of interest to the missions of Federal agencies. Examples of such areas include:

- Better understanding of the collective interaction of particles and waves and the related laser-plasma instabilities, which is vital for achieving inertial confinement fusion.

- The detailed prediction of failure and fracture of materials, an important issue at the boundary of dynamic materials science and HEDP.

- Laboratory experiments in both the high energy density and low energy density regimes that may shed light on the origin of magnetic fields in the universe.

- The behavior of dense plasmas in ultrahigh magnetic fields, a relatively unexplored and intellectually rich regime of plasma physics, has potential applications to energy as well as astrophysics and materials science.

4. Organizing the research thrusts outlined in the *Frontiers for Discovery in HEDP* report along the lines of current agency missions facilitates their Federal management.

- In particular, the fifteen thrust areas fall into four Federal Research Categories: Astrophysics, High Energy Density Nuclear Physics, High Energy Density Laboratory Plasmas, and Ultrafast, Ultraintense Laser Science. Table 3 indicates how the fifteen scientific thrusts map into these four research categories.

- Furthermore, the agency missions must be broadly interpreted to include the university-based research activities that are key to advancing the intellectual frontiers of present or future importance to HEDP and to recruiting and training the next generation of HEDP scientists.

Table 3: *Federal categorization of fifteen thrust areas contained in the Frontiers for Discovery in HEDP report.*

Federal Research Category	Research thrust area(s) from the Frontiers for Discovery in HEDP report
Astrophysics	1. Astrophysical phenomena
	2. Fundamental physics of HED astrophysical phenomena
High Energy Density Nuclear Physics	6. Characterization of quark-gluon plasmas
High Energy Density Laboratory Plasmas	3. Laboratory astrophysics
	4. Heavy ion driven HEDP and fusion
	5. HED physics with ultrarelativistic electron beams*
	7. Materials properties
	8. Compressible dynamics
	9. Radiative hydrodynamics
	10. Inertial confinement fusion
	15. Inertial fusion fast ignition
Ultrafast, Ultraintense Laser Science	11. Laser excitation of matter at the relativistic extreme
	12. Attosecond physics
	13. Ultrafast, high peak-power x-rays
	14. Compact high energy particle acceleration*

**While thrusts 5 and 14 have been placed in High Energy Density Laboratory Plasmas and Ultrafast, Ultraintense Laser Science respectively, they describe research areas focused on particle acceleration by plasma wake fields, which is the domain of accelerator science and primarily supported by DOE/HEP.*

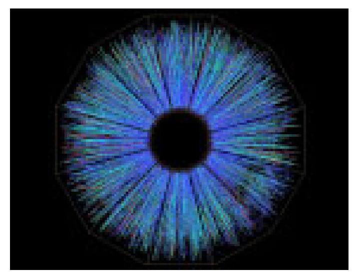
- Description of Federal Research Categories:

A false-color image of the Crab Nebula, a supernova remnant. This NASA composite image combines data from the space-based observatories, Chandra, Hubble, and Spitzer, providing a unique view of the expanding debris from the death explosion of a massive star in X-ray (blue-purple), optical (green) and infrared (red) light.

Credits: NASA - X-ray: CXO, J.Hester (Ariz. State) et al.; Optical: ESA, J.Hester and A.Loll (Ariz. State); Infrared: JPL-Caltech, R.Gehrz (U. Minn)

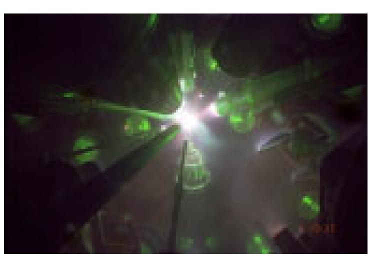
Astrophysics: This category includes core activities in astrophysical research such as the study of matter subject to extreme temperatures, densities, and pressures in supernovae, astrophysical jets and accretion disks, neutron stars, and giant planet interiors. Competitive processes for funding in these areas exist within NASA, NSF, DOE/HEP and DOE/NP. Consistent with their primary mission, NASA resources have been focused on space-based observation and exploration activities.

High Energy Density Nuclear Physics: This category recognizes the distinct nature of quark-gluon plasma research and its foundations in the broader field of nuclear physics. At normal temperatures and densities, nuclear matter contains individual protons and neutrons that are made up of three quarks, "glued" or bound together by gluons. Under the extreme conditions of the early universe, quarks and gluons are believed to be liberated and form a quark-gluon plasma. The study of nuclear matter subject to these conditions is a major scientific thrust of nuclear physics and is the central mission of the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory. Research priorities regarding quark-gluon plasmas are set in the context of fundamental questions regarding nuclear physics, rather than the behavior of materials at extreme conditions.



End view of a collision of two 30-billion electron-volt gold beams in the STAR detector at the Relativistic Heavy Ion Collider at BNL. The beams travel in opposite directions at nearly the speed of light before colliding.

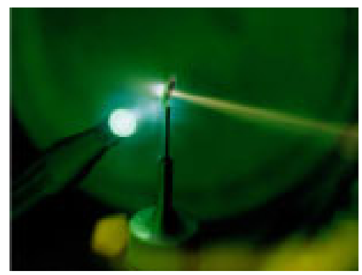
Credit: Courtesy of BNL



View of Omega chamber during cryogenic target implosion

Credit: LLE

High Energy Density Laboratory Plasmas (HED-LP): This category includes the rich and varied set of activities involved in the study of ordinary (as opposed to quark-gluon) plasmas with energy densities exceeding 10^{11} J/m^3 and the applications of these studies to research problems in other areas of science. The activities in this category are highly interdisciplinary in nature, and have been enabled by frontier technologies developed to produce and characterize matter at high energy densities. Pulsed power and high-energy/high-power laser facilities utilized primarily for defense-related research produce extreme conditions of x-ray and laser energy density which enable new regimes of material, plasma, and fusion science to be explored. Those facilities have also opened up a new frontier in laboratory astrophysics. When further equipped with appropriate advanced diagnostic tools, these facilities have already contributed to advancing our understanding of key phenomena in materials properties, compressible dynamics, radiative hydrodynamics, laboratory astrophysics, and controlled thermonuclear fusion and burn. Moreover, when coupled with continually increasing capabilities in computation (soon to reach and exceed petaflop speeds), it is expected that predictive power from basic principles for many of the above phenomena will be within reach. The various reports cited in Section II have highlighted the need for further additional Federal attention to this particular area of science.



Photograph of the LLNL Petawatt laser striking a solid gold target and producing a cone of accelerated electrons and protons with energy up to 100 MeV. The laser enters from the left.

Credit: T. Ditmire (UT Austin)

Ultrafast, Ultraintense Laser Science: This category includes all research thrusts involving the explicit application of ultrafast, ultraintense laser sources. Recent breakthroughs in laser technology have opened two new research frontiers: the ultrafast, featuring laser pulses of less than a femtosecond and down towards atomic time scales measured in attoseconds; and the ultraintense, featuring irradiances whose electromagnetic fields create relativistic particle motion. The span of research activity exploring these new frontiers, separately or in combination, covers the mission interests of several Federal agencies. The four research thrusts placed in this category – relativistic excitation of matter, attosecond physics, ultrafast x-ray generation for time resolved structural studies of solids and molecules, and compact high energy particle acceleration – were identified by previous reports as areas of particularly promising opportunities. These application areas have substantial impact on a very broad range of scientific fields. For example, ultrafast science is relevant to atomic and molecular physics, chemistry and chemical biology, materials sciences, magnetic and electric field phenomena, optics, and laser engineering. Research in these areas is also intimately connected in many cases to activities ongoing in the astrophysics and high energy density laboratory plasmas categories. Further examination of the scientific opportunities and agency interconnections in this area is needed. A key feature of this category is that many of the cutting-edge research facilities are in universities where they are used to address a great diversity of scientific questions. This is a vital platform for the field of HEDP in that it investigates a broad range of frontier questions, can serve as a test bench for experiments destined for national facilities, and is a magnet for the talent that will enable HEDP to prosper in the future.

- Lead agencies and participating agencies are defined in Table 4 for the four Federal Research Categories defined above.
- The lead agencies shown in Table 4 are responsible for stewardship of the areas identified in the left-hand column. The research in a given area is primarily supported by the lead agencies, and is relevant to, or enabled by, the work of the participating agencies.

Table 4: *Agencies leading and participating in the four Federal Research Categories of HEDP. The research in a given area is primarily stewarded and supported by the lead agencies, and is relevant to, or enabled by, the work of the participating agencies.*

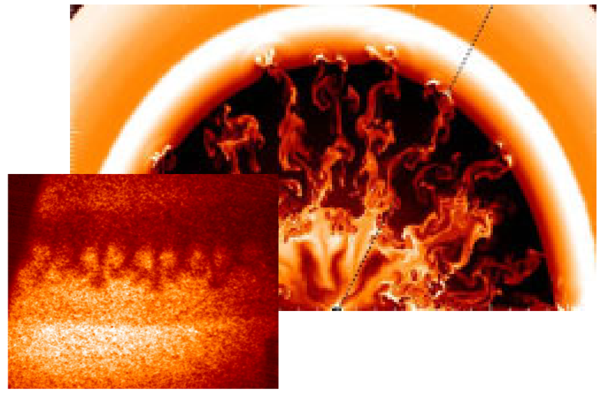
Federal Research Categories	Research Examples	Lead Agencies	Participating Agencies
Astrophysics	Astrophysical jets, physics of astrophysical plasmas; neutron star interiors; core-collapse supernovae	NASA, NSF	DOE/NNSA, NSF, DOE/NP, NIST, DOE/FES, DOE/HEP
High Energy Density Nuclear Physics	Physics of quark-gluon plasmas; nuclear astrophysics	DOE/NP	NSF, NASA
High Energy Density Laboratory Plasmas	Fundamental studies of hydrodynamics, radiation flow, material properties, fusion burn, and materials under condition of extreme laser and particle beam irradiation; dense plasmas in ultrahigh fields; laboratory studies of astrophysical plasmas and associated material properties	DOE/NNSA, DOE/FES	NSF, DOD, DOE/HEP*, DOE/BES, DOE/NP, NIST, NASA
Ultrafast, Ultraintense Laser Science	Ultraintense x-rays for material science studies; applications of ultraintense lasers to chemistry and materials; advanced accelerators	DOE/BES, NSF	DOE/NNSA, DOE/HEP*, DOE/FES, DOD

[*]DOE/HEP is the primary steward of accelerator science and technology, including the use of particle and laser-driven plasma wake fields for particle acceleration.

5. Applying laboratory high energy density plasma capabilities to astrophysical problems is a promising area of research whose research opportunities and stewardship responsibilities are not yet well defined.

- NASA and NSF have primary responsibilities for funding research in astrophysics. The laboratory study of high energy density phenomena relevant to astrophysics will be primarily sponsored by the Department of Energy. DOE, NASA, and NSF activities in this area should be coordinated.

- Mechanisms for nurturing the synergy between the astrophysics and high energy density laboratory plasmas scientific communities should be established.



A simulation of a Type II Supernova shock wave, exhibiting complex compressible hydrodynamic flow compared with a radiograph showing the results of an experiment using the Omega laser to create a shock wave which exhibits similar behavior on a much smaller scale.

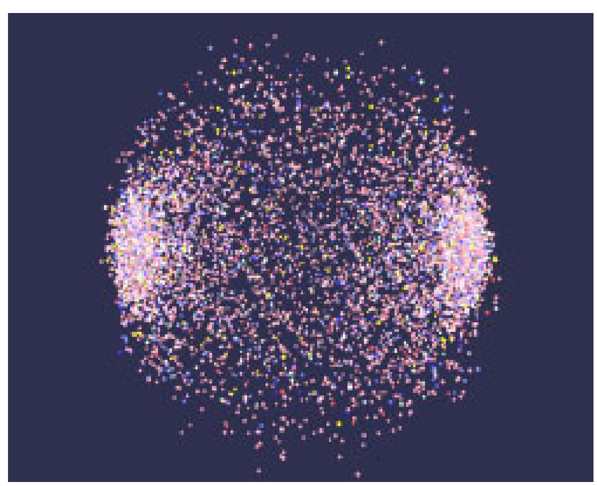
Credits: Supernova simulation, K. Kifonidis (Max Planck Inst.) et al., experimental radiograph H. F. Robey (LLNL) et al.

- It is appropriate that the scientific opportunities and priorities continue to be established in the context of agency overall missions.

6. The study of quark-gluon plasmas and other new states of nuclear matter is a well-identified area of research that needs little additional attention from this task force.

- A mature user community as well as established funding solicitations and user facilities such as the RHIC are in place.

- It is appropriate that the scientific opportunities and priorities continue to be established in the context of overall agency missions.



The aftermath of a head-on collision of two gold nuclei at RHIC in which over 6,000 particles (shown as dots) are produced.

Credits: Image produced by Jeffery Mitchell (BNL). Simulation by the UrQMD Collaboration.

7. Stewardship of basic research in High Energy Density Laboratory Plasmas (HED-LP) needs to be improved within the Department of Energy.

- DOE/NNSA and DOE/FES have developed capabilities for their stockpile stewardship and fusion energy missions that enable studies of high energy density laboratory plasmas. Significant investments and efforts are presently being expended in studies of high energy density plasmas.

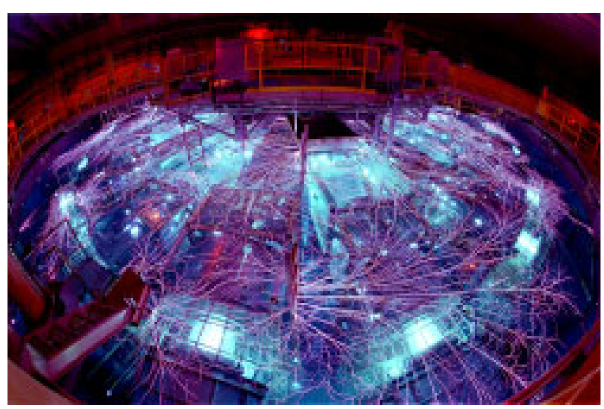
The Neutralized Drift Compression Experiment at the LBNL to study the limits of compression of ion beams in the presence of a neutralizing plasma. Large compression of the ion beam is required for using the ion beams to perform experiments to investigate Warm Dense Matter.

Credit: Courtesy of LBNL.

- While both DOE/NNSA and DOE/FES support competitively awarded university research in this area, Federal mechanisms for stewardship of fundamental research in high energy density laboratory plasma science are poorly defined or do not exist today. DOE needs to ensure that the management of HED-LP is consistent with both agency programmatic objectives and sound stewardship of this area of science.

- Because there is no primary Federal steward, the peer review infrastructure required to support a sound scientific program of academic basic research in high energy density laboratory plasma science is not well established. Facility usage policies and practices, funding support and scientific evaluation infrastructure, and user communities are not in place to take full advantage of the research capabilities within DOE. A summary of current user policies for these programs and other NNSA facilities is provided in Appendix E.

- DOE/HEP is the primary federal steward of accelerator science and technology, including the study of beam-driven plasma wake fields for particle acceleration. It is appropriate that the scientific opportunities and priorities in this area continue to be established in the context of accelerator science and technology.



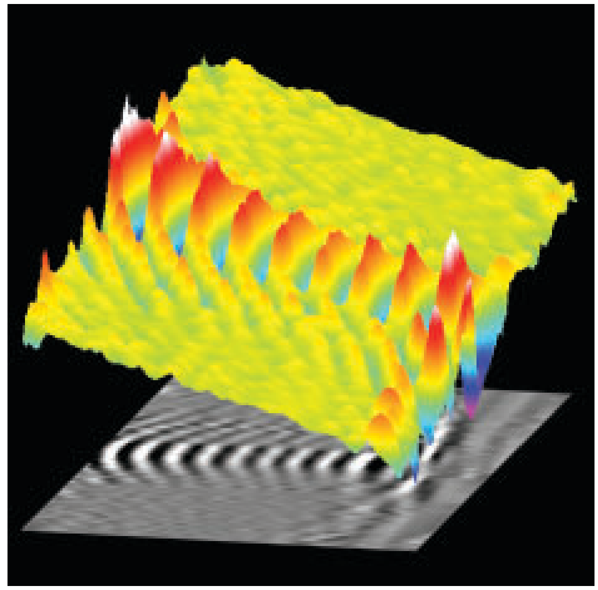
Time-exposure photograph of electrical flashover arcs produced over the surface of the water in the accelerator tank as a byproduct of the operation of the Z pulsed power facility at SNL. These flashovers are much like strokes of lightning.

Credit: Courtesy of SNL

8. Ultrafast, Ultraintense Laser Science is currently stewarded within DOE/BES and NSF. Many cross-cutting scientific opportunities exist in this increasingly interdisciplinary field.

- The scientific thrusts outlined in the *Frontiers for Discovery in HEDP* report relevant to ultrafast, ultraintense laser science are primarily being supported by peer-reviewed research in DOE/BES and NSF. Compact high-energy particle acceleration is supported by DOE/HEP.

- The facility needs of the ultrafast, ultraintense laser science community are being addressed through the normal peer-review process at DOE/BES and NSF, resulting, for example, in several high power lasers coming on line at national laboratories and in university settings with multiple principal investigators.



Images of a wake field produced by a 30 TW laser pulse in plasma of density 2.7 x 10^{18} cm^{-3}. These waves show curved wavefronts, an important feature for generating and accelerating electrons that had been predicted, but never before seen.

Credits: M. Downer (UT Austin), N. Matlis (UC Berkeley)

- X-ray radiography of high energy density experiments in radiation hydrodynamics and dynamic materials is a major need of DOE/NNSA. Such radiography is often best achieved using ultraintense laser pulses. NNSA also uses ultrafast laser technology as a probe of materials dynamics of interest to its mission. These requirements drive NNSA investments in ultrafast, ultraintense laser facilities. These facilities are also useful for the study of inertial fusion using ultraintense lasers to heat a pre-compressed fuel mass ("fast ignition") and fundamental scientific questions involving the behavior of matter in the presence of extreme electromagnetic fields.

- The connections of ultrafast, ultraintense lasers, both as enabling technologies and of intellectual value, to HEDP have been noted in previous studies. The cross-cutting areas of research enabled by the development of ultrafast, ultraintense laser science are important and would benefit from interagency cooperation. For example, the potential co-location of facilities supporting multiple agency missions – such as an ultraintense laser facility at LCLS to allow materials and high energy density laboratory plasma research – should be explored further.

9. It is important to encourage interactions between the fields of research studying aspects of HEDP.

- Only very recently have synergies been established among the disparate fields, for example, nuclear physics – with the discovery of new states of matter created at RHIC – and plasma physics. Both nuclear physics and plasma physics are traditional in the sense mentioned above, yet researchers in both fields would benefit from enhanced interactions. This example is only one of many.

- A forum that encourages fruitful interactions of these diverse communities and nurtures possible synergies would benefit research in the various areas of HEDP studies.

V. Agency Actions

High Energy Density Physics cuts across many traditional fields of physical science. Many of these fields are already well-established in terms of their scientific communities, peer-review mechanisms for funding, open facility access and technical reporting. Since HEDP encompasses multiple disciplines, its support crosses agency boundaries. Current HEDP-related activities are supported by the DOE, NASA, NIST, NSF, and the DOD. However, limited Federal coordination among these agencies has existed to date on the broad topic of HEDP.

Enhanced coordination among the agencies is necessary in order to nurture relationships among the range of scientific disciplines relevant to HEDP. No single agency can or should be the sole steward for this highly diverse area of study. *This Task Force asserts that the scientific frontiers should be advanced for the benefit of all the component disciplines in a manner that optimizes the Federal investment through interagency coordination.*

Action Item

Three of the four areas of HEDP research have existing mechanisms for Federal planning, management and stewardship. The scientific opportunities in these three areas should be exploited in the context of primary agency missions.

Astrophysics: NASA and NSF are the lead Federal agencies for planning, prioritizing and managing Astronomy and Astrophysics research and facilities. Participating agencies will continue to contribute in this area consistent with priorities established within their missions and by the communities they serve.

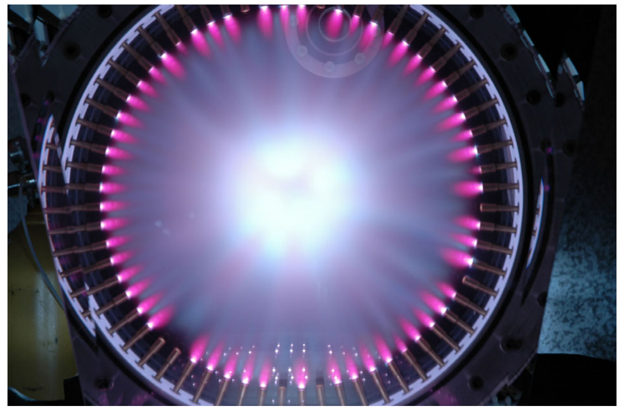
High Energy Density Nuclear Physics: DOE/NP, in collaboration with NSF, is the lead Federal organization for planning, prioritizing and managing high energy density nuclear physics, in the context of its overall Nuclear Physics Mission. Participating agencies will continue to contribute in this area consistent with priorities established within their missions and by the communities they serve.

Ultrafast, Ultraintense Laser Science: DOE/BES and NSF are the lead Federal agencies for planning, prioritizing and managing ultrafast, ultraintense laser science in the context of their missions and the communities they serve. Participating agencies will contribute in this area consistent with priorities established within their missions and by the communities they serve. It is anticipated that some studies of high energy density laboratory plasmas created using ultrafast/ultraintense lasers will be funded by NNSA and/or DOE/FES through the joint program in high energy density laboratory plasmas described below.

Action Item

Advancing research in High Energy Density Laboratory Plasmas (HED-LP) requires Federal organization and mechanisms for planning, management and merit-based, science-driven stewardship. The following actions will be implemented to address these deficiencies:

1. DOE/SC and NNSA will establish a joint program in HED-LP. This program will be responsible for stewarding fundamental high energy density laboratory plasma science within DOE. The SC Associate Director for DOE/FES and the NNSA Assistant Deputy Administrator for Inertial Confinement Fusion and the NIF Project will coordinate joint program activities within SC and NNSA, respectively. Programmatic activities involving high energy density laboratory plasmas will continue to report through their current offices. Participating agencies will continue to contribute in this area consistent with priorities established within their missions and by the communities they serve.



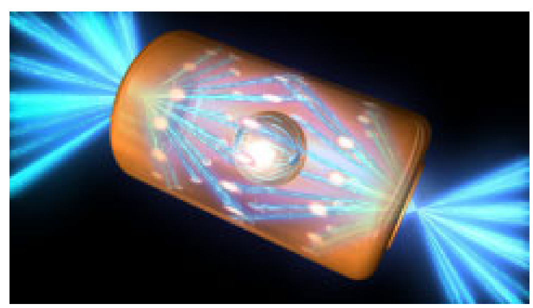
Convergence of high velocity plasma jets creates high energy density plasmas.

Credit: Courtesy of HyperV Technologies Corporation, Virginia.

2. The DOE will ensure that the joint program solicits advice from the scientific community regarding opportunities and priorities in fundamental HED-LP science.

3. The joint program, in consultation with NSF, will develop a coordinated strategic plan for a national program in fundamental high energy density laboratory plasma science.

4. The joint program will support peer-reviewed research through normal agency planning processes and joint solicitations. The initial such joint solicitation is planned for FY2008. Coordination will take place with NSF, when appropriate.



An artist's rendering of a gold cylinder or "hohlraum" approximately 1 cm in length being illuminated in the indirect drive configuration by the NIF laser. The laser beams deposit their energy on the inside surface of the hohlraum, where the energy is converted to thermal x-rays which heat and ablate the surface of the ignition capsule, causing it to implode.

Credit: Courtesy of LLNL

5. NNSA will develop management processes to provide access to major facilities by HEDP researchers external to the NNSA national laboratories. These researchers should be involved in both programmatic activities as well as fundamental high energy density laboratory plasma science of broader national interest, as the two are strongly linked. User groups and workshops should be established to inform researchers of the opportunities for HED-LP research at these major facilities. Research conducted at these user facilities should be done in a manner consistent with the mission goals of NNSA. Further information on NNSA user facility policies is contained in Appendix E.

6. Workshops will be organized to deal with specific areas of interest. In particular, DOE, NASA and NSF will sponsor a workshop on scientific opportunities in laboratory astrophysics. NASA will broaden its existing solicitation in laboratory astrophysics to include the possibility of supporting activities in high energy density laboratory plasma science applicable to NASA missions.

Strengthening university activities in high energy density laboratory plasmas will help advance the Nation's basic science mission goals and ultimately contribute to achieving major programmatic goals of DOE in nuclear weapons stewardship and fusion energy.

Action Item

Information regarding the scientific opportunities and funding mechanisms for HEDP research should be easily accessible to interested researchers. Mechanisms will be put in place to encourage and nurture synergies among the very diverse range of physical phenomena and enabling technologies that encompass HEDP. The following specific actions will be taken:

1. An interagency website will be established that provides information regarding the various mission-critical programs and their connection to HEDP with links to all the participating agencies' web sites, information on HEDP research activities, funding mechanisms, user facilities, workshops, studies, and interagency coordinating activities. This website will be maintained by the HED-LP joint program within the Department of Energy.

2. A regular, interdisciplinary, international meeting on HEDP will be organized and supported by all relevant agencies, to strengthen the collaboration among the wide-ranging subfields of HEDP and facilitate cross-fertilization. Further workshops will be organized as needed in specific areas that cut across the subfields of HEDP.

VI. APPENDICES

Appendix A. TF-HEDP Charter

Charter

of the

Task Force on High Energy Density Physics

Interagency Working Group on the Physics of the Universe
Committee on Science

National Science and Technology Council

A. Official Designation

The Task Force on High Energy Density Physics is hereby established under the auspices of the Interagency Working Group on the Physics of the Universe by action of the National Science and Technology Council (NSTC) Committee on Science (CoS).

B. Purpose and Scope

The purpose of the Task Force on High Energy Density Physics (TF-HEDP) is to advise and assist the Interagency Working Group on the physics of the Universe in developing and implementing a strategic plan for advancing non-defense scientific research in High Energy Density Physics. The TF-HEDP will provide a forum for discussion of interagency issues in High Energy Density Physics, facilitate interagency coordination, and establish priorities for the development of scientific research capabilities to address the vexing questions and opportunities in this area. Specifically, the TF-HEDP will provide guidance for implementing the recommendations of the National Task Force on HEDP as delineated in the report titled Frontiers for Discovery in High Energy Density Physics.

C. Functions may include, but are not limited to:

1. Review agency programs and plans for scientific research specifically relevant to research in HEDP.
2. Identify and recommend priorities for scientific research in HEDP.
3. Develop plans and recommendations for implementing a coordinated, multi-agency research and development agenda in this area.
4. Facilitate interagency cooperation and policy development regarding use of scientific facilities.

5. Foster the development of the research community and facilitate coordination of HEDP activities across the agencies.

The TF-HEDP will make recommendations regarding policy, research and development issues and opportunities in this area of study to the National Science and Technology Council through the Committee on Science via the Interagency Working Group on the Physics of the Universe.

D. Membership

The following NSTC departments and agencies are represented on the Task Force on High Energy Density Physics at the director or associate director level, as appropriate:

Department of Commerce, National Institute of Standards and Technology
Department of Energy
National Aeronautics and Space Administration
National Science Foundation
Smithsonian

The following organizations in the Executive Office of the President shall also be represented on the Task Force, as appropriate:

Office of the Vice President
Office of Management and Budget
Domestic Policy Council
National Economic Council
Office of Science and Technology Policy
Council on Environmental Quality

E. Private Sector Interface

The TF-HEDP may seek advice from members of the President's Council of Advisors on Science and Technology (PCAST) and will recommend to the Director of the Office of Science and Technology Policy the nature of additional private sector advice needed to accomplish its mission. The task force may also interact with and receive ad hoc advice from various private-sector groups as consistent with the Federal Advisory Committee Act (FACA).

F. Termination Date

Unless renewed by the Co-chairs of IWG on the Physics of the Universe prior to its expiration, the TF-HEDP shall terminate no later than March 31, 2009.

G. Determination

We hereby determine that the formation of the Task Force on High Energy Density Physics is in the best interests of the Interagency Working Group on the Physics of the Universe and its purpose can be best performed through the advice and counsel of such a group.

Approved:

Joseph Dehmer, Co-chair, Physics of the Universe IWG
Robin Staffin, Co-Chair, Physics of the Universe IWG
Eric Smith, Co-Chair, Physics of the Universe IWG

Appendix B. The Interagency Task Force on HEDP

NSTC Committee on Science

Co-Chairs:
Sharon Hays, Office of Science & Technology Policy
Arden Bement, National Science Foundation
Elias Zerhouni, National Institutes of Health

Interagency Working Group on the Physics of the Universe

Co-Chairs:
Michael H. Salamon, National Aeronautics & Space Administration
Joseph L. Dehmer, National Science Foundation
Robin Staffin, Department of Energy

Task Force on High Energy Density Physics

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Christopher J. Keane, Department of Energy

Executive Secretary:
Francis Thio, Department of Energy

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Appendix C Federally Supported Research and Capabilities Relevant to HEDP *

* As outlined in the Federal Research Categories: Astrophysics, High Energy Density Nuclear Physics, High Energy Density Laboratory Plasmas, and Ultrafast, Ultraintense Laser Science.

High energy density physics research and enabling capabilities have arisen through the mission critical work supported by several Federal agencies in areas ranging from space exploration to nuclear stockpile stewardship. Detailed understanding of the corresponding high energy density physics is both enabled by and important to the missions of these programs. The research and activities supported by Federal programs, a list of relevant facilities, and the relationship of the study of high energy density physics to each agency's missions are outlined below.

Department of Defense (DOD)

Air Force Research Laboratory (AFRL)

The Air Force Research Laboratory is responsible for the discovery, development and integration of affordable warfighting technologies in support of the Air Force's future and existing aerospace and space weapons systems. Within the AFRL, the Directed Energy Directorate (AFRL/DE) develops high energy lasers, high power microwaves, advanced optics, beam control and other directed energy technologies for the USAF and Department of Defense.

Three mission-critical U.S. Air Force (USAF) supported R&D areas – pulsed power, ultra-short pulse lasers, and high-energy-density materials – have connections to HEDP. The USAF operates high current pulsed power facilities such as the Shiva Star Facility which can produce extreme pressures for fractions of a second with applications to high power microwave technology, radiation sources, nuclear stockpile stewardship and other defense purposes. The USAF interest in ultra-short pulse lasers includes modest effort on laser-induced plasma channels for various purposes, such as remote sensing, target illuminators, and micro-machining. USAF also supports complementary theoretical and computational abilities and resources which have been developed and used to guide and interpret experiments.

Federal Research Categories:
High Energy Density Laboratory Plasmas
Ultrafast, Ultraintense Laser Science

Facilities:
Shiva Star – Air Force Research Laboratory on Kirtland AFB

Naval Research Laboratory (NRL)

NRL operates high energy Krypton Fluoride (KrF) laser-target facilities such as Nike, the world's highest energy KrF laser, with applications to direct-drive laser fusion energy, KrF laser research, as well as nuclear stockpile stewardship. These lasers are unique in their ability to deliver energy uniformly to their targets at smaller wavelengths than other high energy lasers. Nike is coupled with a full suite of diagnostics for HEDP research to allow studies in high-pressure hydrodynamics and equations of state, x-ray radiation from high temperature plasmas, and laser-plasma interactions. The repetitively-pulsed laser technology being developed on the NRL Electra laser under the High Average Power Laser (HAPL) program is potentially very useful for laboratory HEDP experiments. The requirements for HEDP experiments are much less stringent than for inertial fusion energy (IFE), and a repetitively-pulsed capability does not need to be expensive (e.g. while operation at 0.1 to 1 Hz is inadequate for IFE, it would represent a vast improvement in data generation capability over existing single shot facilities). This would allow single large facilities to handle many more users and would permit individual users to quickly cover a much broader range of parameters and configurations.

Federal Research Categories:
High Energy Density Laboratory Plasmas

Facilities:
Nike – Naval Research Laboratory (with NNSA)
Electra – Naval Research Laboratory (with NNSA)

Department of Energy (DOE)

Office of Science (SC)

Office of Fusion Energy Sciences (FES):
The combination of high plasma density and high plasma temperature needed for inertial fusion produces plasmas with very high energy densities, in excess of 100 billion J/m^3. The studies of these plasmas and their interaction with radiation and magnetic fields are undertaken in the FES program in HEDP, with the goal of making progress toward developing the fundamental understanding and predictability of the high energy density plasmas. The FES program in HEDP is designed to highly leverage the NNSA high energy density facilities and involves research in heavy ion beam, fast ignition, plasma jets, and dense plasmas in ultrahigh magnetic fields.

Federal Research Categories:
Astrophysics
High Energy Density Laboratory Plasmas
Ultrafast, Ultraintense Laser Science

Facilities:
Heavy Ion Fusion Science Virtual National Lab – Lawrence Berkeley National Laboratory

Office of Nuclear Physics (NP):
Searching for the predicted novel forms of matter and other new phenomena that might occur in extremely hot, dense bulk nuclear matter is one of the three major

scientific thrusts of modern nuclear physics research. At normal temperatures and densities, nuclear matter contains individual protons and neutrons (nucleons), within which the quarks and gluons are confined. However, at extremely high temperatures, such as those that existed in the early universe immediately after the "Big Bang," the quarks and gluons become deconfined and form a quark-gluon plasma. Collisions of heavy ion beams at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory create fleeting fireballs in which a tiny amount of matter is subject to the enormous temperatures and densities required for the formation of a quark gluon plasma. The distributions and properties of particles emerging from these collisions are studied for the predicted signatures of the quark-gluon plasma to establish its existence and further characterize its properties experimentally. These measurements may also shed light on several key questions in nuclear astrophysics, such as the state of nuclear matter relevant to the interior of a neutron star.

Federal Research Categories:

Astrophysics
High Energy Density Nuclear Physics

Facilities:

Relativistic Heavy Ion Collider (RHIC) – Brookhaven National Laboratory

Office of High Energy Physics (HEP):
The primary areas of interaction between HEP and high-energy-density physics involve research in supernovae simulations and novel plasma-wake field accelerator technologies performed in universities as well as several national labs. HEP work on supernovae includes simulations of the relevant particle and nuclear physics as well as the HEDP of matter and energy subject to the extraordinary gradients in temperature and pressure in the supernova shock wave. Better understanding of supernovae has wide ranging implications in high energy physics, astrophysics and cosmology, and in particular on the mystery of dark energy. HEP is currently interested in exploring the use of the extraordinarily high electric wake fields in plasma driven by a high-intensity laser or electron beam to accelerate particle beams to very high energies in a short distance. These devices have the potential to dramatically reduce the cost of advancing the energy frontier for experimental studies of the fundamental nature of matter, and to be the core technology for a new generation of more compact particle accelerators with applications ranging from nuclear physics to material science, atomic physics and the biological sciences.

Federal Research Categories:

Astrophysics
High Energy Density Laboratory Plasmas
Ultrafast, Ultraintense Laser Science

Office of Basic Energy Sciences (BES):

BES is the Federal steward of X-ray, electron, and neutron-based user facilities with applications ranging from atomic physics to the biological sciences. These facilities are open to the general scientific community and could be used to characterize high energy density (HED) matter. BES sponsors research to enable dynamic structural characterization important to advancing atomic and molecular physics, chemistry and chemical biology, and materials sciences. BES-sponsored research includes efforts to understand interactions of intense ultrafast (<1 ps = 10^{-12} s) x-ray pulses with matter for chemical and materials sciences applications. BES also supports development of tools to understand physical phenomena that occur on ultrafast timescales. BES is supporting the construction and subsequent operation of the Linac Coherent Light Source (LCLS), an ultra-bright, tunable, short-pulse x-ray free electron laser. Thus, while BES does not fund investigations of HED matter *per se*, elements of BES's mission-driven activities enable, or are enabled by, HEDP science. BES funding is provided on a peer review basis to academic institutions and national labs; currently approximately 35% of the program's research activities are sited at academic institutions.

Federal Research Categories:
Ultrafast, Ultraintense Laser Science

Facilities:
Linac Coherent Light Source – Stanford Linear Accelerator Center (SLAC)

National Nuclear Security Administration (NNSA)

Office of Defense Programs:
The NNSA is the largest supporter of facilities generating high-energy-density matter as well as their scientific applications. NNSA operates experimental facilities which can create extreme conditions of x-ray energy output (over 2.5 MJ on the pulsed power facility ZR), ultra-short-pulse laser power at significant energy (5 kJ of Petawatt power in the laser facility Omega EP, for example), and high energy and power (1.8 MJ in 192 beams on the National Ignition Facility (NIF), for example). The major scientific goals of the research at these facilities are mission critical needs such as the achievement of controlled thermonuclear ignition and burn in the laboratory and the development of scientific predictive capability for understanding nuclear weapons. In pursuing these goals, NNSA facilities are both instrumental to and critically dependent upon making progress in many thrust areas of HEDP. For example, the extreme conditions of pressure and temperature achieved by NIF will revolutionize the studies of radiation hydrodynamics, turbulent mix, and dynamic material properties. This work at NIF is complemented by NNSA-funded researchers, both at national laboratories and through university grants, who use the study of high energy density astrophysics to develop improved models of radiation hydrodynamics validated by scaled experiments at NIF. If the Office of Science LCLS is further coupled with a sufficiently high energy laser driver,

through efforts currently being considered by NNSA, it would provide the scientific community with a diagnostic tool for HED plasmas for studying photon-material interactions, generating and interrogating warm dense matter, and developing experimental techniques and diagnostics. NNSA also provides major computational resources critical for HEDP research via its Advanced Strategic Computing (ASC) Campaign computers such as Q, Purple, Blue Gene/Lighting, or the upcoming Roadrunner. Researchers use NNSA-funded computers and codes in such areas as radiation hydrodynamics, dynamic materials, and wave-particle interactions.

Federal Research Categories:

Astrophysics
High Energy Density Laboratory Plasmas
Ultrafast, Ultraintense Laser Science

Facilities:

NNSA High Energy Laser Facilities:

National Ignition Facility – Lawrence Livermore National Laboratory
Omega Laser Facility – University of Rochester
Omega EP – University of Rochester
Z-Beamlet – Sandia National Laboratory
Trident Laser Laboratory – Los Alamos National Laboratory
Jupiter – Lawrence Livermore National Laboratory

NNSA High Intensity / Short Pulse Laser Facilities:

Z Petawatt – Sandia National Laboratory
Trident Laser Laboratory – Los Alamos National Laboratory
Jupiter Laser – Lawrence Livermore National Laboratory
Texas Petawatt – University of Texas in Austin

NNSA Pulsed Power Facilities:

ZR Pulsed-Power Accelerator – Sandia National Laboratories
COBRA – Cornell University
ZEBRA – University of Nevada, Reno

National Aeronautics and Space Administration (NASA)

NASA's observatories provide a wealth of information regarding various astrophysical sources that push the frontiers of high energy density physics. In return, laboratory HEDP experiments provide information critical to understanding what is observed in the sky. Thus the Hubble Space Telescope, the Chandra X-ray Observatory, the Spitzer Space Telescope, future major space observatories, and other space missions provide details of complex phenomena whose accurate representations pose substantial challenges to HEDP models and often require the knowledge of parameters that can only be measured in the laboratory. In addition to experiments, theoretical investigations and numerical simulations play an essential role in both HEDP and high-energy-density astrophysics (HEDA). NASA provides support for such theoretical studies within its general Astrophysics Theory Program (ATP) and the Beyond Einstein Foundation Science (BEFS) Program. NASA also provides support for laboratory-based astrophysics in its Astronomy and Physics R&A (APRA) program. The major observatories, such as HST and Chandra, also have their own analysis grant programs which support theoretical and numerical studies related to the data of the given observatory.

Federal Research Categories:
Astrophysics
High Energy Density Nuclear Physics
High Energy Density Laboratory Plasmas

Facilities (operating Astrophysics Major Observatories):
Hubble Space Telescope (HST)
Chandra X-Ray Observatory (CXO)
Spitzer Space Telescope (SST)

National Institute of Standards and Technology (NIST)

NIST provides some of the x-ray data, metrology, and metrological tools used in the field of high-energy-density physics. NIST's small scale Electron Beam Ion Trap (EBIT) facility can produce very hot, highly ionized, but low density plasmas and has been used in support of laboratory astrophysics and fusion energy research. Research at this facility has involved a substantial number of university students, postdocs, and professors, so it may also have a role to play in developing a user community and training students for HEDP research. NIST has designed, built, and deployed core x-ray diagnostic spectrometers on Omega, Titan, and several other large lasers used in HEDP research. Microcalorimeters are being developed and tested for x-ray astronomy. Calibration services are available in the EUV spectral range using NIST's Synchrotron Ultraviolet Radiation Facility (SURF) and in the x-ray regime using standard reference spectra and measurement of exposure. A wide variety of tabletop laser research at NIST includes the use of femtosecond lasers and frequency combs to directly produce high harmonics.

Federal Research Categories:
Astrophysics
High Energy Density Laboratory Plasmas
Ultrafast, Ultraintense Laser Science

Facilities:
Center for High Resolution Atomic Spectroscopy and X-ray Metrology
Electron Beam Ion Trap (EBIT)
Synchrotron Ultraviolet Radiation Facility (SURF)

National Science Foundation (NSF)

The National Science Foundation (NSF) is an independent Federal agency created by the National Science Foundation Act of 1950, as amended (42 USC 1861-75). The Act states the purpose of the NSF is "to promote the progress of science; [and] to advance the national health, prosperity, and welfare by supporting research and education in all fields of science and engineering."

NSF funds research and education in most fields of science and engineering. It does this through grants and cooperative agreements to more than 2,000 colleges, universities, K-12 school systems, businesses, informal science organizations and other research organizations throughout the US. The Foundation accounts for about one-fourth of Federal support to academic institutions for basic research.

Directorate for Mathematical and Physical Sciences:

Divisions of Physics, Astronomical Sciences, Materials Sciences, Chemistry, and Mathematics

In fulfilling its broader mission in promoting the progress of science, the NSF supports basic research in high energy density physics as it relates to particular subfields of physics such as astrophysics, atomic molecular and optical physics, physical chemistry, condensed-matter physics, and plasma science. As part of the NSF/DOE (FES) Partnership in Basic Plasma Science and Engineering, NSF supports research in fundamental physics of plasmas, including transport in plasmas in confined magnetic structures, non-neutral plasmas in traps, and high-field laser-plasma interactions. NSF support in these research areas is funded primarily at universities.

Federal Research Categories:

- Astrophysics
- High Energy Density Nuclear Physics
- High Energy Density Laboratory Plasmas
- Ultrafast, Ultraintense Laser Science

Facilities

NSF Ground-based telescopes:

- National Optical Astronomy Observatory (NOAO)
- National Radio Astronomy Observatory (NRAO)
- National Astronomy and Ionosphere Center (NAIC)

NSF Synchrotron radiation facilities:

- Cornell High Energy Synchrotron Radiation Center – Cornell University
- Synchrotron Radiation Center – University of Wisconsin

NSF University-based ultra-fast, ultra-intense laser laboratories:

- Frontiers in Optical, Coherent, and Ultrafast Science (FOCUS) Physics Frontiers Center – University of Michigan

Appendix D. Cross-Cutting Interests in HEDP

Representatives from each of the TF-HEDP participating Federal agencies reviewed the science research thrusts laid out in the 2004 NTF-HEDP *Frontiers for Discovery in HEDP* report. They identified the respective agency's mission relevance and interests related to those science thrusts, and identified the thrusts for which the agency was a primary Federal sponsor or thrusts for which they supported related research.

These tables represent a significantly abbreviated list of topics and cross-cutting interests prepared by the Federal agencies with the purpose of being illustrative rather than comprehensive. The Other Agency Interest column lists the agencies that have the identified cross-cutting interests in the research supported by the Lead Agency or the products of that research; these agencies may also directly fund research in the cross-cutting research area.

Astrophysics

Research Thrust Area	Lead Agency	Mission	Topics	Cross-Cutting Interests	Other Agency Interest
1. Astrophysical Phenomena	NASA, NSF	Astrophysical observation	Astrophysical HED plasmas	Compact astrophysical objects, stellar evolution	NSF, DOE/HEP
				Origin and evolution of structure in the universe	NASA, NSF, DOE/HEP
				MHD instabilities, plasma acceleration	NNSA, DOE/FES
2. Fundamental Physics of HED Astrophysical Phenomena	NASA	Astrophysical observation	Neutron star mass-radius relation	Nuclear equations of state	DOE/HEP
			Accretion disks	Highly ionized atoms	NSF, NIST
			Interstellar clouds	Molecular physics relevant to astronomy	NSF, NIST

High Energy Density Nuclear Physics

Research Thrust Area	Lead Agency	Mission	Topics	Cross-Cutting Interests	Other Agency Interest
6. Characterization of Quark-Gluon Plasmas	DOE/NP	Nuclear physics	QGP and new states of nuclear matter	Cosmology	NASA, NSF, DOE/HEP
				Interior of neutron stars	NASA
				Cosmic ray air showers, particle accelerators	NSF, DOE/HEP

High Energy Density Laboratory Plasmas

Research Thrust Area	Lead Agency	Mission	Topics	Cross-Cutting Interests	Other Agency Interest
3. Laboratory Astrophysics	NSF	Basic astrophysics	Laboratory astrophysics	• Validation of astrophysical models	NASA, NIST, DOE/NP, DOE/HEP
				• The solar dynamo	NASA
				• Validation of radiation hydrodynamics models	NNSA, DOE/FES, NASA
4. Heavy-Ion-Driven HEDP and Fusion	DOE/FES	Fusion Energy	High-brightness ion beams	• Accelerator science and technology; ion sources	DOE/HEP, DOE/NP, NSF
				• Inertial fusion target design and fabrication	NNSA
				• Creation of warm dense matter using ion beams	NNSA
5. HED Physics with Ultrarelativistic Electron Beams	DOE/HEP	Advanced accelerators	Plasma wake field acceleration	• Charged particle acceleration and sources	DOE/FES, NSF
7. Materials Properties	NNSA	Stockpile Stewardship Program	Fracture, failure predictive capability	• First principles models of fracture and failure	DOE/BES, NSF
				• Nanoscale materials structures / inhomogeneities	DOE/BES, NSF
				• Atomic scale materials structure and evolution	DOE/BES, NIST, NSF
				• Characterization of new nanoscale materials	DOE/BES, NIST
			Warm, dense matter, opacities and EOS	• Stellar opacities	NASA, DOE/FES
				• Planetary science (EOS)	NSF, NASA
				• Fundamental condensed matter physics	NSF
				• Condensed matter in extreme conditions	DOE/BES, NSF, NIST
8. Compressible Dynamics	NNSA	Stockpile Stewardship Program	Compressible nonlinear flows	• Mix and turbulence in astrophysics, supernovae	NASA, NSF, DOE/FES
				• Multiphase phase fluid flow, granular materials	NSF
				• Nonlinear dynamics	NSF, DOE/FES
9. Radiative Hydrodynamics	NNSA	Stockpile Stewardship Program	Radiative hydrodynamics	• Astrophysical radiative hydrodynamics, type II supernovae	NASA, NSF, DOE/FES
			X-ray generation using short pulse lasers	• Fast particle generation; fast ignition	DOE/FES
				• Compact accelerators	DOE/HEP, DOE/FES
				• Ultrashort pulse x-ray generation	DOE/BES, DOE/FES
10. Inertial Confinement Fusion	NNSA	Stockpile Stewardship Program	Burn physics	• Inertial confinement fusion	DOE/FES
			ICF targets	• Novel materials through nanoscience	DOE/FES
			Effects	• Modeling radiation effects in materials	DOE/BES, DOE/FES
15. Inertial Fusion Fast Ignition	DOE/FES	Fusion Energy	Short-pulse laser plasma heating	• Fast particle generation, warm dense matter	NNSA

Ultrafast, Ultraintense Laser Science

Research Thrust Area	Lead Agency	Mission	Topics	Cross-Cutting Interests	Other Agency Interest
11. Laser Excitation of Matter at the Relativistic Extreme	NSF	Basic Atomic Physics	Atoms in intense electromagnetic fields	▪ Nonlinear response of isolated atoms to intense ultra-short electromagnetic fields	DOE/BES
12. Attosecond Physics	DOE/BES	Ultrafast Science	Ultrafast chemical and materials science	▪ Characterization of novel energetic materials.	NNSA
				▪ Time-resolved molecular dynamics	NSF, NNSA, NIST
				▪ Single atom/molecule manipulation	NIST, NSF
13. Ultrafast, High Peak-Power X-Rays	DOE/BES	X-ray sources, ultrafast science	Dynamic structural characterization	▪ Nano-scale materials dynamics	NNSA, NSF
				▪ Pulsed x-ray diagnostics	DOE/FES, NNSA, NIST
				▪ Extreme non-linear optics	NIST, NSF
14. Compact High Energy Particle Acceleration	DOE/HEP	Advanced accelerators	Laser acceleration of particles	▪ Particle acceleration for warm dense matter	NNSA, DOE/FES
				▪ Accelerator research and development	NSF, DOE/FES

Appendix E. NNSA User Facility Programs

Facility Use Policies for major NNSA HEDP facilities

As part of the ongoing Complex 2030 effort to transform the weapons complex, NNSA is developing a policy for the operation of its HEDP facilities as national, shared facilities for programmatic and external user needs. The major facilities covered under this new policy are: the National Ignition Facility (NIF) at the Lawrence Livermore National Laboratory (LLNL), Omega/Omega EP at the Laboratory for Laser Energetics (LLE) at the University of Rochester,* and the ZR/Z-Beamlet/Petawatt at Sandia National Laboratories (SNL).

Although the primary mission of these facilities is weapons and ignition physics in support of the Stockpile Stewardship Program (SSP), these facilities will also support research in inertial fusion energy and basic science in HEDP. In addition to user groups from programs at the Defense Program (DP) national laboratories, user groups representing DOD contractors, fusion energy researchers, scientists from academia, and international users sanctioned by DP will also have access to the NNSA HEDP facilities. The policy is intended to address the optimal use of NNSA's HEDP facilities in the context of this broader user community of the future.

Under the new policy, each facility will have a Facility Director who will be accountable for the quality of work and for the management systems required to maintain a user community supporting both the applied and basic science missions. The Facility Director will develop and implement a governance plan that defines the procedures and creates the advisory committees that will be used for proposal solicitation and review, and for allocation of system shot time.

A committee including broad representation from the academic community will be used to review proposals in the basic science area. In addition to the quality of science, the proposals will be judged for the feasibility of execution, the uniqueness of the facility to perform the experiment, and the impact of the experiment on the facility. To aid the development of proposals and enable the growth of the various user communities, each facility will have a user support group that will provide technical information and support to users for planning and conducting experiments.

NNSA expects that intermediate-scale facilities will also be covered under this policy: Trident at the Los Alamos National Laboratory (LANL), Jupiter Facility at LLNL, the Nevada Terawatt Facility (NTF) at University of Nevada at Reno, and other NNSA-funded facilities as appropriate. A small pilot program soliciting proposals for intermediate-scale facilities was recently initiated and the first awards will be made in FY2007.

In general, allocation of system shot time on NNSA HEDP facilities for science in support of other national missions is expected to be up to 15% annually. System shot time availability will depend on specific programmatic demands as well as system maturity, operational optimization, and scientific opportunity.

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* An external user access program for Omega has been in place and funded since 1979. The National Laser User's Facility User's Guide for this facility can be found at the following website: http://www.lle.rochester.edu/

Acronym List

2004 POU	*A 21st Century Frontier of Discovery: The Physics of the Universe*
AFRL	Air Force Research Laboratory
APRA	Astronomy and Physics R&A Program at NASA
ASC	Advanced Strategic Computing Campaign at NNSA
ATP	Astrophysics Theory Program at NASA
BEFS	Beyond Einstein Foundation Science Program at NASA
BES	Office of Basic Energy Sciences in DOE/SC
BNL	Brookhaven National Laboratory
CoS	Committee on Science
CXO	Chandra X-Ray Observatory
DOD	Department of Defense
DOE	Department of Energy
EBIT	Electron Beam Ion Trap
EOS	Equation of State
ESA	European Space Agency
FACA	Federal Advisory Committee Act
FES	Office of Fusion Energy Sciences in DOE/SC
FOCUS	Frontiers in Optical, Coherent, and Ultrafast Science
HED	High Energy Density
HED-LP	High Energy Density Laboratory Plasmas
HEDP	High Energy Density Physics
HEDP/X-Games	*High Energy Density Physics: The X-Games of Contemporary Science*
HEP	Office of High Energy Physics in DOE/SC
HST	Hubble Space Telescope
DOE/NNSA-ICF	Inertial Confinement Fusion Program at DOE/NNSA
IWG-POU	Interagency Working Group on the Physics of the Universe
KrF	Krypton-Fluoride
LANL	Los Alamos National Laboratory
LBNL	Lawrence Berkeley National Labs
LCLS	Linac Coherent Light Source at SLAC
LLE	Laboratory for Laser Energetics at the University of Rochester
LLNL	Lawrence Livermore National Laboratory
MHD	Magneto-hydrodynamics
MPS	Directorate for Mathematical and Physical Sciences at NSF
NAIC	National Astronomy and Ionosphere Center
NASA	National Aeronautics and Space Administration
NIF	National Ignition Facility at Lawrence Livermore National Laboratory
NIST	National Institute of Standards and Technology
NNSA	National Nuclear Security Administration in DOE
NOAO	National Optical Astronomy Observatory
NP	Office of Nuclear Physics in DOE/SC
NRAO	National Radio Astronomy Observatory
NRL	Naval Research Laboratory
NSF	National Science Foundation
NSF/AST	Division of Astronomical Sciences in NSF/MPS
NSF/PHY	Division of Physics in NSF/MPS
NSTC	National Science and Technology Council
NTF	Nevada Terawatt Facility
NTF-HEDP	National Task Force on High Energy Density Physics
OSTP	Office of Science and Technology Policy
PCAST	President's Council of Advisors on Science and Technology
QGP	Quark-Gluon Plasma
Quarks to Cosmos	*Connecting Quarks with the Cosmos: Eleven Science Questions for the New Century*
RHIC	Relativistic Heavy Ion Collider at Brookhaven National Laboratory
SAULL	The Science and Applications of Ultrafast, Ultraintense Lasers
SC	Office of Science in DOE
SLAC	Stanford Linear Accelerator Center
SNL	Sandia National Laboratories
SSP	Stockpile Stewardship Program at NNSA
SST	Spitzer Space Telescope
SURF	Synchrotron Ultraviolet Radiation Facility at NIST
TF-HEDP	Task Force on High Energy Density Physics
USAF	U. S. Air Force

Report of the Interagency Task Force on High Energy Density Physics

National Science and Technology Council
Committee on Science
Interagency Working Group on the Physics of the Universe

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