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OFFICE OF SCIENCE

Fusion Energy Sciences
Overview

Presented at the Workshop on

Large Scale Computing and Storage Requirements for Fusion Energy Sciences

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Office of Fusion Energy Sciences
Office of Science
U.S. Department of Energy

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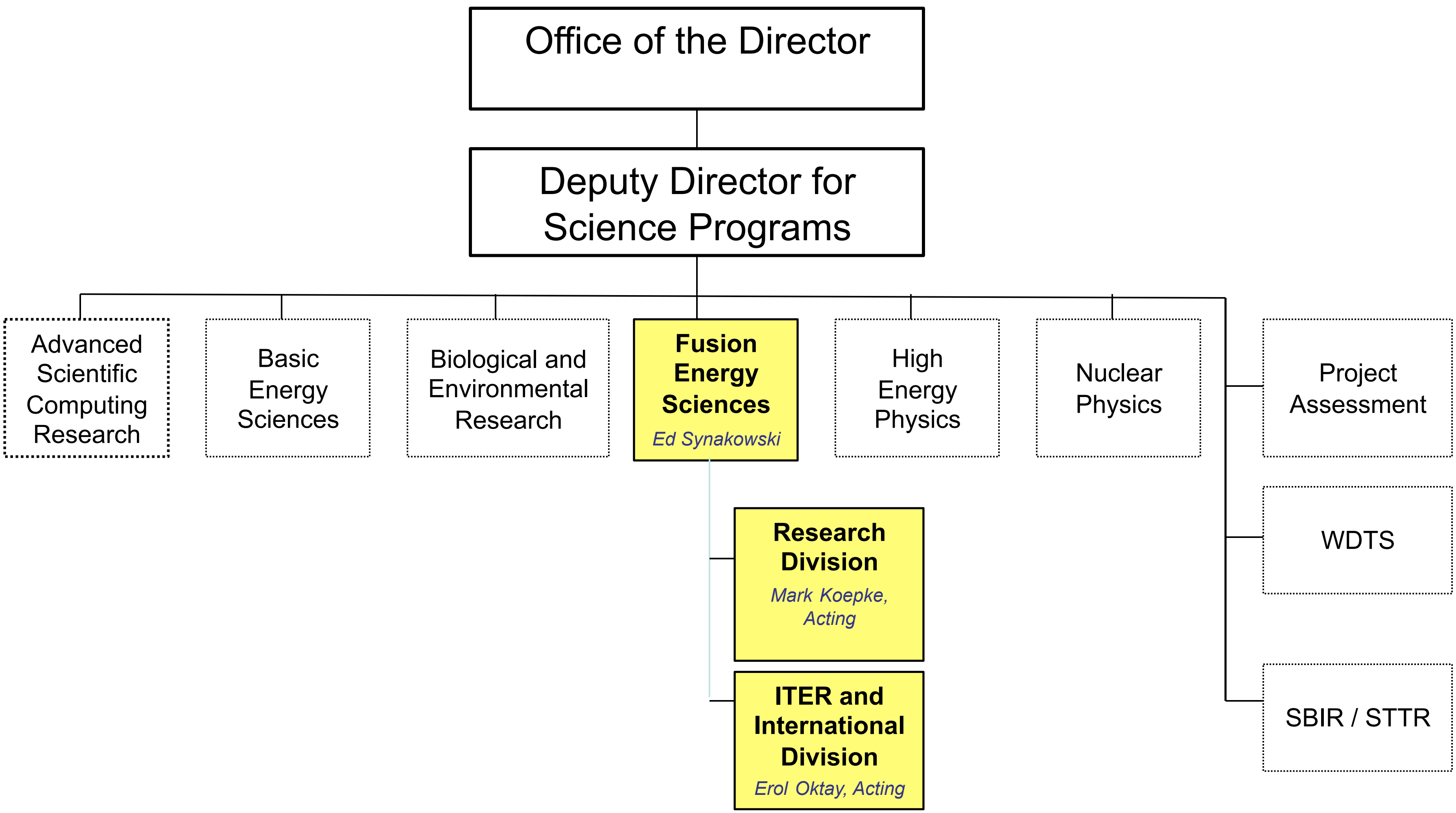
DOE Office of Science and FES



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FES Mission & Goals

FES Mission

The mission of the Fusion Energy Sciences (FES) program is to expand the fundamental understanding of matter at very high temperatures and densities and to build the scientific foundations needed to develop a fusion energy source. This is accomplished by studying plasmas under a wide range of temperature and density conditions, developing advanced diagnostics to make detailed measurements of plasma properties, and creating theoretical and computational models to resolve the essential physics ideas and principles.

Goals

- Advance the fundamental science of magnetically confined plasmas to develop the predictive capability needed for a sustainable fusion energy source
- Pursue scientific opportunities and grand challenges in high-energy-density plasma science to explore the feasibility of the inertial confinement approach as a fusion energy source, to better understand our universe, and to enhance national security and economic competitiveness
- Support the development of the scientific understanding required to design and deploy the materials needed to support a burning plasma environment; and
- Increase the fundamental understanding of basic plasma science, including both burning plasma and low temperature plasma science and engineering, to enhance economic competiveness and to create opportunities for a broader range of science-based applications

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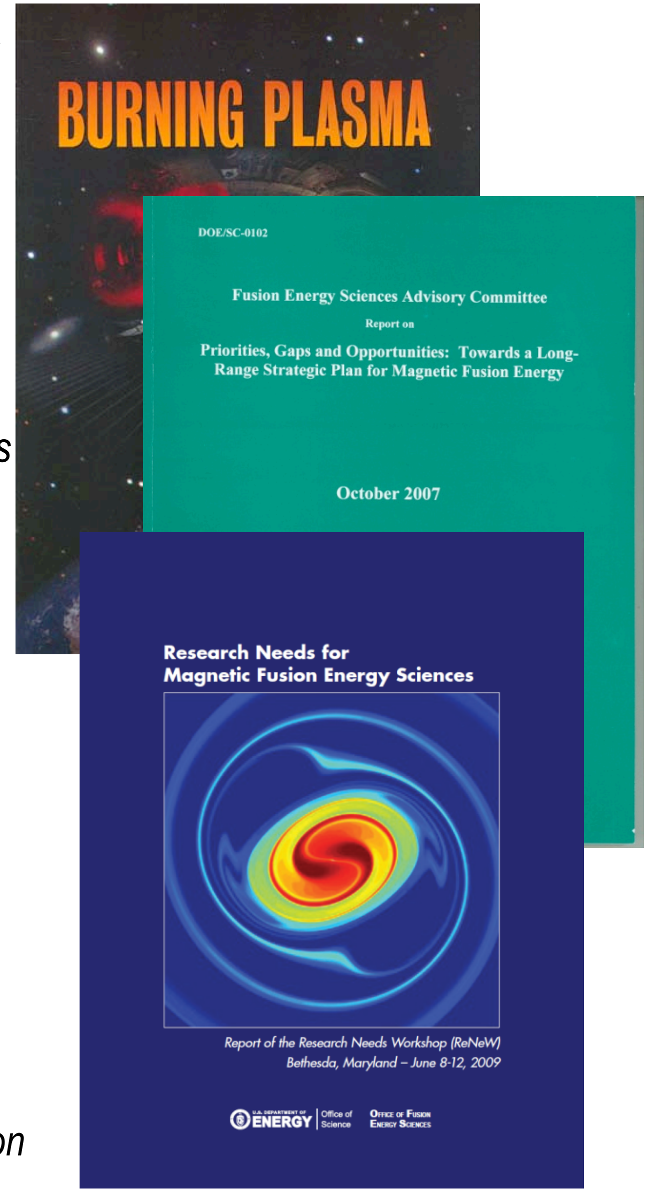
Magnetic Fusion Energy Sciences

Advance the fundamental science of magnetically confined plasmas to develop the predictive capability needed for a sustainable fusion energy source

- **ITER** – the world's first burning plasma experiment
  - *Explore regime of self-sustained plasmas*
- **National Facilities** – DIII-D, NSTX, C-Mod
  - *Provide world-class experimental facilities to build the predictive science needed for ITER and burning plasmas and deliver solutions to high priority ITER technical issues*
- **ICC –** ~25 small-scale experiments
  - *Explore improved pathways to practical fusion power & deepen scientific foundations of understanding and improving tokamak concept*
- **Theory**
  - *Advance scientific understanding of fundamental processes governing the behavior of magnetically confined plasmas*
- **SciDAC**
  - *Advance science of magnetic confinement by exploiting HPC resources*
- **FSP**
  - *Develop an experimentally validated, integrated predictive simulation capability for burning plasmas*



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Role of Advanced Simulations in MFES

FES SciDAC Portfolio

- Advance scientific discovery in fusion plasma science by exploiting the emerging capabilities of petascale computing and associated progress in software and algorithm development
  - *How does turbulence cause heat, particles, and momentum to escape from plasmas?*
  - *How does magnetic field structure impact fusion plasma confinement?*
  - *How do electromagnetic waves and energetic particles interact with the plasma?*
  - *How can RF waves be used to control & mitigate MHD instabilities?*
  - *How does the edge region affect plasma performance?*
  - *How do we develop a framework to model the closely coupled core and edge regions in tokamak plasmas?*

Fusion Simulation Program (FSP)

- An initiative to develop a validated integrated predictive simulation capability for magnetically confined fusion plasmas in the regimes and geometries relevant for practical fusion energy
- Two-year planning study to be completed by mid-2011; full program will be launched in late FY 2011 / FY 2012

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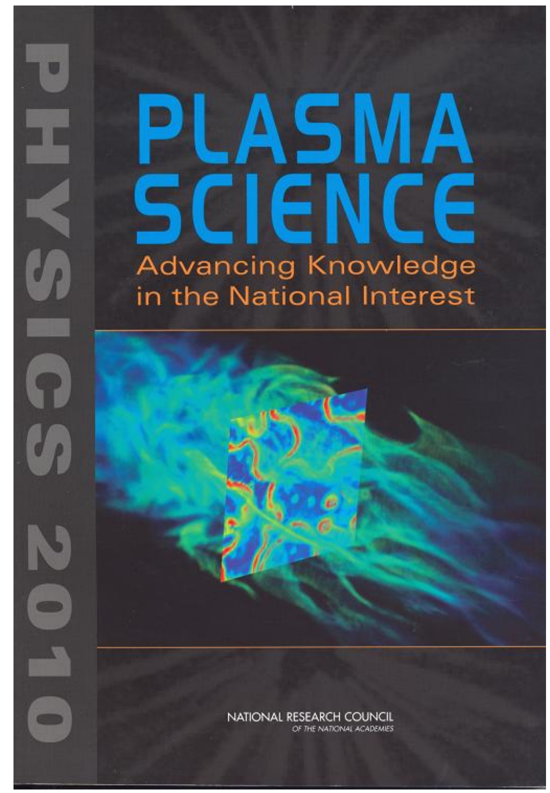
Plasma Science

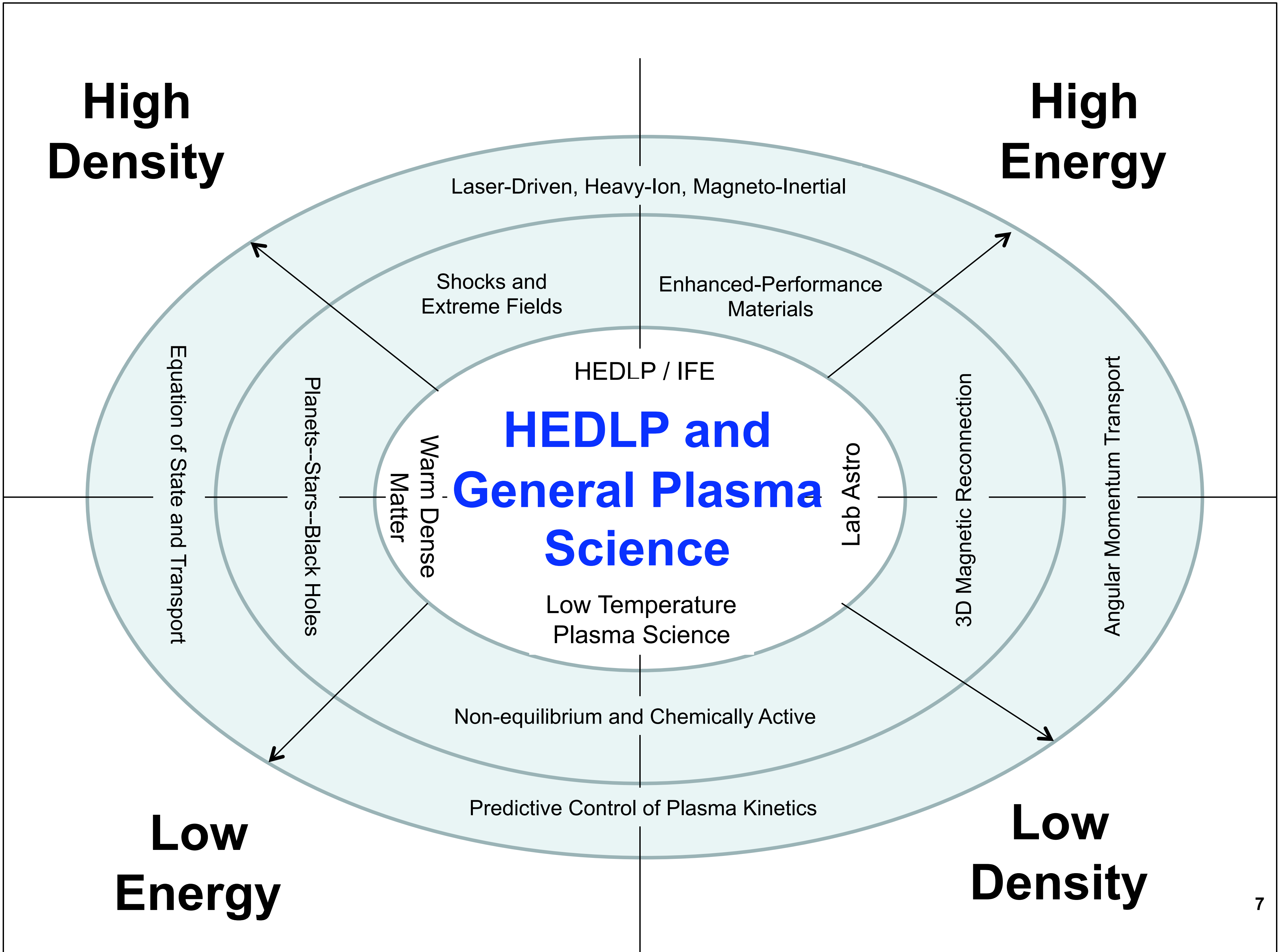
Plasma science has a coherent intellectual framework unified by physical processes that are common to many subfields of science and engineering and, therefore, it is more than a basket of applications

Grand challenges span the thematic spectrum:

- high-energy and low-energy density plasmas
- low temperature plasma science & engineering
- magnetic fields in plasmas
- micro-plasma behavior
- atomic processes in plasmas
- plasma astrophysics
- laser-produced plasmas
- warm dense matter
- ultra-cold plasmas
- complex and single-component plasmas
- nonlinear dynamics
- plasma effects in solids



Joint programs with NNSA (SC/NNSA program in HEDLP) and NSF (NSF/ DOE Partnership in Basic Plasma Science and Engineering) advance the General Plasma Science and HEDLP missions


High Density
High Energy
Laser-Driven, Heavy-Ion, Magneto-Inertial
Shocks and Extreme Fields
Enhanced-Performance Materials
HEDLP / IFE
HEDLP and General Plasma Science
Equation of State and Transport
Planets--Stars--Black Holes
Warm Dense Matter
Lab Astro
3D Magnetic Reconnection
Angular Momentum Transport
Low Temperature Plasma Science
Non-equilibrium and Chemically Active
Predictive Control of Plasma Kinetics
Low Energy
Low Density

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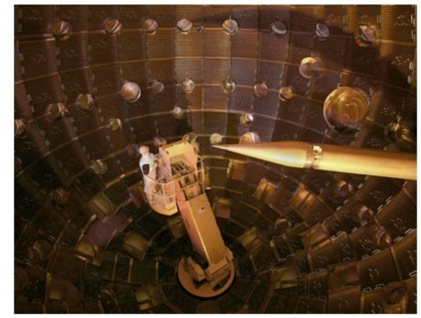
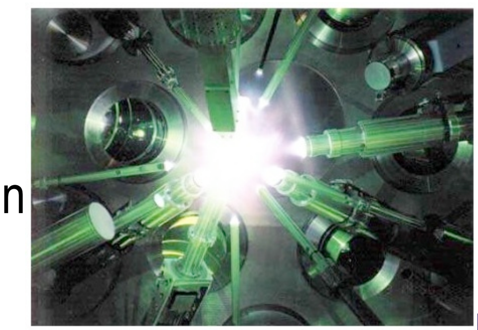
HEDLP has fusion energy science as a major centerpiece, but is broader

- Unique opportunity with imminent full-scale National Ignition Facility research, but contributions from both large and small facilities can be essential
- Physics reach: extreme states of matter associated with exploding stars, interiors of giant planets
- The science of extreme astrophysical phenomena are common to the inertial fusion realm
  - High energy density hydrodynamics
  - Nonlinear optics
  - Relativistic HED plasma and intense beam physics
  - Magnetized HED plasma physics
  - Radiation-dominated HED plasma physics
  - Warm dense matter physics



NIF

Omega-EP



M. Koepke

Materials Science

- Support the development of the scientific understanding required to design and deploy the materials needed to support a burning plasma environment
  - **Plasma/surface interactions**: establishing boundary of a fusion plasma. Plasma facing surface survival, renewal: cracking, annealing. Fuel retention. Important for industrial, non-energy applications as well
  - **Nuclear effects on materials and structures**, including the effects of > 100 dpa on structure integrity, helium creation in situ, and time evolving properties
  - **Harnessing fusion power** depends on the nuclear material science above and is extended to tritium breeding and extracting fusion power

Ed Synakowski, FESAC 2010

- The role of simulations is expected to be significant (materials by design?)
- Opportunities for leverage within SC and across DOE

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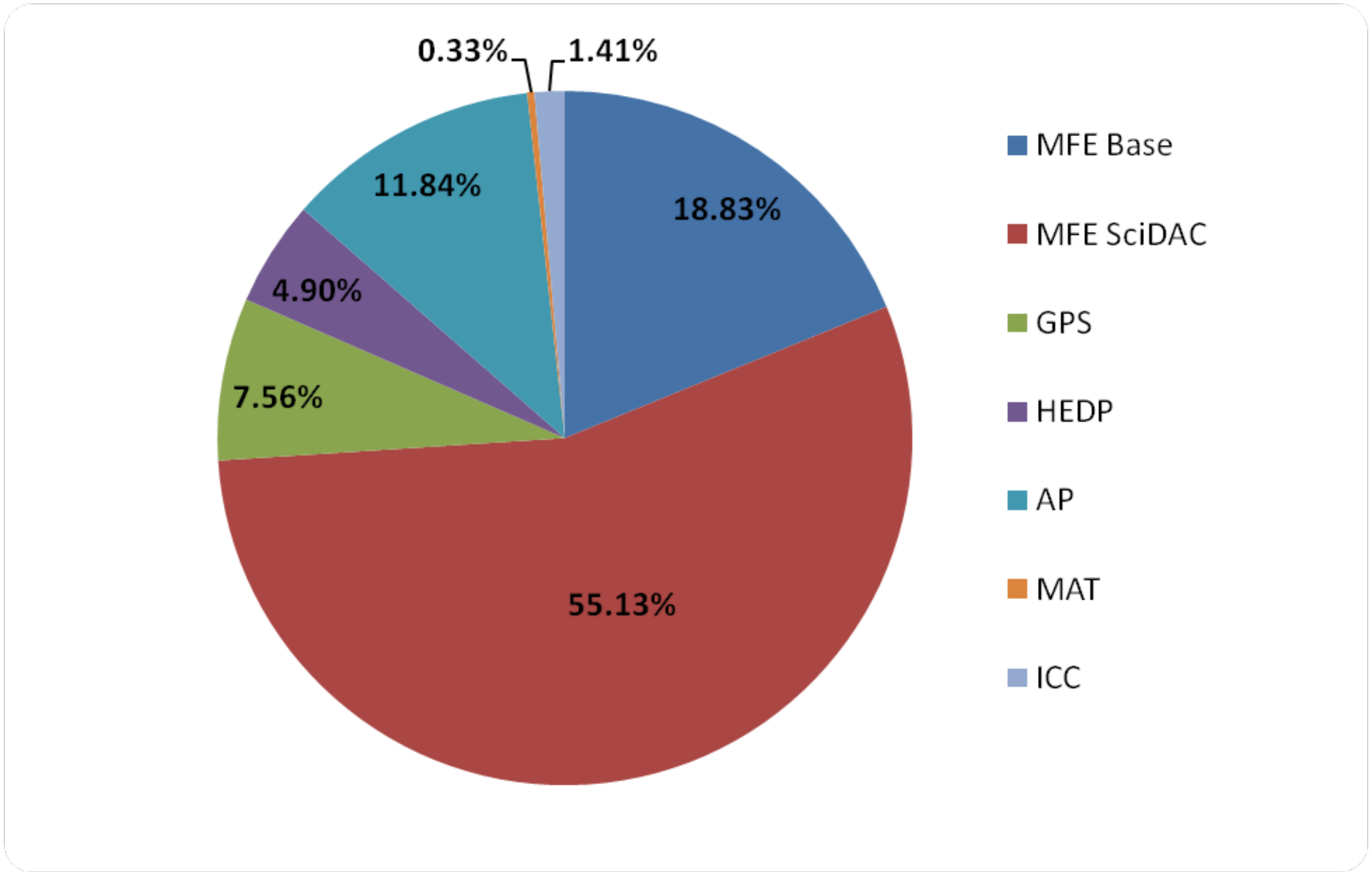
FES and NERSC

- From the days of the National Magnetic Fusion Energy Computer Center (MFECC) in the mid-1970's—the predecessor of NERSC—High Performance Computing (HPC) and NERSC have played a significant role in fusion energy research

NATIONAL MFE COMPUTER CENTER

- In AY 2010, **44,711K** Processor Hours have been allocated to **61** FES repositories:
  - MFE Base: 24
  - MFE SciDAC: 13
  - GPS: 8
  - ICC: 6
  - HEDP: 5
  - Atomic Physics (AP): 3
  - MAT 2

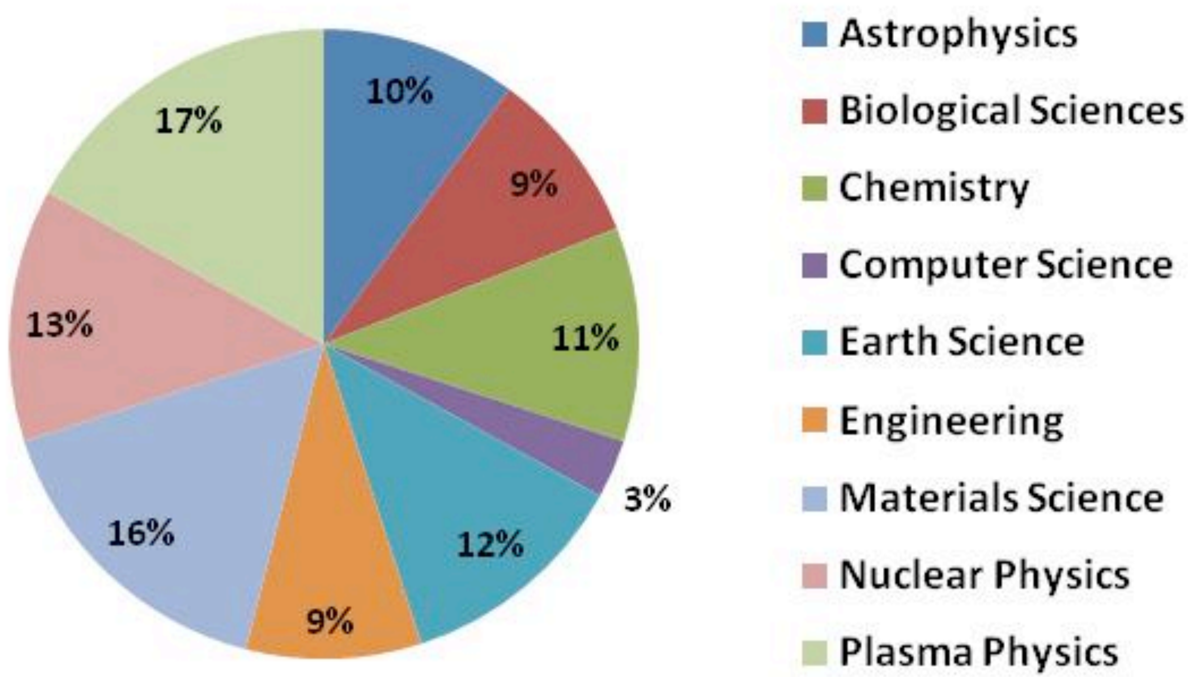
AY 2009 Topical Usage Distribution



FES & INCITE

2010 INCITE Allocations

- Fusion and plasma scientists are among the largest users of INCITE resources



Source: *Julia C. White ASCAC presentation, 3/30/10*