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# Fusion Energy Sciences Program
## Summary & Status

### Presented at the DOE Technical Program Review on Large Scale Production Computing and Storage Requirements for Fusion Energy Sciences: Target 2017


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*Fusion Energy Sciences*
*Office of Science*
*US Department of Energy*


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# 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.

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# FES Strategic Goals

- Advance the fundamental science of magnetically confined plasmas to develop the predictive capability needed for a sustainable fusion energy source
- Support the development of the scientific understanding required to design and deploy the materials needed to support a burning plasma environment
- 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
- 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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# FES Strategic Goals

- **Advance the fundamental science of magnetically confined plasmas to develop the predictive capability needed for a sustainable fusion energy source** ← ***Magnetic Fusion Energy Science (MFES)***
- Support the development of the scientific understanding required to design and deploy the materials needed to support a burning plasma environment
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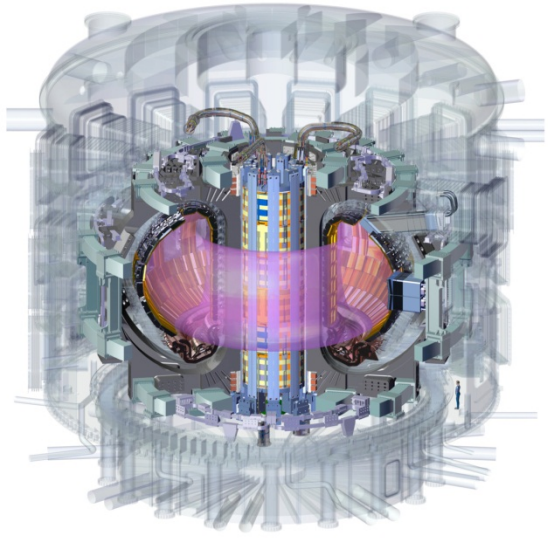
# MFES - ITER

- World's first burning plasma experiment
  - Enable the creation & study of self-heated plasmas
- ITER's mission: demonstrate the scientific and technological feasibility of fusion energy
- Being built in Cadarache, France, by an international consortium (U.S., China, India, Japan, South Korea, Russian Federation, & EU)
- First plasma expected ~ 2020

*Status of ITER site – February 2013*



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# ITER Physics R&D Needs

| Area | Issues |
|---|---|
| **MHD Stability** | • Disruption Mitigation System (DMS)<br>• Error field control<br>• RWM / locked modes control by ELM coils |
| **Divertor & Plasma-Wall Interactions** | • All metal wall for DT phase (Be first wall & W divertor)<br>• Heat Fluxes to PFCs<br>• W performance<br>• material migration, fuel (T) retention, dust |
| **Pedestal Physics** | • ELM Control<br>• Pedestal Characteristics<br>• H-mode access |
| **Confinement & Transport** | • H-mode access / exit<br>• Particle / impurity transport<br>• Rotation & momentum transport<br>• Model validation |
| **Integrated Operating Scenarios** | • Investigation of candidate hybrid & steady-state scenarios<br>• Heating & Current Drive scenario validation<br>• Integrated plasma control capability |
| **Energetic Particle Physics** | • Fast ion transport, redistribution, & loss<br>• Prediction & control of Alfvén Eigenmodes |

*David Campbell, ITER Directorate for Plasma Operation (POP), ITPA meeting, December 2012*

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# ITER Physics R&D Needs - 2

- **US MFES efforts strongly focused on addressing ITER Physics R&D needs**
  - Consistent with ITER Organization's (IO) expectation to rely on its members for resolving physics issues
- **High fidelity simulations critical during ITER operations**
  - Each ITER shot may cost ~$1M
  - Experimental proposals expected to be accompanied by modeling justification to ensure machine integrity and consistency with ITER's capabilities
- **NERSC resources critical for advancing this mission:**
  - Large fraction of NERSC MFES repository allocation used to address—directly and indirectly—ITER Physics R&D needs
  - The FES 7 SciDAC Centers—major users of NERSC resources—are well aligned with ITER priorities
  - Need for NERSC allocations expected to rise as ITER first plasma date approaches and a formal ITER research program is initiated, and as demand for higher fidelity / more integrated simulations increases

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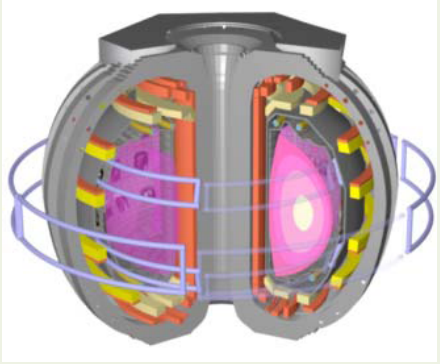
# MFES – Major User Facilities

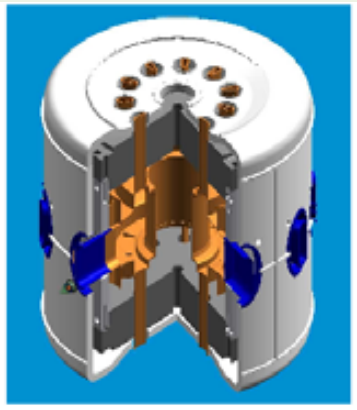
The major FES magnetic confinement **user facilities** provide the essential tools for the U.S. research community to explore and solve fundamental issues of fusion plasma physics. In addition, research at these facilities focuses on developing the predictive science needed for ITER operations and providing solutions to high-priority ITER technical issues.

DIII-D NATIONAL FUSION FACILITY SAN DIEGO



NSTX-U

Alcator C-Mod



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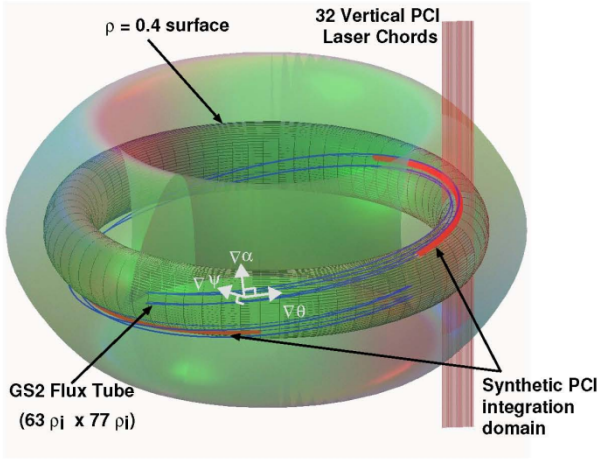
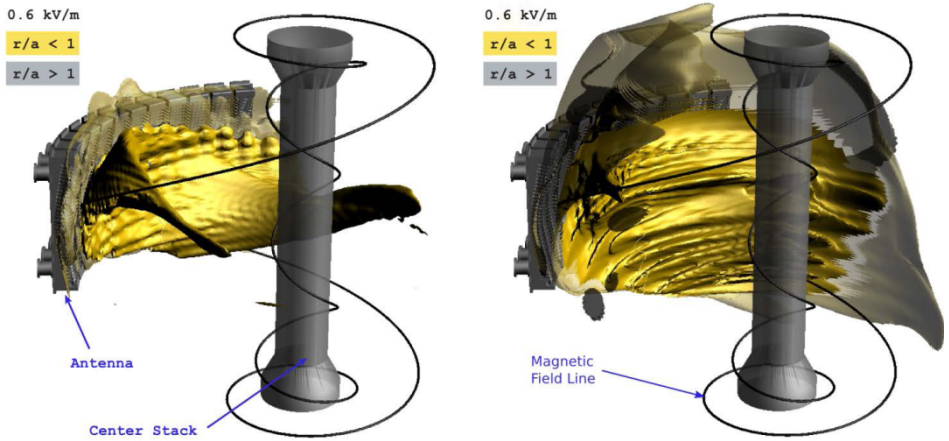
# User Facilities & NERSC

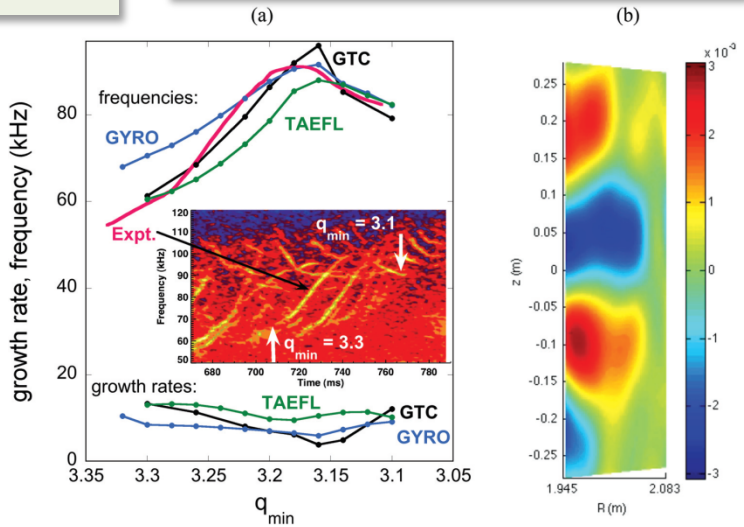
- While local computing resources at each facility are still used for supporting day-to-day operations and between-shot analysis, NERSC resources are becoming increasingly important for validation studies
- A significant fraction of the MFES repo allocation is used for simulations supporting each facility's experimental program as well as joint coordinated activities, such as the annual FES Joint Research Target (JRT)
- Need is expected to increase as more computationally demanding, high physics fidelity models are employed in the validations studies




*GS2 TEM simulations on C-Mod*




***CSWPI**: 3D RF simulations for NSTX*




*Alfvén mode simulations on DIII-D*

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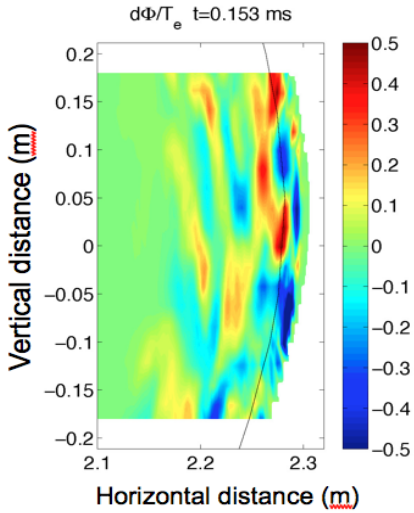
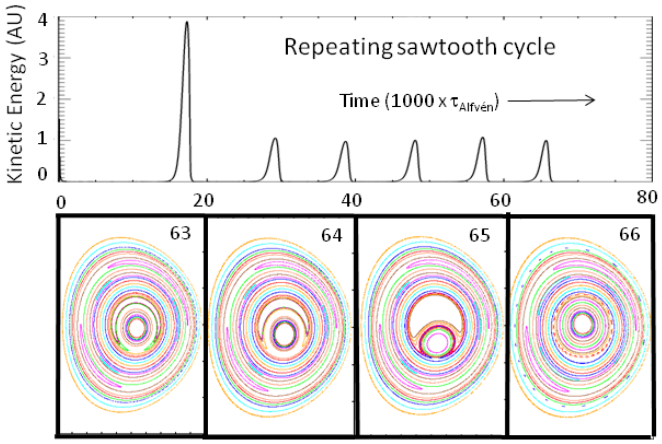
# MFES --Theory & Advanced Simulations

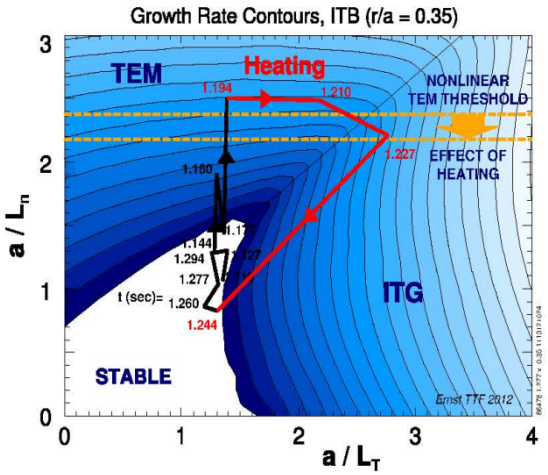
- **Theory**: advances scientific understanding of the fundamental physical processes governing the behavior of magnetically confined plasmas
- **SciDAC**: advances scientific discovery in fusion plasma science and materials science by exploiting leadership-class computing resources and associated advances in computational science
- NERSC resources—along with INCITE resources at the OLCF and ALCF Centers and HPC resources allocated via the ALCC program—are ***critical*** for advancing the mission of these programs
  - *SciDAC projects collectively used more than **50%** of the entire FES NERSC allocation in AY2012*



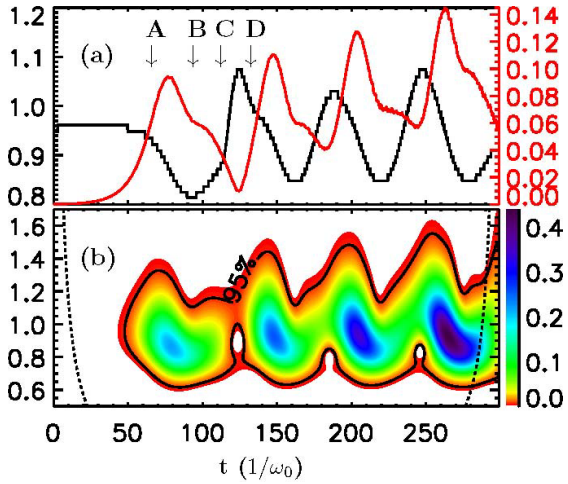

***EPSI**: XGC edge simulations*




***CEMM**: M3D-C¹ sawteeth simulations*




***CSPM**: GS2 ITB simulations*




***GSEP**: BAE simulations with GTC*

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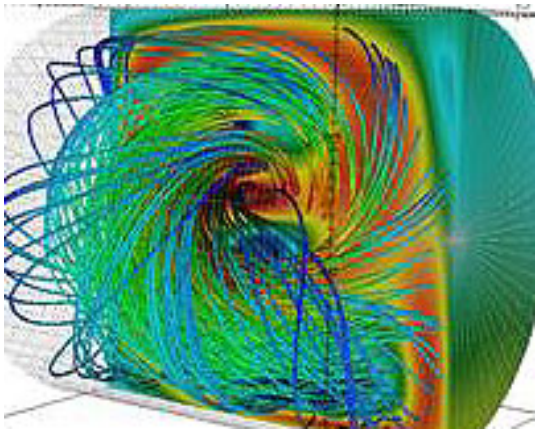
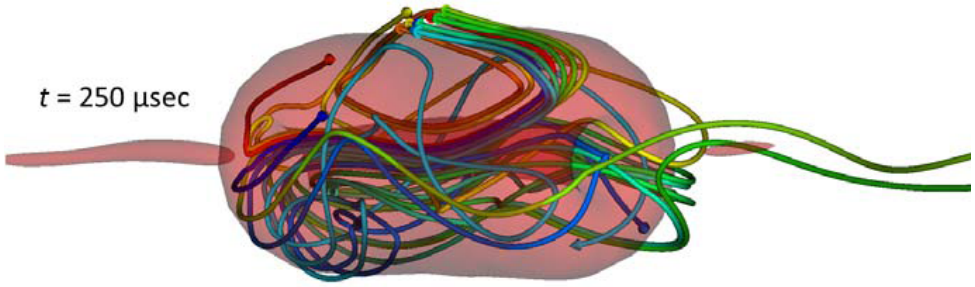
# MFES--Small Scale Experimental Plasma Research (EPR)

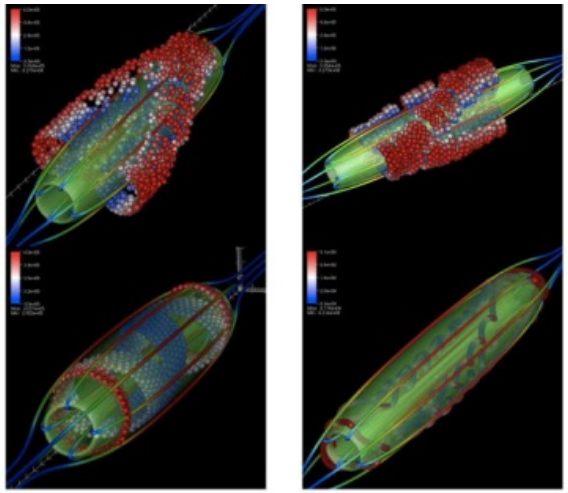
- The EPR program provides data from small/intermediate-scale experiments at universities and national laboratories to:
  - Help validate theoretical models and simulation codes to develop an experimentally validated predictive capability for magnetically confined fusion plasmas
  - Test theories and scale phenomena relevant to burning plasma systems
- The EPR program emphasizes stellarators, spherical tori, field-reversed configurations, and spheromaks
- Within the EPR program, the multi-institutional **Plasma Science & Innovation (PSI) Center** uses NERSC resources to provide simulation support to the EPR community



*Spheromac HiFi Simulation*




*Magnetic field lines during θ pinch implosion in an FRC*



*Particle orbits for a single particle in an FRC field.*

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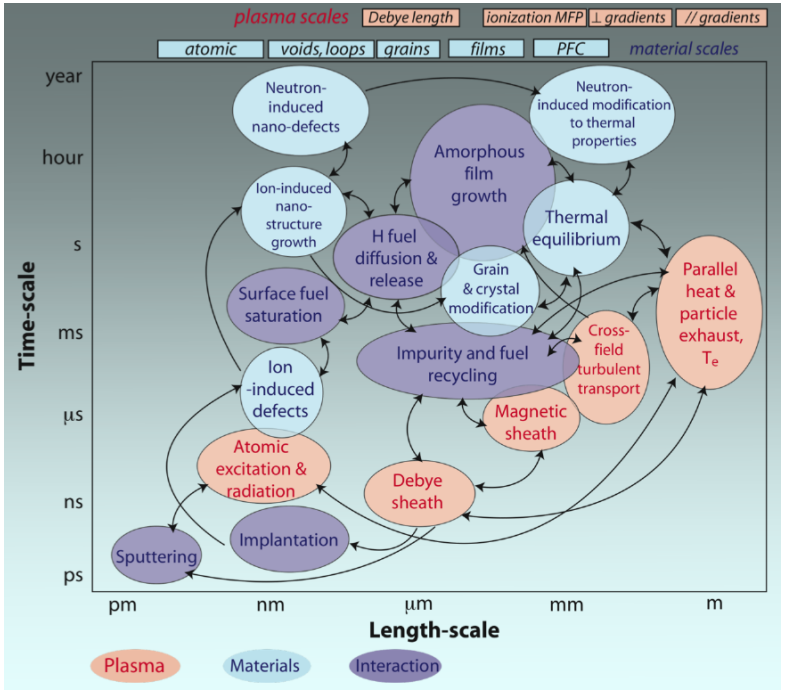
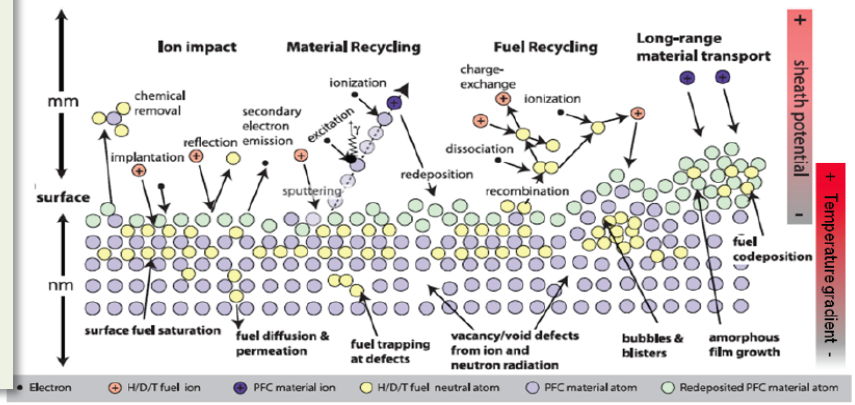
# Materials Science

- Challenge is to develop a scientific understanding of candidate materials in order to better understand the mechanisms controlling performance limiting phenomena of materials for fusion reactors.
- Advanced simulations have a unique role to play, considering the significant extrapolation necessary to bridge the gap from the existing parameter space to the fusion energy regime due to the current absence of fusion-relevant neutron sources and plasma material interactions test stands.
- Although, historically, materials science research was a modest user of NERSC resources, this is rapidly changing after the addition of a multi-institutional Plasma Surface Interaction SciDAC partnership in the FES portfolio.
- Structural materials researchers have been relying on local resources for their simulation needs but, as their needs grow, migration to NERSC is very likely.
- Access to NERSC resources can help address the multiphysics, multiscale challenges of fusion materials science.




Wirth, Nordlund, Whyte, and Xu, *Materials Research Society Bulletin* **36** (2011) 216-222

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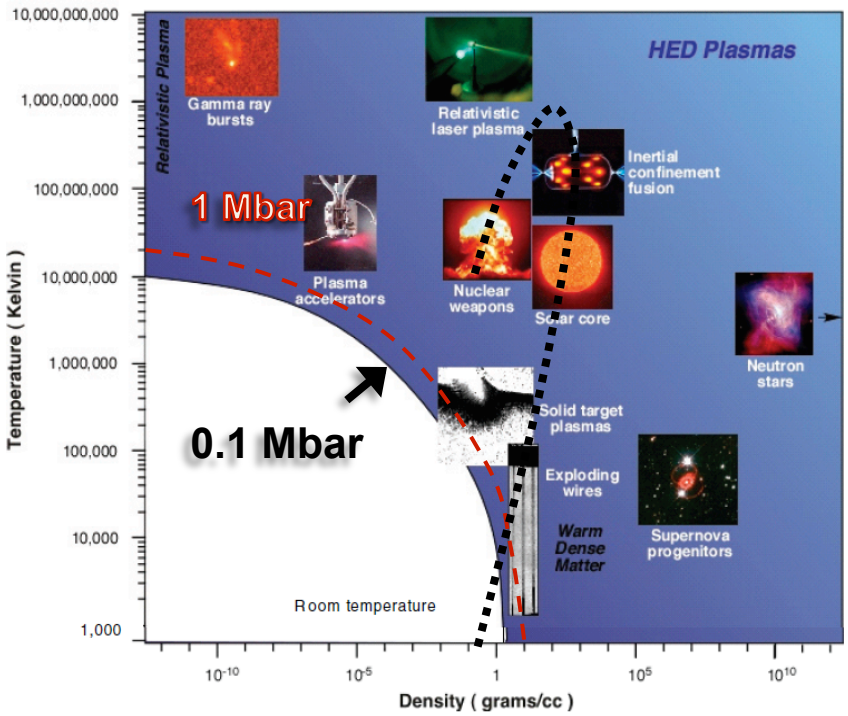
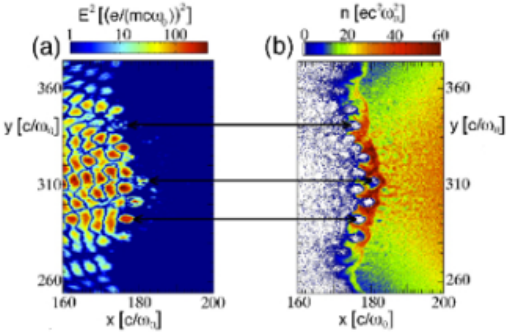
# HEDLP & IFES

- HPC role in advancing HEDLP and IFE science is significant
- Large fraction of this community relies on NNSA or other HPC resources, including INCITE
- NERSC usage has been steadily increasing

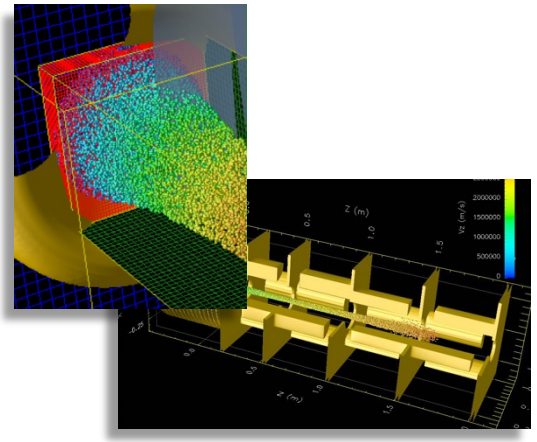



## HEDLP on NERSC

***Laser Plasma Interaction***




***Ion Accelerator: NDCX-II***



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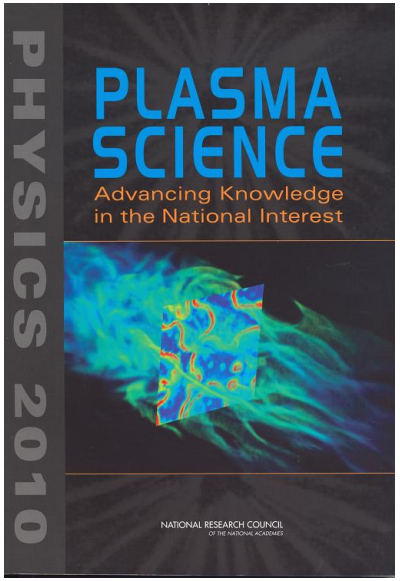
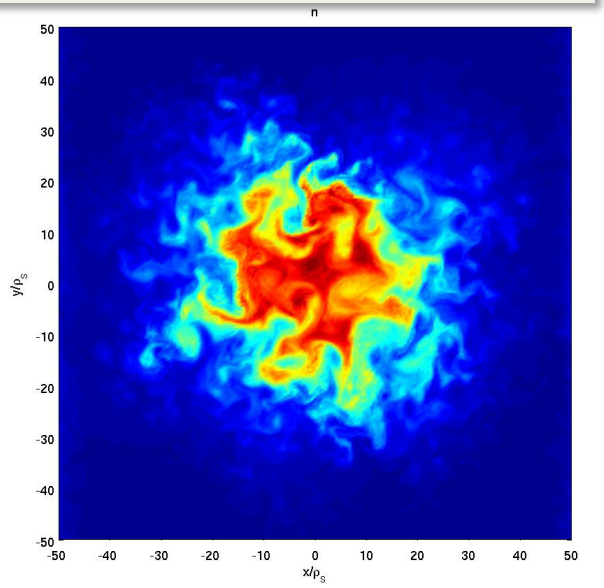
# General Plasma Science

- An area of FES stewardship, consistent with the recommendations of the Plasma 2010 National Academies report
- Includes the NSF/DOE Partnership in Basic Plasma Science and Engineering, multi-institutional Plasma Science Centers, General Plasma Science efforts at National Laboratories, and an EPSCoR Center at UNH
- Most computational intensive efforts are in the crosscutting areas of magnetic reconnection and turbulence and in fusion-relevant atomic physics research




The LAPD device at the UCLA Basic Plasma Science Facility (BaPSF)




**Turbulent Transport**: Global 3D 2-fluid Braginskii simulations of LAPD (CICART)

CICART
Center for Integrated Computation and Analysis of Reconnection and Turbulence

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# NERSC & FES

- From the days of the Controlled Thermonuclear Research (CTR) & the National Magnetic Fusion Energy Computer Center (MFECC) in the mid-1970's—the predecessors of NERSC—High Performance Computing (HPC) and NERSC have played a significant role in fusion energy research
- NERSC allocations—distributed via the annual ERCAP process and supplemented by ALCC—provide a reliable and predictable resource for meeting critical FES mission needs
  - Although allocations at OLCF and ALCF tend to be larger, the award process through INCITE entails significant risk and cannot be relied upon for programmatic mission-critical needs.


1976: CDC 7600 at MFECC


2013: Edison, CRAY XC30

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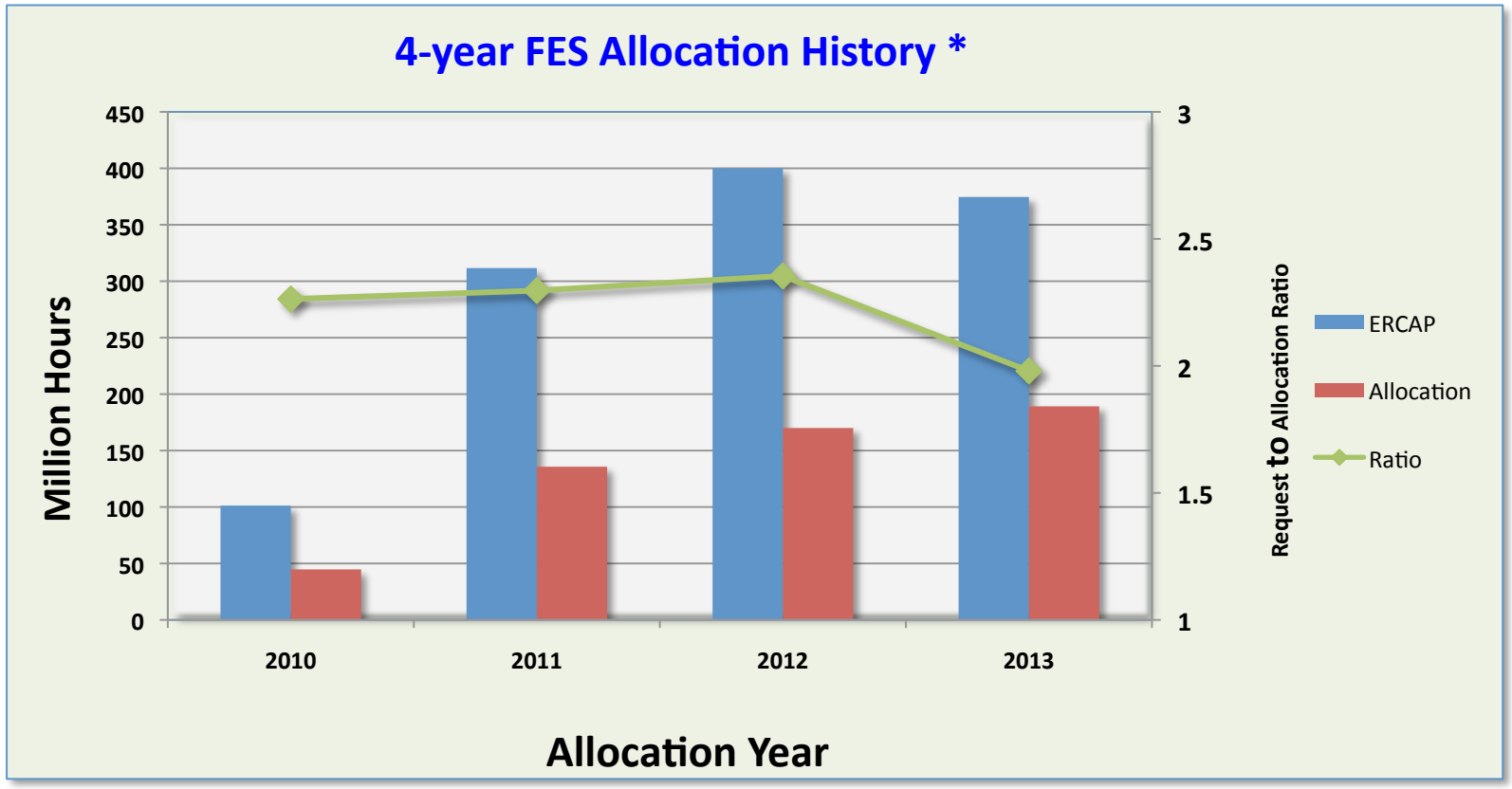
# Allocation History




** Reflects initial allocations; does not include infusions from NERSC reserves during the AY or ALCC allocations*

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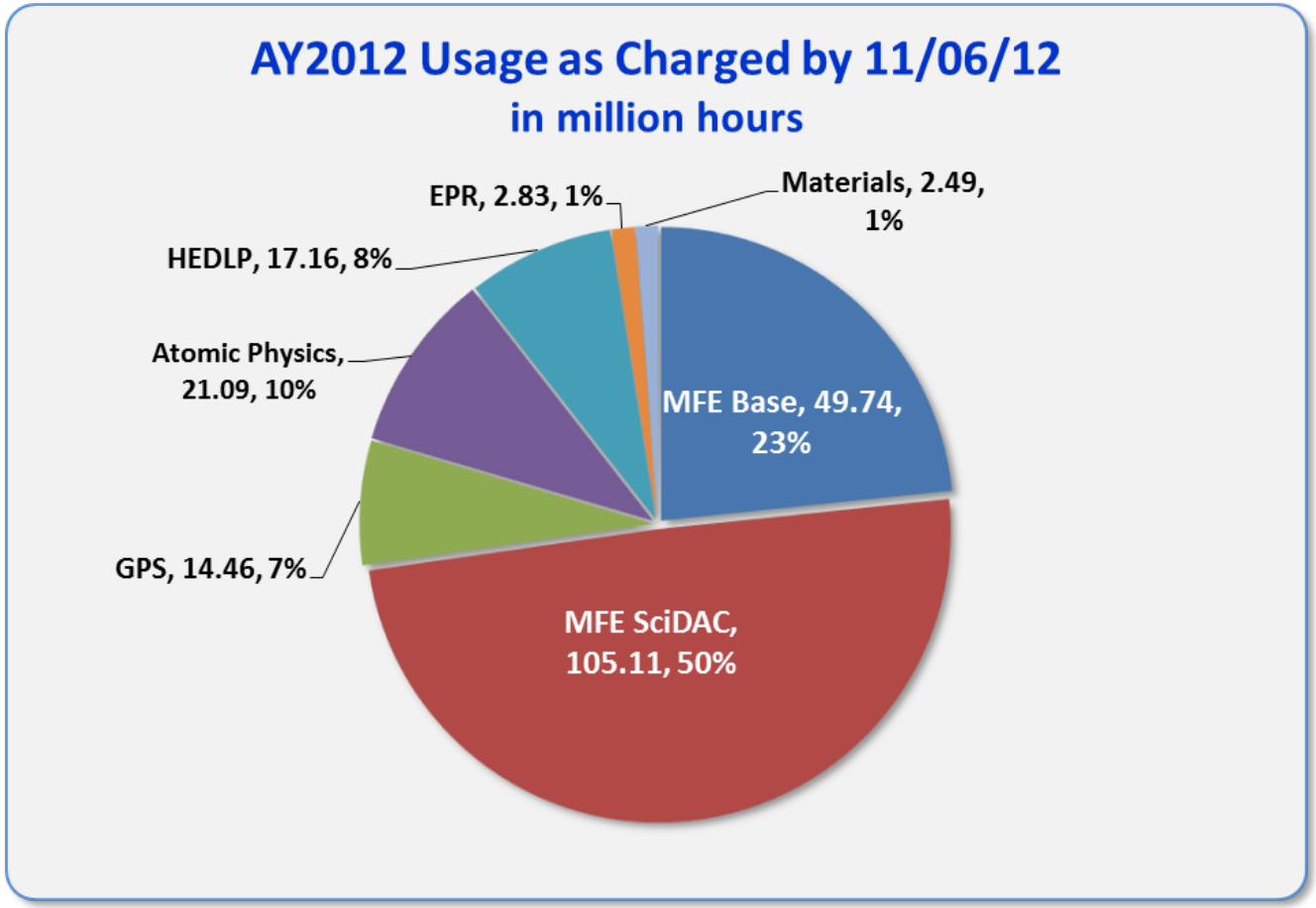
# Usage by Topical Area

**Small change since AY2009:**

- MFE Base ⬆
- MFE SciDAC ⬇
- HEDLP ⬆
- Materials ⬆
- EPR ⬇



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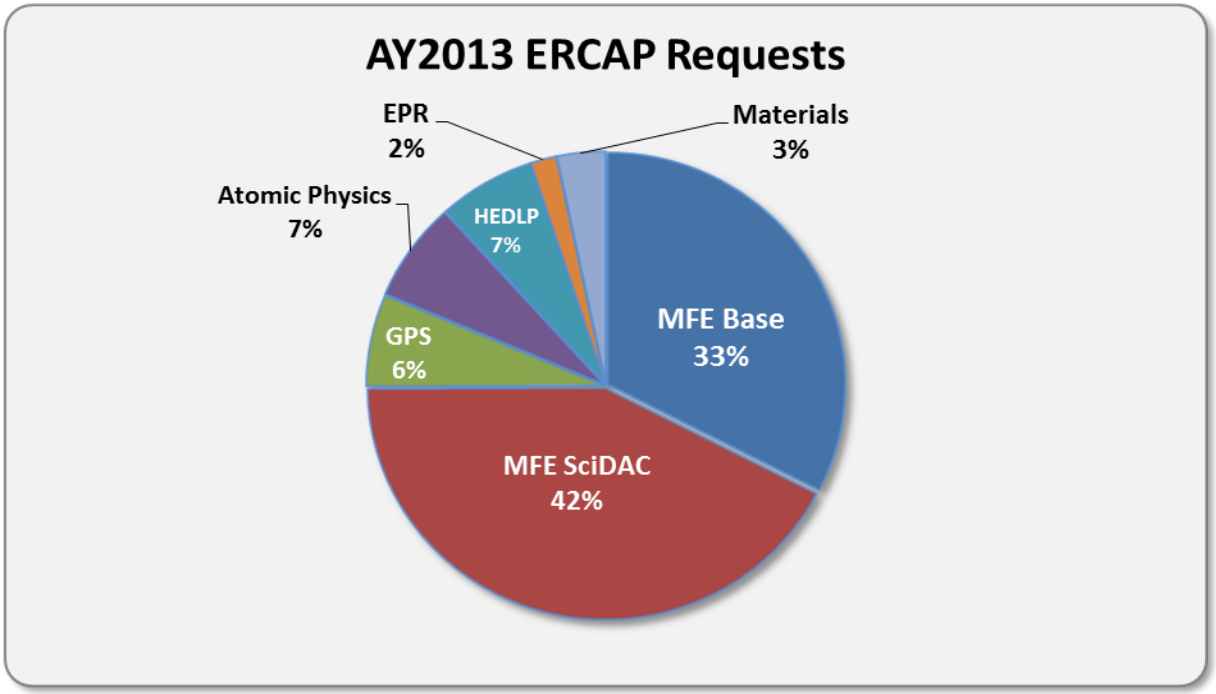
# ERCAP Requests by Topical Area

In AY 2013, ~**180M** Processor Hours have been allocated to **60** FES repositories:

- MFE Base: 25
- MFE SciDAC: 10
- GPS: 5
- EPR: 7
- HEDLP: 7
- Atomic Physics: 2
- Materials 4



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# Program Review Meetings / Workshops

Program review meetings and workshops shape future directions. It's a unique opportunity to exchange information with all stakeholders.

2010 Large Scale Computing & Storage Requirements for FES

# *Thank You!*