DIII-D Program Overview: Future Directions for the Next Five-Year Plan

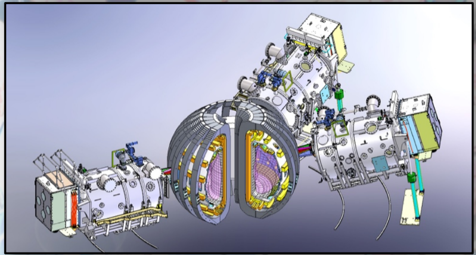
by

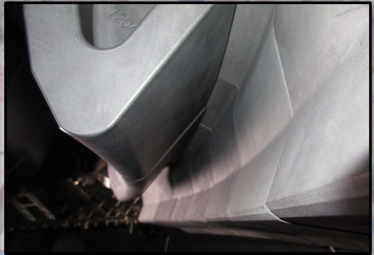
D.N. Hill

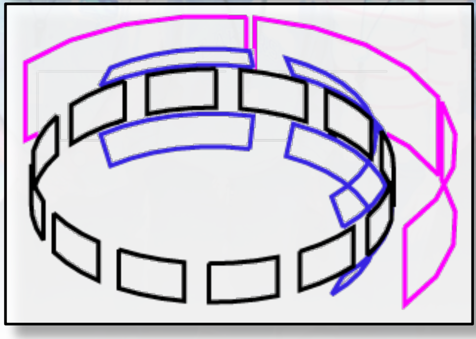
Presented to the

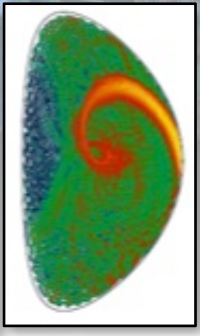
DIII-D Program Advisory Committee San Diego, California

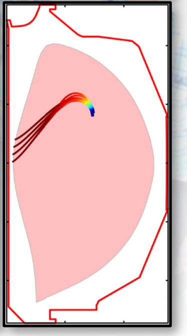
March 28–30, 2017











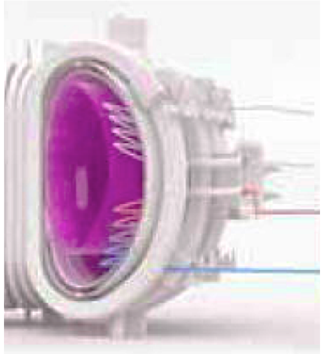
DIII-D NATIONAL FUSION FACILITY SAN DIEGO

GENERAL ATOMICS

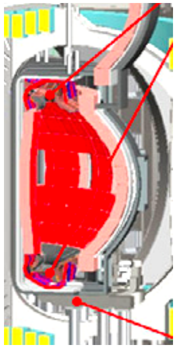
We are Entering the Burning Plasma Era

- **ITER construction underway**
  - Exciting and vital validation of the fusion energy concept

- **World program discussing major facilities beyond ITER**



EU DEMO



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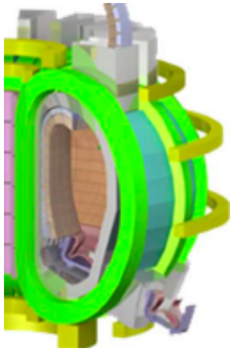
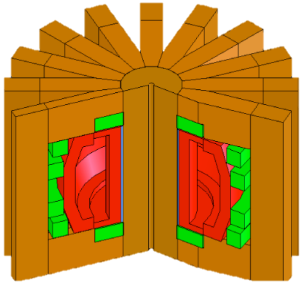
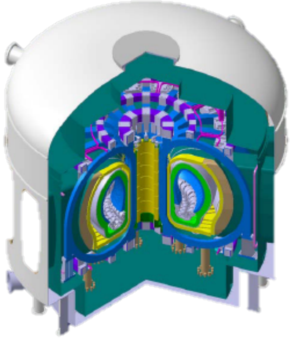


Japan DEMO



FNSF



CFETR

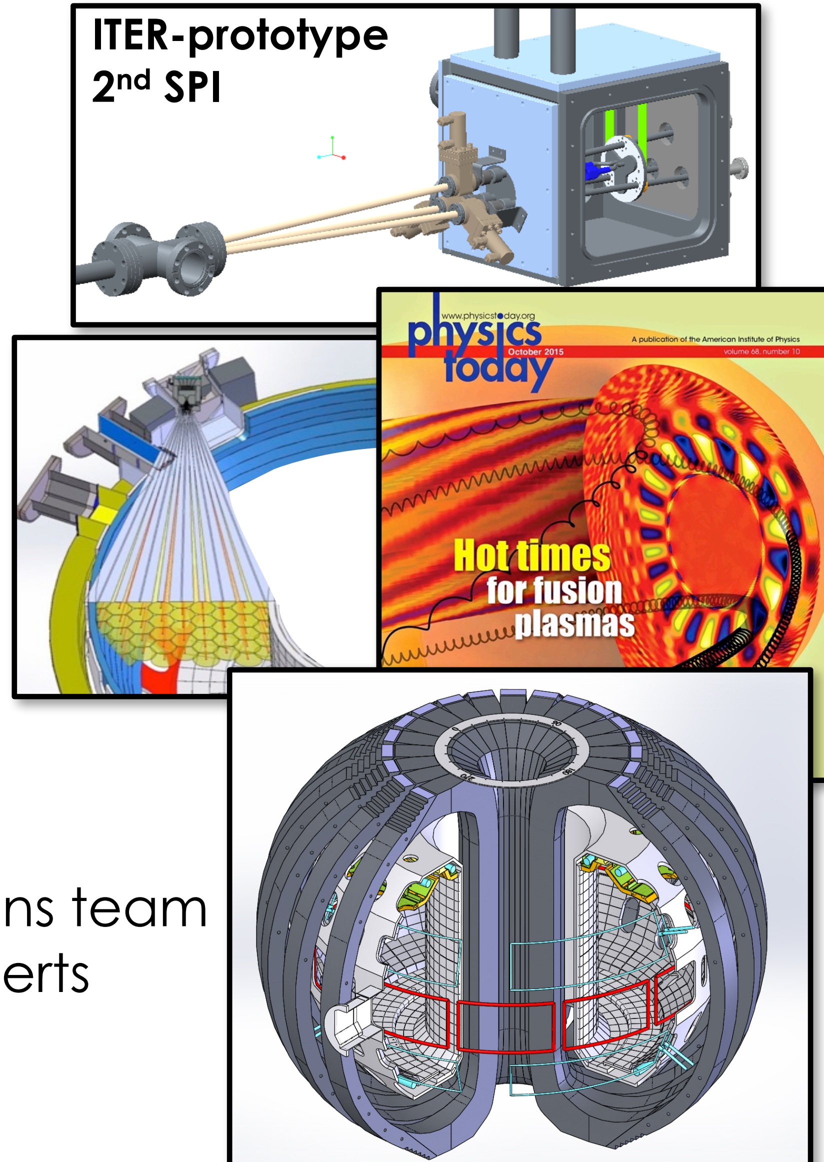
- **Key scientific questions and challenges remain for existing programs to address to inform future missions**

Our Vision for the DIII-D Program Is Based on Three Guiding Principles

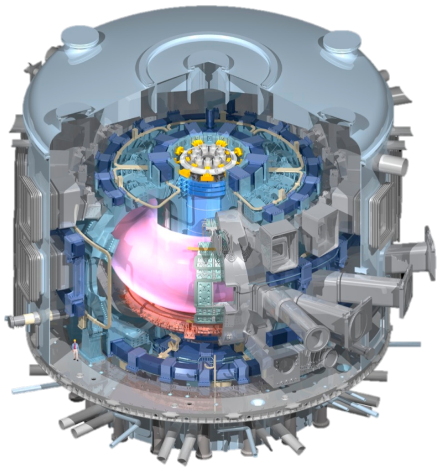
- **Research with an Energy Goal**
  Address challenges to achieving fusion energy

- **Scientific Excellence**
  Fastest route to success and developing predictive capability

- **World-Class Facility for U.S. Office of Science**
  Upgrades for access to new physics
  Highly capable scientific & operations team
  Train future generation of fusion experts

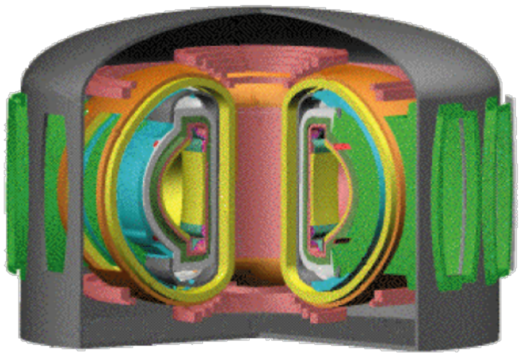


DIII-D Research is Focused on Key U.S. Fusion Energy Goals



- **ITER success**
  - Ensure rapid progress to Q=10
  - Resolve (few) remaining design issues
  - Scientific basis for U.S. exploitation and leadership in ITER

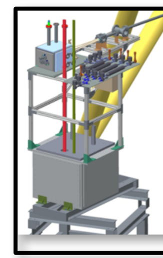
- **Path to Steady-State Fusion Energy**
  - High performance core
  - Power handling & materials
  - Reactor-relevant current drive technology

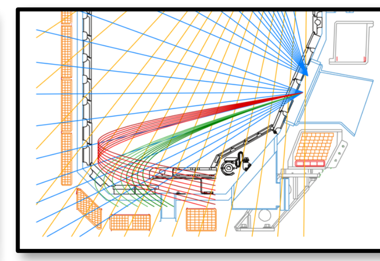


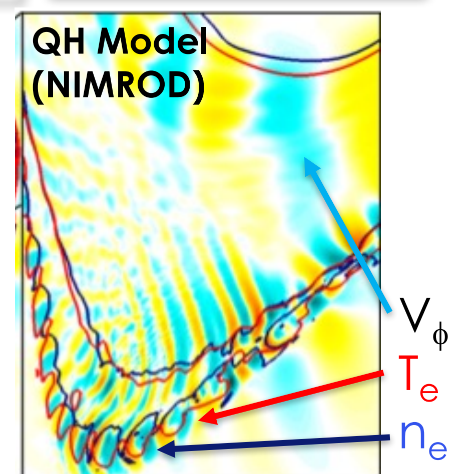
DIII-D Is a Vital Resource to Develop Viable Paths & Establish Scientific Basis

DIII-D is a Highly Capable Facility for Advancing Fusion Energy Development Through Scientific Discovery

- **Flexibility to explore relevant regimes:** Torque, β, n_e, 3D, P & J profile
- **Comprehensive Diagnostics**
  - Profiles, 2D & 3D with spatial & energy resolution
- **Tools to validate advanced Simulation**
- **Capability to Perturb and Control plasmas**
  - Localized heating, current drive, particles
- **Strong collaborative scientific Team**
  - 100 institutions, leading universities, laboratories and joint experiments with international partners





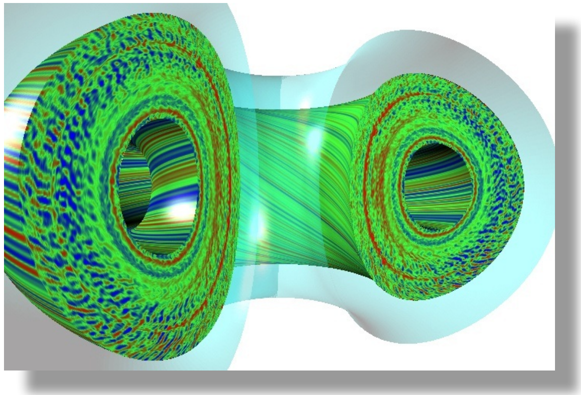


Enables DIII-D to pioneer new approaches, resolve scientific questions, and extrapolate to future reactors

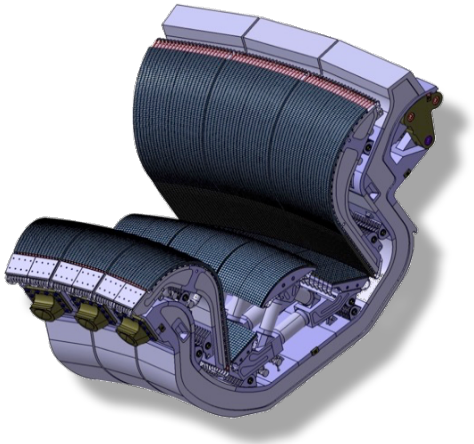
The DIII-D Research Program Emphasizes the Critical Issues for ITER and Future Facilities

Two Main Program Elements

- **Scientific Basis for Burning Plasma Core**
  - Transient Control
  - Enabling ITER Q=10
  - Path to Steady State

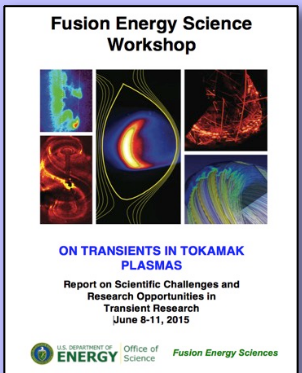


- **Scientific Basis for Boundary Solutions**
  - Detachment control
  - Divertor optimization
  - Test new wall materials



The DIII-D Research Program Emphasizes the Critical Issues for ITER and Future Facilities

Research Program Elements are well-aligned with FES workshops

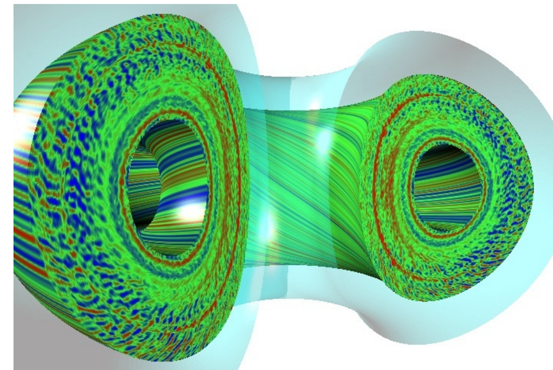

Fusion Energy Science Workshop

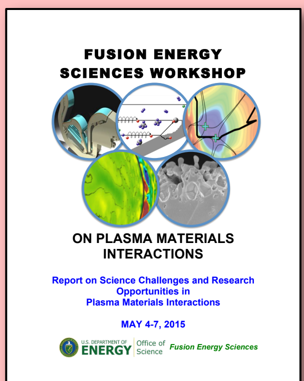
ON TRANSIENTS IN TOKAMAK PLASMAS

Report on Scientific Challenges and Research Opportunities in Transient Research
June 8-11, 2015

U.S. DEPARTMENT OF ENERGY | Office of Science | Fusion Energy Sciences

- **Scientific Basis for Burning Plasma Core**
  - Transient Control
  - Enabling ITER Q=10
  - Path to Steady State




FUSION ENERGY SCIENCES WORKSHOP

ON PLASMA MATERIALS INTERACTIONS

Report on Science Challenges and Research Opportunities in Plasma Materials Interactions

MAY 4-7, 2015

U.S. DEPARTMENT OF ENERGY | Office of Science | Fusion Energy Sciences

- **Scientific Basis for Boundary Solutions**
  - Detachment control
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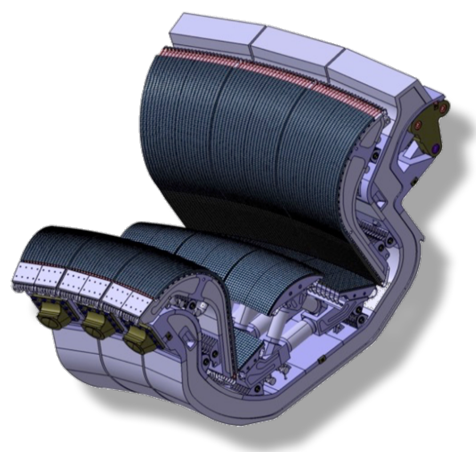
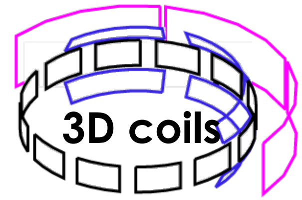
  - Test new wall materials

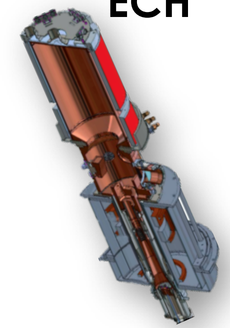


DIII-D Will Help Resolve Key Physics to Validate Attractive Operating Scenarios to Fusion Devices

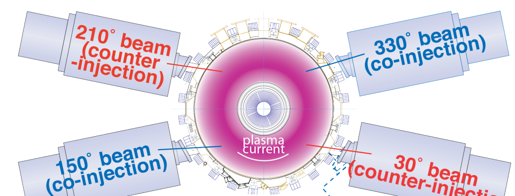
- **Develop robust control of transients**
  - Resolve key tearing, RWM & 3D physics
  - Understand and optimize ELM suppression
  - Safely quench disruptions & dissipate runaways



ECH

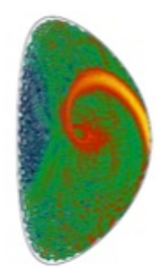


- **Determine how to optimize burning plasma performance**
  - Understand multiscale transport
  - Develop integrated scenarios for Q=10

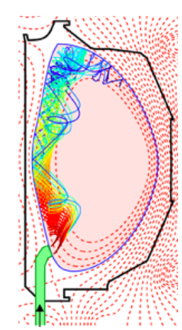


Balanced beams

- **Establish physics basis to design future steady-state fusion reactors**
  - Validate physics in high β_N conditions
  - Show self-consistent stationary solutions exist



Helicon



LHCD

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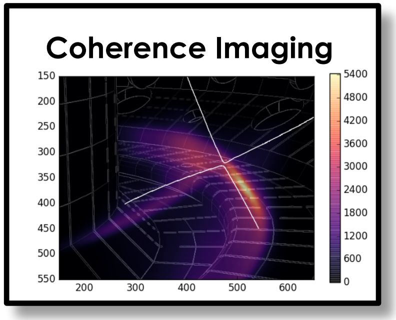
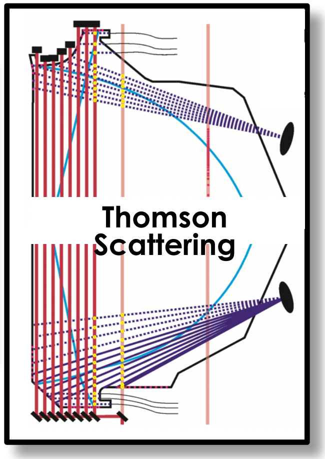
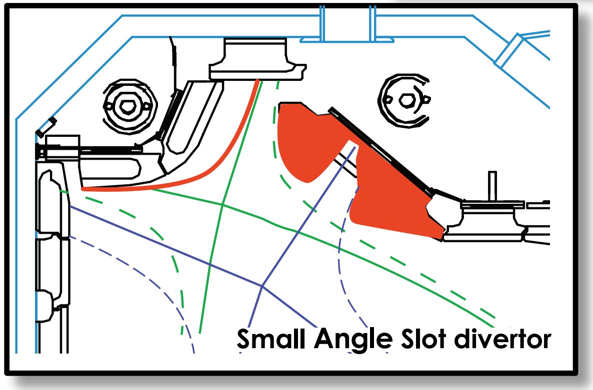
016-17/DNH/rs

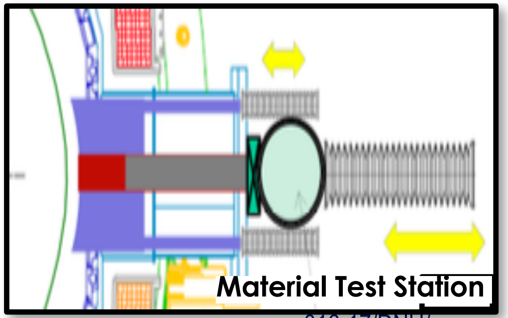
DIII-D Will Help Develop a Scientific Basis for Boundary Solutions Needed for Steady-State Reactors

- **Advance scientific understanding and develop predictive capability through extensive model validation**
  - Determine key processes for divertor dissipation
  - Resolve role of drifts and turbulence
- **Develop advanced divertors compatible with high performance**
  - Maximize heat flux dissipation without degrading core
  - Integrate staged divertor concept tests
- **Validate reactor-relevant materials**
  - Understand impurity sourcing, migration and transport
  - Evaluate compatibility with fusion core



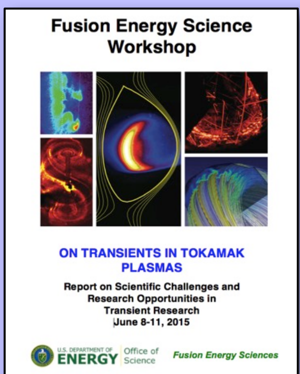






The DIII-D Research Program Emphasizes the Critical Issues for ITER and Future Facilities

Research Program Elements → **Predictive Understanding**



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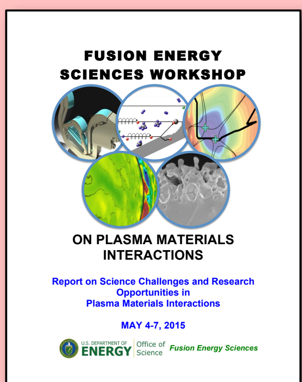

- **Scientific Basis for Boundary Solutions**
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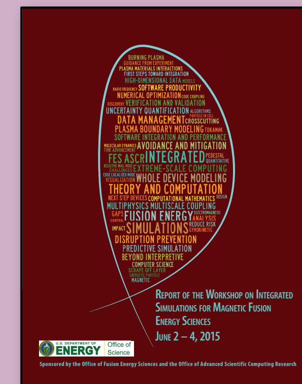
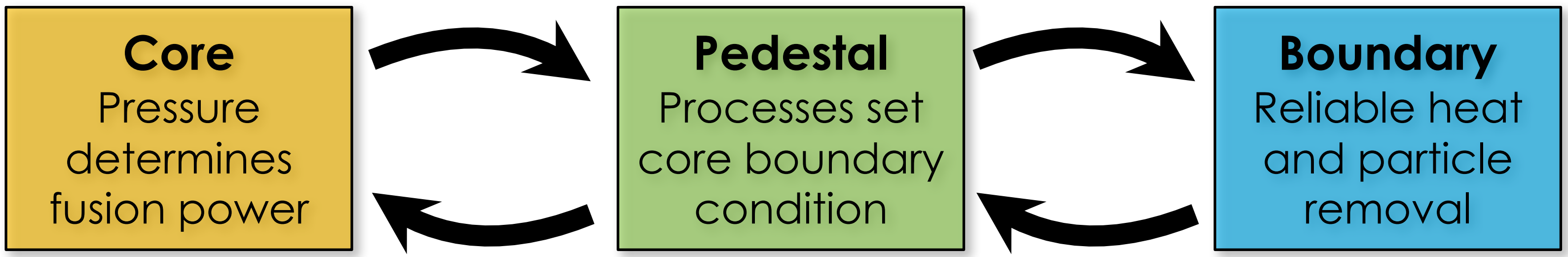
Core-Pedestal-Boundary Integration



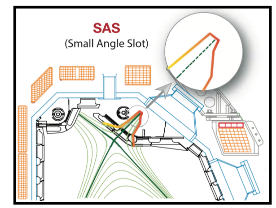
- **Integrated Approach to Physics Interpretation**
  - Innovative diagnostics
  - High-performance computing
  - Experiments targeting model validation

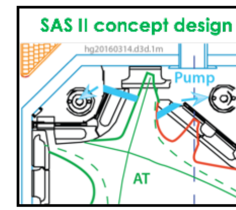
DIII-D Will Explore the Physics Basis For Integrating Core-Pedestal-Edge Solutions

- **Challenge: Minimize dissipative volume to maximize fusion core**

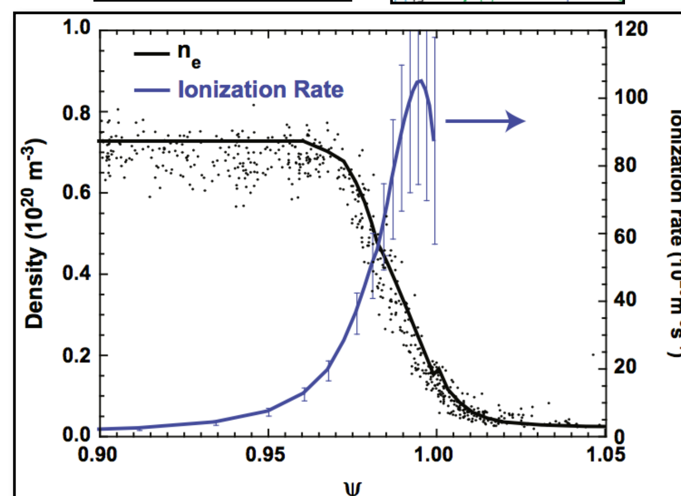


- **Research will uncover pedestal processes**
  - Turbulent transport, rotation, impurities
  - Influence of neutrals, ionization, radiators





- **Develop the scientific basis for optimizing scenarios**
  - Pedestal manipulation to raise performance
  - Reactor relevant materials and geometries



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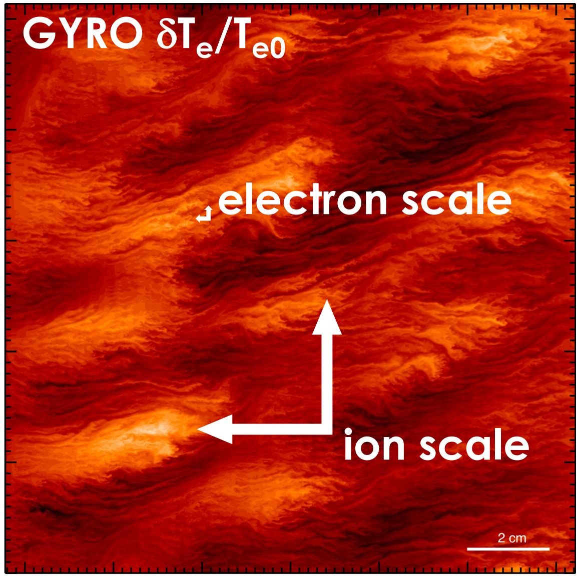
We Are Moving Toward a New Frontier of Integrated Multi-Scale Predictive Simulations

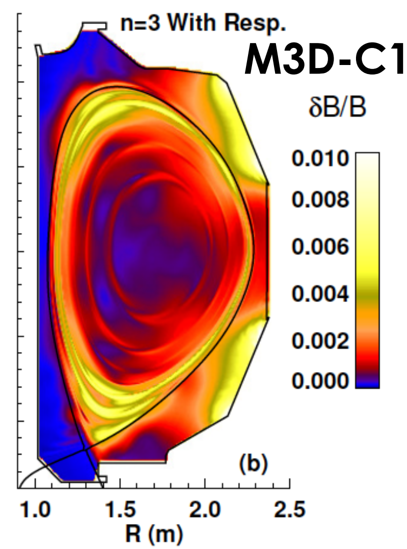
- **DIII-D is an ideal platform for model validation**
  - Extensive diagnostic set
  - Operational flexibility
  - Connections to other tokamaks

- **Advances in theory & simulation facilitate planning, executing and analyzing experiments**
  - Developing "predict first" workflow

- **Simulations integrating coupled scales / regions benefiting from high performance computing**

Spatial structure of turbulence





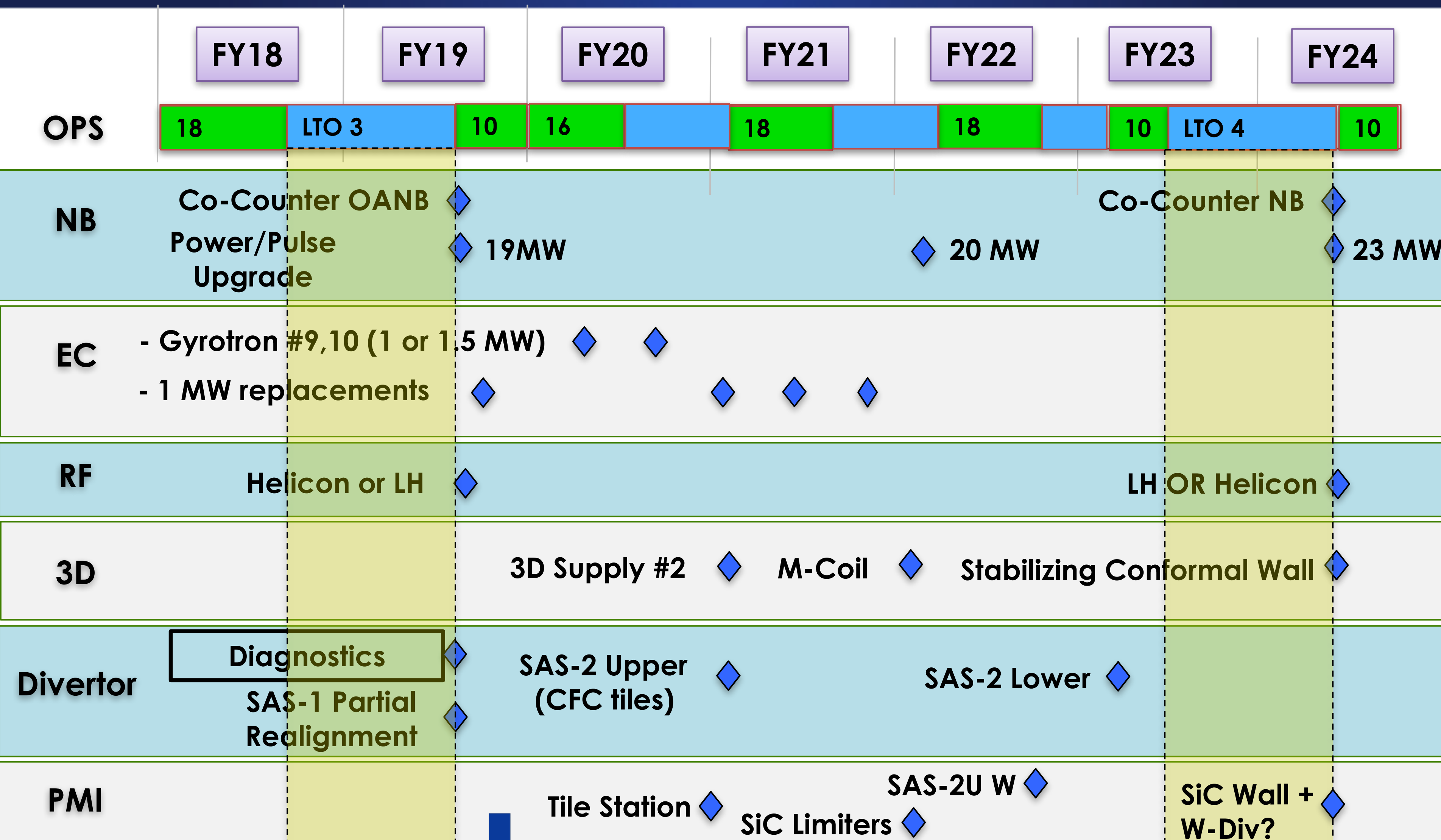
Close coupling between theory/model development and DIII-D experiments enables rapid progress in understanding

Upgrades Leverage Existing Capabilities and Support a Vibrant and Exciting Research Plan

New Scientific Exploration	Enabled by
Low torque, high beta	2nd co-counter steerable NBI
Electron heated regimes	10 gyrotron system
Reactor current drive schemes	Top-launch EC, Helicon, LHCD
3d spectral flexibility (n=1-4)	New 3d coils and power supplies
Divertor model validation & optimization	Divertor mods and diagnostics
Reactor-relevant materials	New PFCs and tests of materials

- **Proposed upgrades are well-suited to resolving critical issues for ITER and steady-state fusion**
  - Control of transients (ELMs, disruptions)
  - Tightly coupled physics of steady-state solution
  - Handling high power exhaust

An Ambitious Plan for Upgrades Appears Feasible with Strong DOE Support



New Cooperative Agreement starts (June '19)

Innovations in Diagnostics will Lead to Breakthroughs in Scientific Understanding and Model Validation

CORE

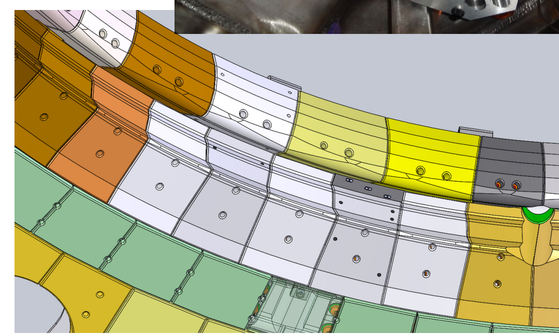
- 3-D Magnetics Phase II
- Thomson Horizontal System Upgrades
- Fast Ion Loss Detector Upgrade
- Improved Fluctuation Diagnostics
- BES Upgrades
- Imaging MSE/Edge j(r)

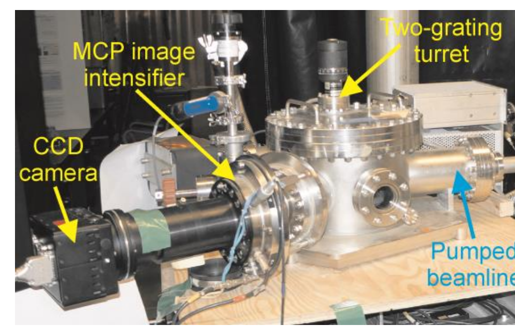
PEDESTAL

- Improved Fluctuation Diagnostics
- BES Upgrades
- Imaging MSE/Edge j(r)
- Upgraded Spectroscopy
- Neutrals

BOUNDARY /PMI

- Upgraded Spectroscopy
- Neutrals
- Heated Tile/ Tile Station
- Divertor T_i
- High Resolution Divertor Bolometry
- Upgraded 2D Divertor Imaging
- Improved IR camera coverage
- Gas Puff Imaging





- Supporting DOE Diagnostic Development Grants (FOA)
- Supporting US-ITER diagnostic testing (TIP, ECE, LFSR)

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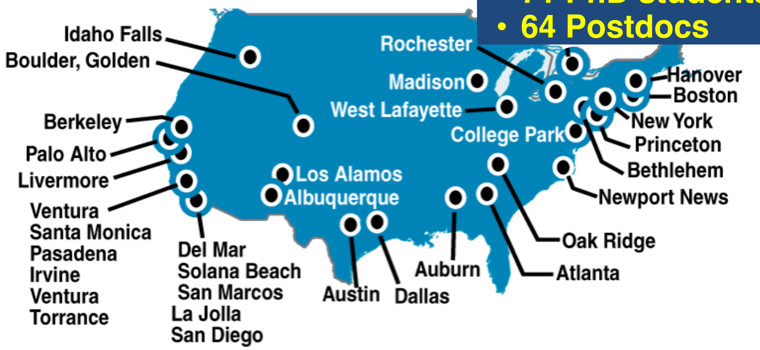
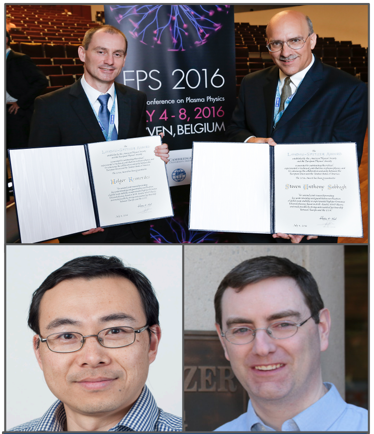
Upgrades Strengthen DIII-D as a Vital User Facility for the U.S. Fusion Community

- **High level of available run time & broad research capability**
- **Offers national and international leadership opportunities to U.S. research scientists and universities**
  - Leading research fields at facility, experiments, diagnostic innovation, testing theory & simulation
  - Leading international teams with worldwide recognition

- 623 Users
- 108 Institutions
- 71 PhD students
- 64 Postdocs



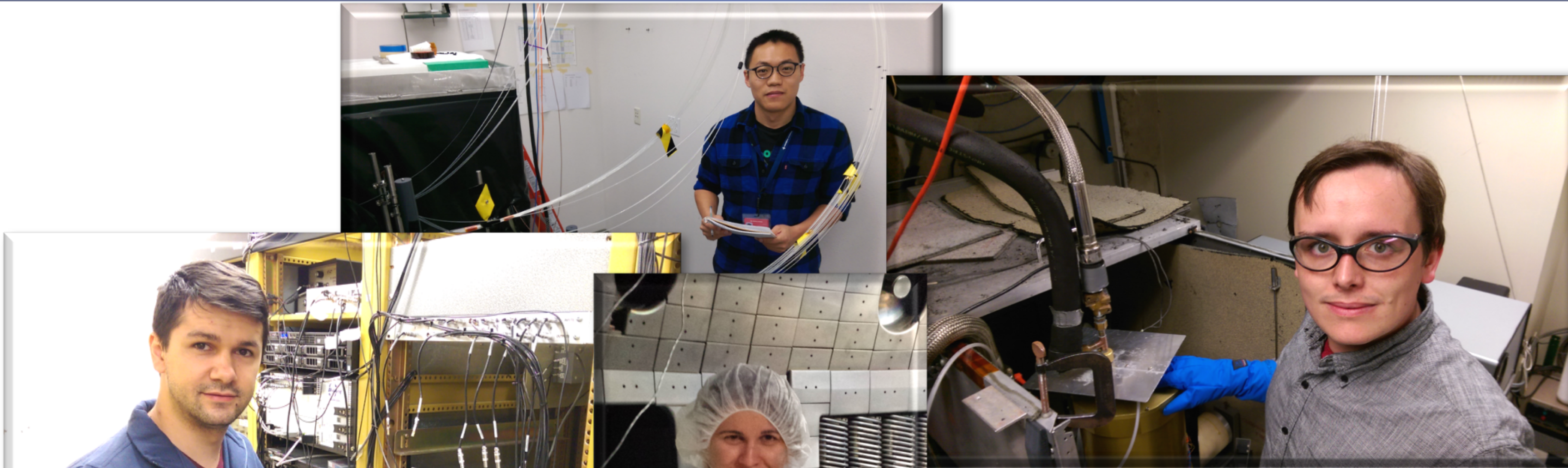
- **Cutting edge scientific tool**
  - Focus on physics. Frontiers initiative explores foundations of plasma & fusion science
  - Six times winner APS Excellence in Plasma Physics



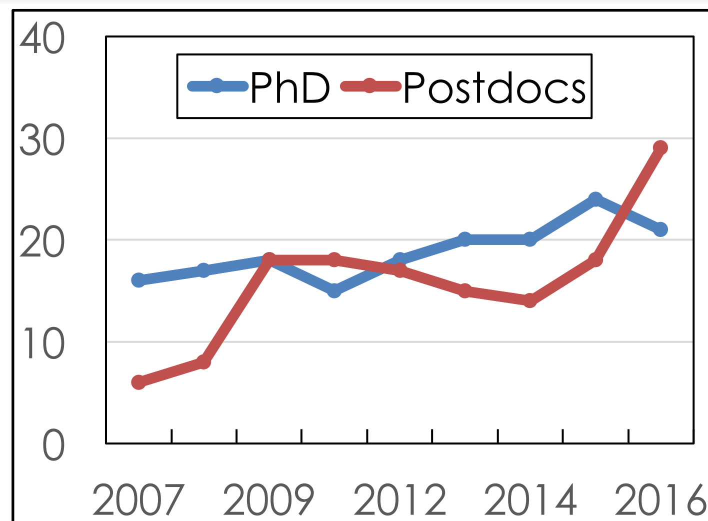
2016 Landau Spitzer Prize

DIII-D is a key element in U.S. scientific leadership

DIII-D Is Supporting a Growing Number of Students and Post Doctoral Fellows Engaged in High Impact Research

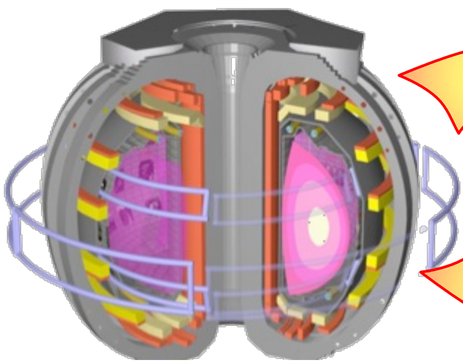


DIII-D can fulfill a critical need to train the next generation of fusion physicists who will pioneer research on ITER



DIII-D Research Plan Facilitates a Bold and Expanding US Fusion Program With a Clear Energy Goal

DIII-D



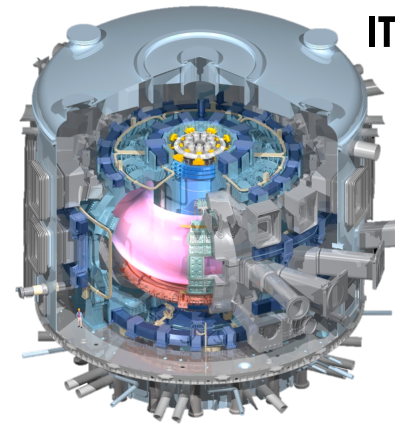
Ensure the Success of ITER

Provide Physics Basis for Fusion Development Beyond ITER

Deliver validated predictive understanding for key scientific challenges

Engage a new generation of fusion scientists

ITER



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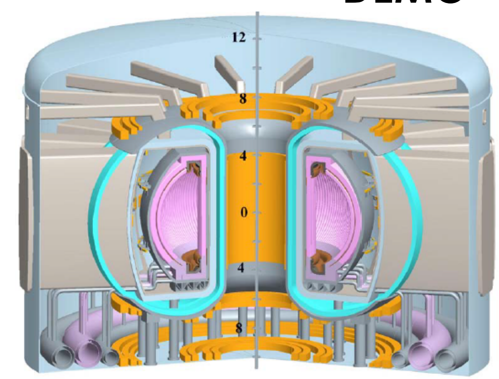

Enabled by a highly capable facility with technical reach and flexibility to probe the relevant physics of burning plasmas

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The Proposed Research and Facility Enhancements Will Keep DIII-D at the Fusion Energy Frontier

Leverages investments in DIII-D to deliver exciting research that is well aligned to FES priorities and world-wide fusion program needs

Plan emphasizes high impact research to help enable a successful program on ITER and strengthen the case for the advanced tokamak approach to fusion energy

Delivers new capabilities through targeted upgrades that should transform the landscape for fusion science