Overview of Recent DIII-D Experimental Results

M.E. Fenstermacher (LLNL)

Presented at the
59th Annual APS Meeting
Division of Plasma Physics
Milwaukee, WI

October 23–27, 2017
DIII-D Continues to Contribute to Fusion Energy Development by Focusing on Three Research Elements

Develop Relevant Boundary Solutions

Strengthen the Basis for Fusion Science

Control Transients
DIII-D Continues to Contribute to Fusion Energy Development by Focusing on Three Research Elements

Develop Relevant Boundary Solutions

- Divertor Geometry
- SOL and Divertor Flows
- Tungsten Migration

Strengthen the Basis for Fusion Science

Control Transients

PMI, Divertor Solutions for Long Pulse
New SAS Divertor Design Achieves Detachment Consistent with Initial Modeling

- Detachment optimized with SP in corner of SAS structure consistent with simplified predict-first modeling
  - Achieved low $T_e < 10$ eV across SOL target
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- SAS upstream density at detachment lower with ion $\nabla B \times B$ drift out of divertor (higher $P_{L-H}$ direction)
  - Flat, low $T_e$ achieved down to $n_e = 4e19$
  - With Grad-B into divertor, low $T_e$ requires significantly higher upstream density
  - Consistent with expected poloidal drift effects
Comparison of New 2D Ion Velocity Imaging and Fluid Modeling Contributes to Validation of Pressure Gradient and Other Forces Determining Parallel Velocity

- Consistency of main ion flow profiles in UEDGE vs. experiment near target plate supports multi-term force balance model
  - Region where He$^+$ and electron-physics dominates
  - Enabled by absolutely calibrated 2D imaging of ion velocities
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• Confirmed EMC3-EIRENE fluid code prediction of temperature dominated pressure-gradient driven C\(^2+\) 3D flows
  – First imaging of 3D flows around magnetic islands in a tokamak
Asymmetries in W Deposition Pattern on Midplane Collector Probe Consistent with Predicted High-Z Impurity Trap

- Expect W Impurities trapped near ‘crown’
  - DIVIMP: Formation of potential well due to ITG force in near-SOL

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Asymmetries in W Deposition Pattern on Midplane Collector Probe Consistent with Predicted High-Z Impurity Trap

- Expect W Impurities trapped near ‘crown’
  - DIVIMP: Formation of potential well due to ITG force in near-SOL
- More W deposited on ISP-facing side of collector probe
  - Features consistent w/ DIVIMP modeling
DIII-D Continues to Contribute to Fusion Energy Development by Focusing on Three Research Elements

1. Develop Relevant Boundary Solutions

2. Strengthen the Basis for Fusion Science
   - 3D Effects
   - Intrinsic Rotation
   - Particle – Wave Coupling
   - Current Drive Optimization
   
   Optimizing Tokamak Plasma Performance

3. Control Transients
With RMP Fields Measurements and Modeling Show Density Changes within Flux Surfaces; Not Only Surface Displacement Effects

- Density modulation with 3D fields leads to toroidal variation of $a/L_{ne}$ and turbulence drive


Wilcox, Tues AM
With RMP Fields Measurements and Modeling Show Density Changes within Flux Surfaces; Not Only Surface Displacement Effects

- Density modulation with 3D fields leads to toroidal variation of $a/L_{ne}$ and turbulence drive
  - Linearized plasma response model predicts 3D deviation, but larger than measured

Wilcox, Tues AM

Main-Ion Pedestal Top Intrinsic Rotation Model Prediction without Free Parameters Consistent w/ Experiments

- Ctr-Ip passing ions stronger turbulent diffusion and higher loss rate than co-Ip ions → Generates net co-Ip rotation

- Predicted value and direction of pedestal top intrinsic rotation w/o free parameters consistent with observed intrinsic rotation
  - Database covers a wide range of parameters (L-mode, H-mode, ECH, NBI, USN, LSN, +/- Ip)

- Model recently extended to include finite NBI torque for predictive scenario modeling

Ashourvan, Tues PM
Frontier Science: First Observations of Runaway Electrons Driving Whistler Waves

• Validates model of Whistler behavior
  – Follows predicted $n_e B_T$ scaling
  – Multiple mode branches & spacing

Whistler frequency bands show intermittency & whistler scattering
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Predator-prey limit cycles between whistler wave amplitude and electron cyclotron emission
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Improved Energetic Ion Confinement at Reduced Energy Gives Increased Neutral Beam Current Drive

- Classical expectation: NBCD increases with voltage
  - Expt: setup three shots with comparable NBCD before beam I-V changes
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- Classical expectation: NBCD increases with voltage
  - Expt: setup three shots with comparable NBCD before beam I-V changes

- Nominal beam current drive (80 kV) improves at intermediate (65 kV) and suffers at low (50 kV) voltage

- Calculated NBCD from balance of improved confinement (inferred from neutrons) vs reduced ion velocity (AE’s off)
  - Suggests optimum injection voltage for maximum current drive

NBCD matched before I-V changes

Intermediate voltage has higher beam current drive

80 kV

50 kV

Pace, Weds NOON
DIII-D Continues to Contribute to Fusion Energy Development by Focusing on Three Research Elements

Develop Relevant Boundary Solutions

Strengthen the Basis for Fusion Science

Control Transients
- Disruption mitigation
- ELMs & 3D

Critical transients issues for the design and operation of ITER
Multiple shattered pellets injected for the first time

- ITER will inject multiple pellets for disruption mitigation
- Effect of multiple pellets appears to **not** sum directly
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ITER-like shallow pellet trajectory reduces SPI performance
- Performance comparable to similar MGI
- Implies ballistic transport important for SPI

Herfindal, ITER session, Shiraki poster Tues AM
ITER-relevant Disruption Mitigation: Changes in Impurity Transport and Assimilation Can Impact SPI Performance

Multiple shattered pellets injected for the first time
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GRI Reveals Energy Dependent Growth of REs

Herfindal, ITER session, Shiraki poster Tues AM
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Paz-Soldan, Weds AM
• Measured $\varepsilon_{\text{par}}$ never exceeds upper boundary of Eich model (from JET, AUG and MAST data) $\varepsilon_{/\!/} = 3 p_{e,\text{ped}} a_{\text{pol}} B_T/B_p$
ELM Parallel Energy Densities Normalized to Eich Model Suggest Dependences on $P_{\text{heat}}/P_{L-H}$ and Highest Growth Rate Mode

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- Scatter of $\varepsilon_{//,\exp}/\varepsilon_{//,\text{Eich}}$ larger close to L-H power threshold

Knolker, this session
ELM Parallel Energy Densities Normalized to Eich Model Suggest Dependences on $P_{\text{heat}}/P_{L-H}$ and Highest Growth Rate Mode

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- ELMs with larger $\epsilon_{//}$ dominated by low-$n$ peeling modes

- Scatter of $\epsilon_{//,\text{exp}}/\epsilon_{//,\text{Eich}}$ larger close to L-H power threshold

Knolker, this session
RMP Threshold Current for ELM Suppression Reduced with Mixed $n = 2 + n = 3$ Spectrum Fields

- ELM suppression at 10% lower total coil current for $I_{n=3} : I_{n=2} = 3 : 1$
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• MARS reproduces HFS response for ELM mitigation, but not for suppression
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• “Predict-First” analysis of plasma response to RMP guides ELM suppression access dependence on triangularity

Y Sun, Fri AM

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DIII-D, ELM suppression threshold

RMP Threshold Current for ELM Suppression Reduced with Mixed n = 2 + n= 3 Spectrum Fields
Edge Electron Turbulence Increases Near Pedestal when ELMs Eliminated in Both RMP and QH-mode Plasmas

- Both $n_e$ and $T_e$ fluctuation increase in RMP & QH
  - Increase only when ELMs gone
Edge Electron Turbulence Increases Near Pedestal when ELMs Eliminated in Both RMP and QH-mode Plasmas

- Both ne and Te fluctuation increase in RMP & QH
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- Growth rate/shearing rate ratios increase in both but for different reasons
  - RMP: inverse scale lengths up, growth rate up more than shearing rate
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- CGYRO tracks both changes well
  - Turbulence increase consistent with increase in growth/shearing ratio
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- Wide pedestal QH extended to ITER relevant LSN and low torque

Burrell (Chen), Weds PM

C. Sung, Mon NOON
### Review Talk

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<tr>
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<th>Topic</th>
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<tr>
<td>Tues</td>
<td>Snyder</td>
<td>REVIEW: Physics of the Toramak Pedestal, and Implications for Magnetic Fusion Energy</td>
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### Invited Talks

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<th>Speaker</th>
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<tr>
<td>Mon</td>
<td>11:00</td>
<td>Staebler</td>
<td>Transport Barriers in Bootstrap Driven Tokamaks</td>
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<tr>
<td>Mon</td>
<td>Noon</td>
<td>C. Sung</td>
<td>Physics of thermal transport and increased electron temperature turbulence in the edge pedestal</td>
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<tr>
<td>Tues</td>
<td>10:00</td>
<td>Wilcox</td>
<td>Toroidally asymmetric density profiles and turbulence induced by applied 3D fields in DIII-D</td>
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<td>Tues</td>
<td>2:00</td>
<td>Ashourvan</td>
<td>Validation of Kinetic-Turbulent-Neo classical Theory for Edge Intrinsic Rotation in DIII-D Plasmas</td>
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<tr>
<td>Weds</td>
<td>10:00</td>
<td>Paz-Soldan</td>
<td>Spatio-temporally resolved measurement of RE momentum distributions during controlled dissipation</td>
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<tr>
<td>Weds</td>
<td>Noon</td>
<td>Pace</td>
<td>Manipulating Energetic Ion Velocity Space to Control Instabilities and Improve Tokamak Performance</td>
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<tr>
<td>Thurs</td>
<td>9:30</td>
<td>Lyons</td>
<td>Predict-first experimental analysis using automated and integrated MHD modeling</td>
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<tr>
<td>Thurs</td>
<td>10:00</td>
<td>Turco</td>
<td>Understanding the stability of the low torque ITER Baseline Scenario in DIII-D</td>
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<td>Thurs</td>
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<td>Luce</td>
<td>Experimental Challenges to Stiffness as a Transport Paradigm</td>
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<tr>
<td>Fri</td>
<td>9:30</td>
<td>Y. Sun</td>
<td>Dynamic ELM and divertor control using resonant toroidal multi-mode magnetic fields in DIII-D and EAST</td>
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<tr>
<td>Fri</td>
<td>10:00</td>
<td>Samuell</td>
<td>Imaging Main-Ion and Impurity Velocities for Understanding Impurity Transport in the Tokamak SOL</td>
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<tr>
<td>Fri</td>
<td>Noon</td>
<td>H. Guo</td>
<td>An innovative small angle slot divertor concept for long pulse advanced tokamaks</td>
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<tr>
<td>Fri</td>
<td>Noon</td>
<td>Spong</td>
<td>First observation of runaway electron-driven whistler waves in tokamaks</td>
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### TO4 Oral Session on Research in Support of ITER-I

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<tr>
<td>Weds</td>
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<tr>
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<td>Weds</td>
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<td>Weds</td>
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### DIII-D Posters Tuesday and Wednesday Mornings