Overview of Recent Alcator C-Mod Results

48th Annual Meeting of the APS Division of Plasma Physics

Presented by S. J. Wukitch on behalf of the Alcator C-Mod Team.

MIT Plasma Science and Fusion Center, Cambridge MA

Selection of topics from C-Mod physics program
- First results from Lower Hybrid current drive system
- Identification of TEM in ITB discharges
- Pedestal scaling
- ELM characteristics
- Disruption mitigation
- Deuterium retention
- RF enhanced boronization erosion.

Briefly discuss facility upgrades
Advertise upcoming C-Mod Ideas Forum

Work supported by US Dept. of Energy
First LHCD results are Promising

LHRF is primary RF current profile control tool.
- Good experimental test for evaluating LHCD for ITER.
- Has similar wave accessibility and interaction with electrons.

Demonstrated near full LHCD 1 MA discharge with ~900 kW coupled. (Parker BI1.00001)
- Measured X-ray emission profile indicates off-axis deposition. (A. Schmidt QP1.00050)
- Current drive efficiency is in reasonable agreement with simulations. (JO1.00002 R. Wilson)

A promising start for future AT experiments requiring current profile control.
Control of the density peaking is achieved with additional on-axis RF power. Synthetic PCI diagnostic implemented in nonlinear GS2 gyrokinetic simulations reproduce wavenumber spectrum measured in experiment and identify TEM turbulence. On axis heating increases Te and TEM becomes unstable and limits density in ITB.

D. Ernst 21st IAEA 2006
H-mode profiles are stiff ⇒ stored energy ∝ pedestal pressure. Pressure pedestal width is 1-6 mm and independent of $I_p$ (0.4-1.5 MA) and $B_T$ (2.5-8T).
- Find $n_{ped}$ is not an easily controllable quantity and
- Transport appears to control density gradient.

As a result, two important considerations for ITER H-modes are:
- Target density is constrained when injected power ∼ threshold power
- Low gas fuelling efficiency resulting from opaque SOL.

**Graphs:**
- $n_e (10^{20} \text{m}^{-3})$
- $T_e (\text{eV})$
- $p_e (\text{kPa})$
- $R - R_{LCFS} (\text{mm})$

**Legend:**
- High B $n_{ped}$ lower
- $T_{ped}$ higher
- $p_e (r)$ same

**Table:**

<table>
<thead>
<tr>
<th>$B$ (T)</th>
<th>$I_p$ (MA)</th>
<th>$n_e$ ($10^{20} \text{m}^{-3}$)</th>
<th>$T_e$ (eV)</th>
<th>$p_e$ (kPa)</th>
</tr>
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<tbody>
<tr>
<td>5.4</td>
<td>1.2</td>
<td>3</td>
<td>0.6</td>
<td>20</td>
</tr>
<tr>
<td>7.9</td>
<td>1.2</td>
<td>2</td>
<td>0.4</td>
<td>15</td>
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</tbody>
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**References:**
- Hubbard GI.00001
- J. Hughes QP.00044
Fast, High Resolution Diagnostics Enable Detailed ELM Study

At high triangularity, low $n^*$ (<1), observe discrete ELMs with
  - $DW/W_{ped} = 10\text{-}25\%$ per ELM.

ELM dynamics:
  - Rapidly growing precursor mode of $n\sim10$ localized to outboard pedestal and $\sim40\ \mu s$ before filament ejection.
  - ‘Primary’ filaments propagate radially ($V_R=0.5\text{-}7\ \text{km/s}$) with radial size 0.5-1.0 cm.
  - Ejection is coincident with 0.5-1 MHz magnetic oscillation
  - Followed by slower secondary filaments.

Gas Puff Imaging $D_\alpha$ emission
Mitigation reduces halo current (~50%) and thermal heat load (~60%) associated with disruptions.

- High Z gases are more effective at mitigating disruptions.
- Important to deliver gas quickly.

Gas (90% He – 10% Ar) mixture allows for fast delivery while retaining high Z like mitigation efficacy. (M. Bakhtiari JO1.00006)

Gas jet does not penetrate plasma and modeling suggests MHD activity leads to transport of core energy and then radiated from the edge. (V. Izzo JO1.00005)
Significant D Retention is Observed with Mo PFCs

Retain ~20-40% of the fuelled gas with no evidence of saturation.

- Retention is present for bare and boronized Mo PFCs independent of plasma confinement mode.

Observed retention is inconsistent with models based upon ion beam data.

- Discrepancy is large (~100).
- Retention is major problem for T in ITER and reactors.
Accelerated Erosion is Linked to Active Antenna

High power ICRF with metallic PFCs has significant challenges.

• Small fractional Mo concentration can affect plasma performance.
• Boronization is used to control Mo and plasma radiation.
• Observed faster boronization erosion with ICRF.

Accelerated erosion is linked to active antenna.

• Earlier experiments showed sheaths local to antenna are NOT the primary source.
Open Field Lines Terminating on Divertor Shelf are Primary Source

Primary source location is outer divertor shelf.
  • Consistent with optimal boronization location.

ICRF enhanced sheaths increase erosion and impurity production by
  • Raising plasma potentials and
  • Increasing the penetration into core region via convective cells.

Hypothesis: Reducing sheath potential will reduce sputtering and impurity penetration.
Facility Upgrades are Underway

Toroidal cryopump for density control particularly for AT plasmas and access lower collisionality H-modes.
- Designed and tested pump capable of pumping the equivalent of all neutrals in the chamber once every 0.3-0.5 s.

Toroidal row of W tiles (prototypical ITER design) on outer divertor to investigate properties in tokamak environment.

Implement fast, real time matching on one antenna.
- Optimize match for each discharge to maximize coupled power and allow greater flexibility.

Marmar QP1.00043
All C-Mod presentations can be found at:


C-Mod’s poster session is tomorrow afternoon.
