OVERVIEW OF ALCATOR C-MOD CONTRIBUTIONS TO THE 2015 JRT ON OFF AXIS CURRENT DRIVE

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57th APS DPP Meeting, Savannah, GA
Annual Joint Research Targets focus participation from across US fusion program on a key research area

- MIT PSFC
- PPPL
- Columbia University
- University of California Irvine
- UCLA
- Florida International University
- MIT LNS
- General Atomics
- Oak Ridge National Laboratory
- University of Wisconsin Madison
- Oak Ridge Associated Universities
- Princeton University
- Fourth State Research
2015 JRT focused on tokamak confinement and stability with off-axis current drive

- **Annual Target:** Conduct experiments and analysis to quantify the impact of broadened current and pressure profiles on tokamak plasma confinement and stability. Broadened pressure profiles generally improve global stability but can also affect transport and confinement, while broadened current profiles can have both beneficial and adverse impacts on confinement and stability. This research will examine a variety of heating and current drive techniques in order to validate theoretical models of both the actuator performance and the transport and global stability response to varied heating and current drive deposition.

G.M. Wallace
Database study shows decreased stability at high Lower Hybrid Current Drive power per particle

Analysis by S. Scott

\( P_{\text{LH}} \) [kW]

\( V_{\text{loop}} \) [V]

Efficiency [10\(^{20}\) A W\(^{-1}\) m\(^{-2}\)]

\( I_p = 500 \text{ kA} \)

\( \overline{n}_e = 5 \times 10^{19} \text{ m}^{-3} \)
Analysis shows double tearing mode may be excited at $q = 3/2$ surfaces in unstable discharges.

- NIMROD analysis by F. Ebrahimi

Graph showing $q$ profile and radius $R$ with two solutions:
- Least Chi^q solution
- Custom solution within errorbars

Core double tearing mode $m=3$, $n=2$ resonant around $r_1=0.67m$ and $r_2=0.75m$ is unstable. The reconstructed equilibrium has strong reversed shear, but it is within the error bars.
First time-dependent integrated simulations of LHCD using GENRAY/CQL3D model

- Latest version of GENRAY/CQL3D included in TRANSP
- Analysis by F. Poli

Since ion temperature measurements are not available, ion temperature is calculated under the assumption of neoclassical ion thermal transport. Ion temperature profiles are then rescaled to satisfy the total (measured) neutron rate.

For electrons, the experimental electron density and temperature profiles are prescribed as a function of time. The deuterium background ion density is calculated from quasi-neutrality based on two different measurements of $Z_{\text{eff}}$.

Since direct, calibrated measurements of the plasma $Z_{\text{eff}}$ are not available for this discharge, $Z_{\text{eff}}$ is inferred from measured radiation profiles.

Since the LH current efficiency is inversely proportional to $Z_{\text{eff}}$, the effect of different $Z_{\text{eff}}$ assumptions has been assessed. Simulation results suggest that:

(i) $Z_{\text{eff}}$ has minor effect in the calculation of the LH current (except perhaps at low values of $n$);
(ii) matching the measured $V_{\text{loop}}$ is not a sufficient criterion to discriminate between different assumptions on $Z_{\text{eff}}$.

Finally, no kinetic profiles are available outside the last closed flux surface, which introduces further uncertainties related to LH wave propagation in the SOL.

As an example of the results obtainable from this analysis, Figure 4.24 compares the profiles of total parallel current and of the safety factor calculated in free-boundary calculations, with profiles from EFIT reconstructions constrained by the MSE diagnostic (black, thick curve). Two cases are shown for the free-boundary calculations, one with no radial diffusion in CQL3D and one with a radial diffusion of $D=0.05 \text{ m}^2/\text{s}$. The latter is the value needed to reproduce the current profile at all times in the simulation, in particular to reproduce the monotonic $q$-profiles during phase III and IV (corresponding time intervals are given in the caption of Fig. 4.23).

This value is close to the range of $n_{||}$ shown in Figure 4.24:
- Top row: plasma current profiles.
- Bottom row: safety factor profiles.
- From left to right, profiles are calculated at (a) 1.16s, (b) 1.36s, (c) 1.56s, (d) 1.76s.

Different curves refer to the constrained profiles from MSE-EFIT (black), calculations with no radial diffusion (blue) with $D=0.01 \text{ m}^2/\text{s}$ (green) and with $D=0.05 \text{ m}^2/\text{s}$ (red).

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Figure 1. Waveforms for discharge 1120912028. (a) Plasma current, (b) LH power coupled to the plasma, (c) Surface voltage, (d) Line averaged density, (e) Central electron temperature from the GPC diagnostic.

Figure 2. Lower Hybrid power coupled to the plasma. Vertical lines indicate the times at which the antenna phasing is changed, with the values of $n_k$ reported in each time window. Each horizontal line indicates the time windows where measurements from the MSE diagnostic are available. The length of each line (60 ms) represents the integration time of the MSE diagnostic.

G.M. Wallace
GENRAY/CQL3D improves understanding of high density LHCD results with new 2D SOL model

- Subject of invited talk at RFPPC 2015 by S. Shiraiwa

Line Integrated HXR Count Rate

Count Rate (Chords 9-24, 40-200 keV) [s⁻¹]

- experiment
- fullwave
- ray-tracing (SOL11)

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Old SOL

New SOL

G.M. Wallace
New experiments show prompt absorption of LHRF power near LCFS at high density

- **Subject of invited talk VI2 (4pm Thursday)** by graduate student I. Faust

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**Graph:**

- **plot:** IR Thermography [with LH], IR Thermography [ohmic], Langmuir Probe [with LH], Langmuir Probe [ohmic]

**Y-axis:** \( q_i \) [MW/m\(^2\)]

**X-axis:** \( \rho - 1 (r/a) \)

**Legend:**
- IR Thermography [with LH] (green)
- IR Thermography [ohmic] (blue)
- Langmuir Probe [with LH] (red)
- Langmuir Probe [ohmic] (black)

**Graph:**

- **plot:** LH power [MW], \( P_{\text{cond}} \) [MW], \( \Delta P_{\text{cond}}/\Delta P_{\text{LH}} \)

**Y-axis:**
- LH power [MW] (top)
- \( P_{\text{cond}} \) [MW] (middle)
- \( \Delta P_{\text{cond}}/\Delta P_{\text{LH}} \) (bottom)

**X-axis:** \( t \) [s]

**Legend:**
- LH power (top)
- \( P_{\text{cond}} \) (middle)
- \( \Delta P_{\text{cond}}/\Delta P_{\text{LH}} \) (bottom)
Impurity peaking reduced in discharges with LHCD

- Injection of Ca via laser blow-off (LBO) into LHCD (partially non-inductive) and Ohmic discharges
- Analysis by L. Delgado-Aparicio
Research on off-axis current drive will continue as high priority for 2016 run campaign

- Explore stability of non-inductive LHCD discharges by pre-forming and $n_{\parallel}$ control
- Plasma current dependence of parametric instabilities of lower hybrid waves
- MSE measurements with single-pass absorption in high $T_e$ targets
- Impurity transport in fully non-inductive plasmas

G.M. Wallace