Reduced-model (SOLT) simulations of an EDA H-mode shot at Alcator C-Mod

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Scrape-Off-Layer Turbulence (SOLT) Code

- Electrostatic Fluid Model, 2D \( \perp \) to B in OM
- Sheath Physics (closure relations)
- \( O(1) \) Turbulent Fluctuations \( (n_e, T_e, \phi) \)
  Blobs, EDWs, profile modification
- Mean Poloidal Flows \( \langle v_y \rangle \)
  momentum conservation, sheath physics and viscosity

This Talk

- parallel heat flux: \( q_{\parallel}(\Delta r) \) & SOL width (original motivation)
- quasi-coherent spectral features (surprise!)
SOL width decreased with increasing power ($T_e$) in the experiment.

\[ q/\Delta r \sim \exp(-\lambda \Delta r) \]

Shot #1100303018 sampled at 2 times:

- $t = 1.05$ sec: $P_{\text{CMOD}} = 1.8$ MW, $\lambda_{\text{CMOD}} = 1.3$ mm
- $t = 1.41$ sec: $P_{\text{CMOD}} = 1.4$ MW, $\lambda_{\text{CMOD}} = 2.3$ mm

How we explore this scaling with SOLT:

- Given $n_e$ and $T_e$ profiles for C-Mod at each time, we adjust the mean flow in SOLT until $P_{\text{SOLT}}$ agrees with $P_{\text{CMOD}}$ at each time.
- We analyze $q/\Delta r$ in each of these 2 power-matched simulations.
Inside the SEP ($\Delta r < 0$), we damp SOLT $n_e$ and $T_e$ to the C-Mod profiles.

Inside the SEP, we damp the mean poloidal flow $\langle v_y \rangle$ to a reference flow ($v_{y0}$) derived from the C-Mod profiles.

Reference flow ($\Delta r < 0$):
\[ e Z n_i E_r - \partial_r (n_i T_i) = 0 \]
\[ \Rightarrow E \times B \text{ drift:} \]
\[ v_{y0} = -\tau \cdot \partial_r (n_e T_e)/n_e, \tau \sim T_i/T_e \]

$\tau$ controls the turbulence e.g. Power $\rightarrow$ SOL
Scaling of SOL width ($\lambda$) with Power ($P$)

- Tune $\tau$ so that SOLT’s Power $\rightarrow$ SOL matches C-Mod’s e.g. at the earlier time slice:

At power-matching for the two time slices, the same trend is observed:

$\lambda$ increases with decreasing power & $T_e$ in experiment and simulation.
Parallel heat flux is limited by collisions in the near-SOL

\[ q_{\parallel} = 1/q_{FL} + 1/q_{SL} + 1/q_{CL} \]

parallel heat flux regimes

- flux - limited:
  \[ q_{FL} = C_{FL} n_e v_e T_e \sim T_e^{3/2} \]

- sheath - limited:
  \[ q_{SL} = s_E n_e c_s T_e \exp[e(\Phi_B - \Phi)/T_e] \sim T_e^{3/2} \]

- collision - limited:
  \[ q_{CL} = 3.2 n_e c_s T_e / \Lambda, \Lambda = v_e L_{\parallel} / \Omega_i p_s \sim T_e^{7/2} \]

\( q_{CL} \) acts as the *bottleneck* in the near-SOL, limiting parallel transport and so increasing the SOL width, most effectively with decreasing \( T_e \).
A string of blobs, radially-localized about a maximum of the mean flow just inside the separatrix (blob birth zone), intermittently emitting plasma into the SOL.

- **C-Mod’s QCM**: $\nu \sim 100$ kHz, $k_y \sim 1.5$ cm$^{-1}$
QCM dispersion is unambiguous in the birth zone.

But other modes emerge in the near-SOL.
Linear Analysis of Time-Averaged Profiles suggests an underlying transport dynamics

- drift-interchange mode
- blob birth zone
- straddles (±) flow regions
- blob emission
- sheath mode
- blob graveyard

\( \gamma (\text{MHz}) \)

\( k_y \text{ (cm}^{-1}) \)

\( \Delta r \text{ (mm)} \)

\( \langle v_y \rangle \)

\( |\delta \phi|^2 \)

\( k_y = 2.66 \text{ cm}^{-1} \)

\( k_y = 0.8 \text{ cm}^{-1} \)
What is the origin of the cascade barrier at $k_y \approx 1 \text{ cm}^{-1}$?

The peak in the energy spectrum does not correspond to the peak in the linear growth rate, in this or in the much richer (3D, B-field geometry, ballooning modes, etc.) linear analysis by Jim Myra at al. (next talk)

Why does the energy collect at $k_y \sim 1 \text{ cm}^{-1}$ in SOLT’s QCM?
Part 1
Scaling of the SOL width for parallel heat flow

• We power-matched SOLT simulations to a C-Mod EDA H-mode shot by adjusting the mean flow in the simulations.
• We recovered the observed SOL($q_{||}$) width scaling with $T_e$.
• $q_{||}$ is limited by collisions in the near-SOL: $q_{||, CL} \sim T_e^{7/2}$
  ➢ consistent with $T_e$ dependence observed for this shot
  ➢ differs from a similar SOLT study of NSTX (sheath-limited) scaling

Part 2
SOLT’s Quasi-Coherent Mode

• consists of a string of blobs, moving with the mean flow in the edge,
  ➢ centered in the birth zone, where the flow shear rate $\approx 0$.
  ➢ Dispersion is set by the birth-zone flow (Doppler) and broadcast into the near-SOL.
  ➢ $\sim \frac{1}{2}$ of the net particle flux comes from the QC mode.
  ➢ Linear unstable modes (D-I, K-H) may drive transport in the saturated state.
  ➢ $|\delta n(k_y)|^2$ peaks at $k_y > 0$. Why? What is the origin of this nonlinear mode?
    No edge-localized, unstable linear eigenmode drives this peak directly.
    See J.R. Myra et al. – next talk.