Relationship between Edge Gradients and Plasma Flows in Alcator C-Mod

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Motivation and Challenge: Develop first-principles understanding of transport physics in Edge Plasma region

Background: We are investigating a new view of edge transport behavior...

- Edge Plasma ~ a system at critical gradient near LCFS
- Critical Gradient ~ set by Electromagnetic Turbulence

LCFS pressure gradients scale with $\sim I_p^2$

Poloidal beta gradients ($\alpha_{MHD}$) are invariant at same normalized collisionality

This behavior makes contact with EM fluid turbulence simulations†.

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This behavior makes contact with EM fluid turbulence simulations†.

Question: Does magnetic shear and/or ExB flow shear also play role? => Focus of this talk

Experiment 1: Does magnetic shear near LCFS influence ‘critical gradient’?

- Run identical ohmic L-mode discharges, with LCFS topology varying from Double-Null to Inner-Wall-Limited
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  - Elongation ~ 1.65
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  - Scanning Langmuir-Mach probes
  See N. Smick, PP6.00085, Wednesday 2:00 pm
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Are steep pressure gradients near the LCFS affected by separatrix location?
Result: SOL profiles are robustly insensitive to location of separatrix flux surface

- **Diverted profiles are reference**
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- Diverted profiles are reference.
- Separatrix sweep has no effect on steep gradients in Near SOL.
- Steep gradients do not appear in Far SOL when separatrix is positioned there.
Result: ‘critical gradient’ ($\alpha_{MHD}$) near LCFS remains the same in Inner Limited versus Double-Null Diverted discharges.
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$$\alpha_{MHD} \sim \nabla nT_e \frac{I^2}{I_p^2}$$

Location: 1 mm outside LCFS

$$\frac{1}{q} \left( \frac{\lambda_{ci}}{R} \right)^{1/2}$$
Result: ‘critical gradient’ \( (\alpha_{MHD}) \) near LCFS remains the same in Inner Limited versus Double-Null Diverted discharges

\[
\alpha_{MHD} \sim \frac{\nabla nT_e}{I_p^2}
\]

Location: 1 mm outside LCFS

- Independent of separatix location, \( \alpha_{MHD} \) near LCFS has same values and trend with inverse collisionality
Result: ‘critical gradient’ \((\alpha_{MHD})\) near LCFS remains the same in Inner Limited versus Double-Null Diverted discharges

\[ \alpha_{MHD} \approx \nabla nT_e / I_p^2 \]

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- Independent of separatix location, \(\alpha_{MHD}\) near LCFS has same values and trend with inverse collisionality
- \(\alpha_{MHD}\) values are slightly lower than those from Lower Single-Null discharges \((Bx\nabla B\text{ toward } x\text{-pt})\)
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Answer: Magnetic Shear (i.e., separatix location, elongation) does not set the value of ‘critical gradient’ observed near LCFS
A strong Velocity Shear Layer persists near the LCFS, independent of magnetic separatrix location.

- Diverted profiles exhibit strong shear layer near separatrix.

*See I. Hutchinson, PP6.00084, Wednesday 2:00 pm*
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Perpendicular Velocity Shear near LCFS is comparable to Ballooning Growth Rate

=> possible explanation for topology insensitivity

- Perhaps ExB flow shear dominates over magnetic shear in setting steep gradients in Near SOL
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- On open field lines, plasma potential is tightly coupled to electron temperature profile

- Resultant shear layer and steep gradients at the LCFS would then be insensitive to limiter versus separatrix topology
Experiment 2:
Does flow shear explain sensitivity of critical gradient ($\alpha_{MHD}$) to upper/lower X-point topology?

Previous experiments revealed sensitivity of $\alpha_{MHD}$ to Upper/Lower X-pt topology†

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- Previous experiments revealed sensitivity of $\alpha_{MHD}$ to Upper/Lower X-pt topology:
  - ‘Favorable’ $B_x \nabla B$ produces higher $\alpha_{MHD}$ near LCFS at mid to high collisionality
  - Correlated with toroidal rotation...
    ...Co-current rotation ---&gt; higher $\alpha_{MHD}$
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$\Rightarrow$ Connection to flow shear implied

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- Perform magnetic X-pt topology scans at “Mid” and “Low” collisionality in ohmic L-mode plasmas

- Record SOL profiles and plasma flows parallel ($V_{||}$) and perpendicular ($V_{\perp}$) to $B$ with new ‘Gundestrup’-type scanning Langmuir probes

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- Experiment 2:
  - Perform magnetic X-pt topology scans at “Mid” and “Low” collisionality in ohmic L-mode plasmas
  - Record SOL profiles and plasma flows parallel ($V_{//}$) and perpendicular ($V_{\perp}$) to $B$ with new ‘Gundestrup’-type scanning Langmuir probes
  
  $\Rightarrow$ What is relationship between gradients and $V_{//}$, $V_{\perp}$ flows/flow shear?

Result:

$V_\perp$ shear is indeed sensitive to upper/lower X-point topology, consistent with changes in ‘critical gradients’ ($\alpha_{MHD}$)

Alcator C-Mod

Mid Collisionality

Plasma Potential

Parallel Flow

$V_\perp$ Flow

$V_\perp$ Phase

Low Collisionality

Parallel Flow

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Result:

\( V_{\perp} \) shear is indeed sensitive to upper/lower X-point topology, consistent with changes in ‘critical gradients’ \( (\alpha_{MHD}) \).

Mid Collisionality

- Reduced near LCFS, Flatter profile

Low Collisionality

- ~ No Change

Plasma Potential

Parallel Flow

\( V_{\perp} \) Flow

\( V_{\perp} \) Phase

Distance into SOL (mm)
Result:

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**Mid Collisionality**

- Reduced near LCFS, Flatter profile
- Reduced Co-Current Flow
- Flatter profile near LCFS
- Flatter profile near LCFS

**Low Collisionality**

- ~ No Change
- ~ No Change
- ~ Similar gradients at LCFS
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- ~ No Change

Pressure Gradient Scale Length, \( L_p \)

Minimum is \( \sim 2 \) mm into SOL

Ballooning Growth Rate

\( \sim \frac{2C_s}{(R \ L_p)^{1/2}} \)

\( V_\perp \) Flow Shear

\( V_\perp \) Phase Shear
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Mid Collisionality

- Reduced Near LCFS
- Pressure Gradient Scale Length, $L_p$
  - Minimum is ~2 mm into SOL

Low Collisionality

- ~ No Change

Balloonning Growth Rate

- $\sim 2C_s/(R L_p)^{1/2}$
- ~2 MHz near LCFS

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Max Shear is ~2 mm into SOL, comparable to Ballooning Growth Rate

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**Low Collisionality**

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\( V_\perp \) shear appears to be key controlling element!
Summary

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  ‘Critical gradient’ ~ set by EM turbulence ($\alpha_{MHD}$), tied to collisionality

What is the role of Magnetic Shear and ExB Shear in setting these gradients?
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What is the role of Magnetic Shear and ExB Shear in setting these gradients?

• L-mode critical gradients ($\alpha_{MHD}$) are found insensitive to magnetic shear
  SOL profiles are unchanged in Double-Null versus Inner-Wall-Limited discharges
  Persistent $V_{\perp}$ shear layer observed near LCFS
  $V_{\perp}$ shear ~comparable to ballooning growth rate near LCFS
  => may explain topology insensitivity
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Upper versus Lower X-point topology is found to act as a ‘control knob’ on $V_\perp$ shear layer and attained $\alpha_{MHD}$ at mid-to-high collisionality

$B_x \nabla B$ toward X-point:

Increased co-current toroidal rotation

More positive potential at LCFS

Increased $V_\perp$ shear => higher values of $\alpha_{MHD}$
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=> Edge ‘critical gradient’ ~ set by ExB shear-regulated EM turbulence...