On the non-stiffness of edge transport in L-modes

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Outline

• Motivation
  – Carbon profile shown independent of Ip on TCV
  – Core scalelengths seem independent of Ip, despite $\tau_E \propto I_p$
• Determine R/L$_{Te}$ vs I$_p$, P$_{EC}$, $\delta$ in core AND edge regions
• Core region is stiff, edge is not
• 1-D transport simulation with new model
• Conclusions
Impurity transport independent of Ip

O. Sauter et al, IAEA 2010 EXPC/P8-13 and EXS/P2-1
Same for $T_i, \nu_\Psi$ independent of $I_p$

O. Sauter et al, IAEA 2010 EXPC/P8-13 and EXS/P2-1
electron transport independent of \( I_p \) as well

\[ \text{Profiles self-similar outside mixing radius} \]

\[ \text{We} \propto I_p \]

\[ \text{Ip scan: } q_{95} \text{ from 2.5 to 10} \]
What is $R/L_{Te}$ global profile for gyrokinetic?

- **A**: $R/L_{Te} \rightarrow 0$ at $\rho=1$ : Used in most simulations
- **B**: $R/L_{Te} \rightarrow 3-10*(\text{core})$ at $\rho=1$ : seems proposed by expt
$n_e, T_e$ versus $I_p$ in TCV, with $z$-axis sweep

Thomson data, with slow $z$-axis sweep
$n_e, T_e$ versus $I_p$ in TCV, with z-axis sweep

Clear increase of total energy with $I_p$
Change of scalelengths only for $\rho_V > 0.85$

- Normalization vs value at $\rho=0.8$ is not a good idea
- Normalizing at $\rho=0.98$ depends on the quality of fit
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Note: $\rho_\psi$ too narrow edge region.

R/Lpe identical in core.

R/Lpe $\propto I_p$ for $\rho_V > 0.8$ (x2.6>core at $I_p = 285kA$)

Note: $\rho_\psi$ too narrow edge region.
PEC scan at constant Ip
PEC scan at constant Ip

- Normalization on $p_e(0.8)$ shows self-similar profiles
PEC scan at constant Ip

![Graph showing PEC scan at constant Ip](image)

- Stiff in core
- Non-stiff in edge
$P_{EC}$ scan at constant Ip

- Stiff in "core" region $R/L_{Te} \approx 15$
- $R/L_{Te} > 30-40$ in edge region
Strong effect of $\delta$ on global profiles

- $\delta < 0$: same prof with $\frac{1}{2} P_{EC}$

Strong effect of $\delta$ on global profiles

- $\delta < 0$: same profile with $\frac{1}{2} P_{EC}$
- $\delta < 0$: higher $p_e$ with same $P_{EC}$
"Local" transport characteristics in stationary state:

\[ V' Q_e = \int_0^\rho S_e dV = -n_e \chi_e V' \langle |\nabla \rho|^2 \rangle \frac{\partial T_e}{\partial \rho} \]

\[ V' = \frac{\partial V}{\partial \rho} \quad \frac{R_0}{L_{Te}} = - \frac{R_0}{T_e} \frac{\partial T_e}{\partial \rho} \langle |\nabla \rho| \rangle \]

\[ \frac{\langle |\nabla \rho| \rangle}{\langle |\nabla \rho|^2 \rangle} \frac{V' Q_e}{T_e} = n_e \chi_e V' \frac{R_0}{L_{Te}} \]

Stiff: \( \chi_e \) increases when \( Q_e \) increases \( \Rightarrow R/L_{Te} \approx \text{cst} \)
Qe/Te versus R/LTe from TCV data

\[ \frac{\langle | \nabla \rho | \rangle}{\langle | \nabla \rho |^2 \rangle} \frac{V' Q_e}{T_e} = n_e \chi_e V' \frac{R_0}{L_{Te}} \]

\[ \chi_e \rho = \nabla \nabla \]

\( X_e(\text{edge}) \) is large but it is relation between \( Q_{e\_norm} \) and \( R/L_{Te} \) which matters
Qe/Te versus R/LTe from TCV data

\[
\frac{\langle | \nabla \rho | \rangle}{\langle | \nabla \rho |^2 \rangle} \frac{V'Q_e}{T_e} = n_e x_e V' \frac{R_0}{L_{Te}}
\]

X_e (edge) is large but it is relation between Q_e_norm and R/LTe which matters
$$\frac{\langle |\nabla \rho| \rangle}{\langle |\nabla \rho|^2 \rangle} \frac{V'Q_e}{T_e} = n_e \chi_e V' \frac{R}{L_{Te}}$$

$X_e(\text{edge})$ is large but it is relation between $Q_{e\_norm}$ and $R/L_{Te}$ which matters.
A combined core-stiff / edge-non-stiff model

Assuming edge non-stiff:

(3) $\chi \propto \frac{a^2}{\tau_E} \propto P^{0-0.2}$

Three main regions w.r.t transport:
1) center: ST/current hole effects: large $\chi$
2) Core: stiff, $R/L_{Te}\sim$ cst
3) Edge: non-stiff

Stiffness: $\tau_E \propto P^{-0.7}$

(2) $\chi \propto \frac{a^2}{\tau_E} \propto P^{0.7}$

test on P scan

(1) $\sim P^{0.1}$
A combined core-stiff / edge-non-stiff model

Stiffness: \( \tau_E \propto P^{-0.7} \)

Assuming edge non-stiff:

\( \chi \propto \frac{a^2}{\tau_E} \propto P^{0.7} \)

(3) \( \chi \propto \frac{a^2}{\tau_E} \propto P^{0.7} \)

Leads to strong diff. with P↑

\( \chi_e/\chi_e(400\text{Kw}) \)

\( P \)
Results using 1-D ASTRA model

• We start from this $\chi_e$ profile and other plasma parameters
• Scale core $\chi_e \sim P^{0.7}$ and edge with $P^{0.1}$
Results using 1-D ASTRA model
Same technique for $\delta=+0.4$, $\delta=-0.4$ cases

Recover profiles with:
1. Same transport in core: $P^{-0.7}$
2. Reduced transport near edge with $\delta<0$

Stiff edge not sufficient
Reconciles with gyrokinetic simulations

- Difference in linear and nonlinear simulations found only for $\rho > 0.7$
- Present model resolves this issue

\[ \gamma k_\bot^2 |v_{\text{th}}|^2/\alpha \]

A. Marinoni et al, PPCF Plasma 51 (2009) 055016

GAMs, see TCV comprehensive analysis S. Coda TTF2013
Conclusions

- Core transport limits $R/L_{Te}$ (and $R/L_{Ne}$ to some extent)
- Even with favourable $I_p$ scaling profiles remain self-similar
- Therefore values at $\rho=0.8$ are changing with $I_p$
- This is possible with non-stiff transport in $[0.8,1]$
  - $\chi$ hardly increase with increased power
- Simple model recovers $I_p$, $P$ scaling and $\delta$ effects with:
  - $\chi \sim P^{0.7-0.8}$ in core
  - $\chi \sim P^{0-0.2}$ in edge
- Explains effects of negative $\delta$ (which does not penetrate)
- Explains good $P$ scaling of edge I-mode
- Explains profile consistency
- Explains "I-family", + can have wide variety of parameters
- Shows how L-mode builds up $R/L_{Te} \rightarrow 100$ with increasing power towards H-mode transition