Barriers in different transport channels (e- and i-thermal, particle) and relation to pedestal structure

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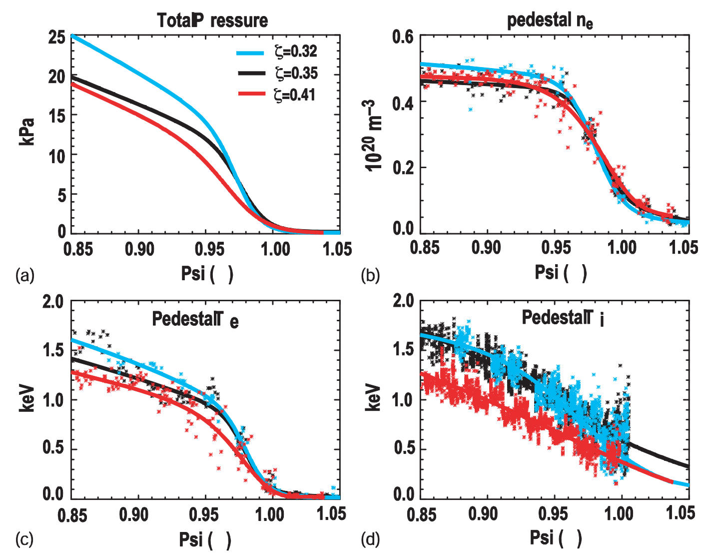
Edge Transport Barriers exist in multiple channels

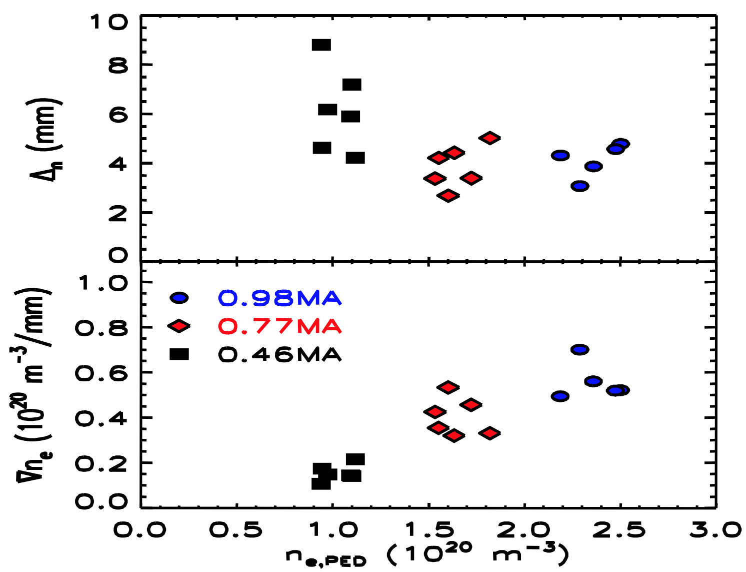
- In general, edge transport barriers (aka H-mode, pedestal) form in multiple channels:
  – Ion thermal
  – Electron thermal
  – Multi-species particles
  – Momentum
- In H-modes, barriers in different channels often have roughly comparable extent and degree. **However (as in core transport), this is not always the case!**
- Both theorists and experimentalists often speak loosely of “the pedestal”, or “pedestal width”, usually meaning electron or total *pressure* pedestal.
- In both our measurements and our modeling, it is important to consider all channels (in particular thermal vs particle barriers) and their contributions to pedestal structure.

Many examples of different pedestal structures exist

- To first order, widths of n_e, T_e, T_i pedestals are often similar.
- This makes intuitive sense if ∇/n term is dominating E_r well, suppressing turbulence.
- But, many measurable differences in structure and strength of barriers.
- Eg. T_i widths can be larger than n_e (JT-60U, DIII-D).
- Density widths can be wider at low n_e, when neutrals penetrate further. $n_e(r)$ shifts wrt T_e with gas puffing.
- Not many systematic comparisons of structure, width across channels are published.



D3D
Leonard
NF
2007



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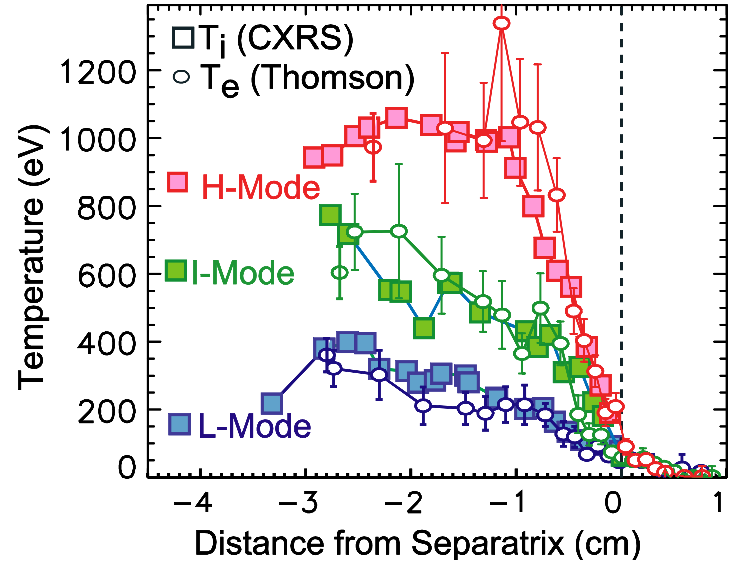
PoP
2006

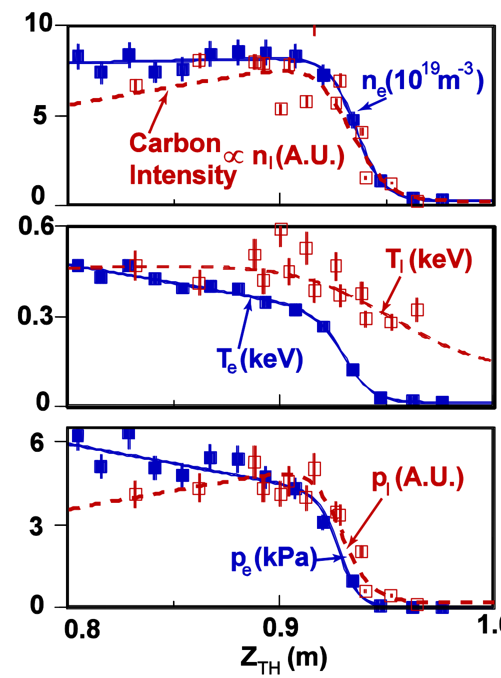
$T_i(r)$ can be quite different from $T_e(r)$

- In high density, strongly coupled regime T_i=T_e to within error bars. (eg, C-Mod)

- In other cases, likely due to different neoclassical regime, lower coupling, the T_i gradient is much weaker, hardly any "pedestal" (eg, D3D,NSTX).



C-Mod, McDermott PoP 2008



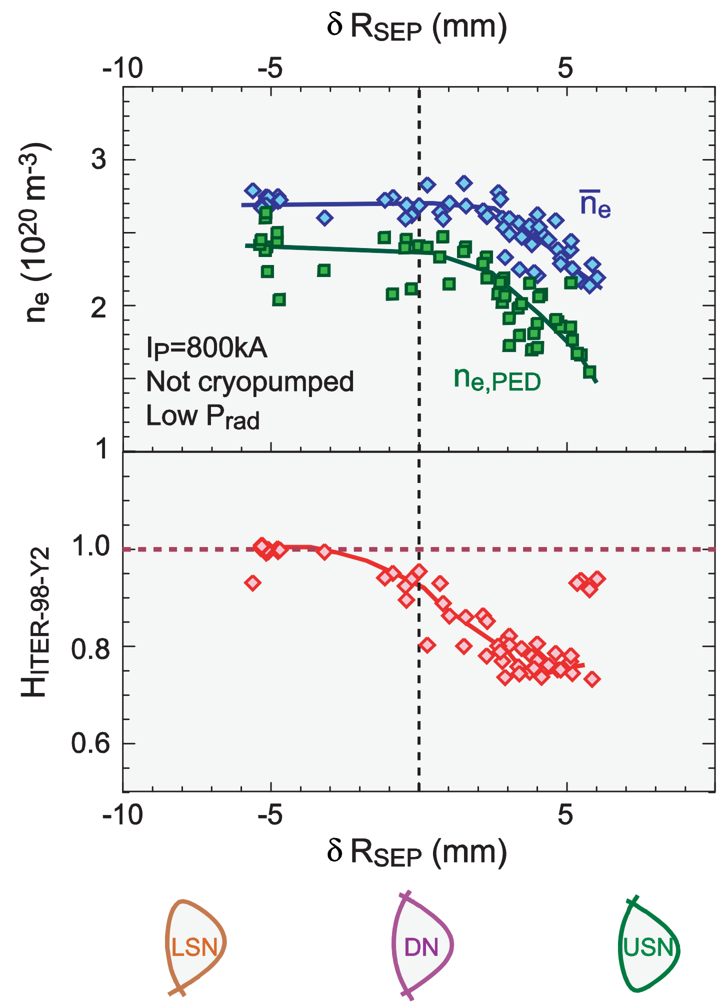
DIII-D, Groebner 1998

A. Hubbard, Pedestal workshop 2010

Degree of transport suppression can differ, and scale differently

- For example, when S_{sep} is varied on C-Mod, n_e and confinement (p_e, T_e) pedestals vary differently.

- The ideal regime would have independently **controlled** energy and particle barriers, to avoid impurity buildup and pressure limits.
- Fortunately, many fluctuations & waves do seem to affect D more than χ.
  - eg QC mode in EDA, EHO in QH mode).
  - eg, LHCD reduces n_e, raises T_e.



C-Mod
Hughes
APS
2009

An extreme example is "I-mode"; strong thermal barrier, little or no particle barrier

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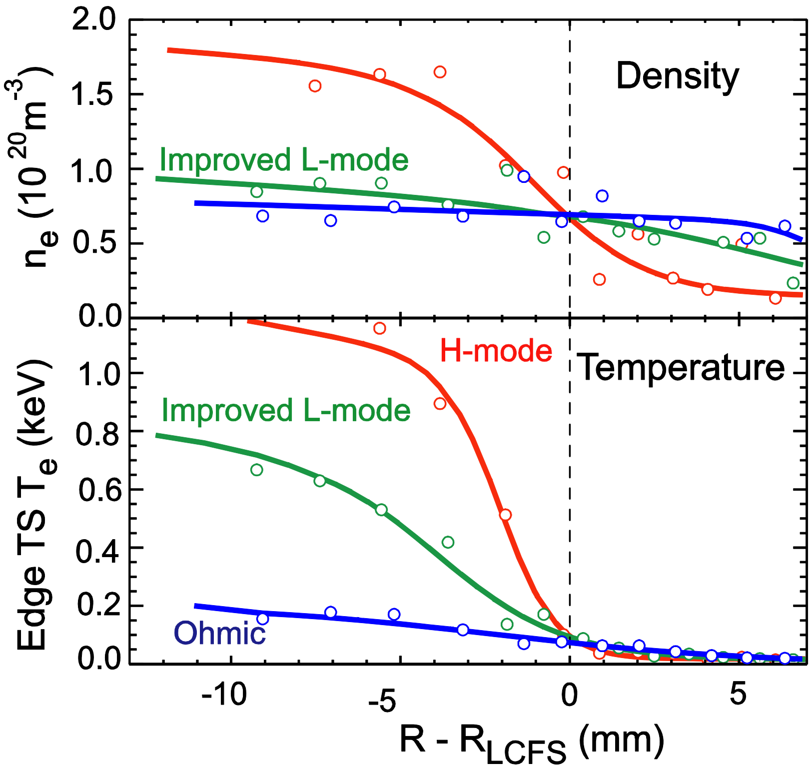
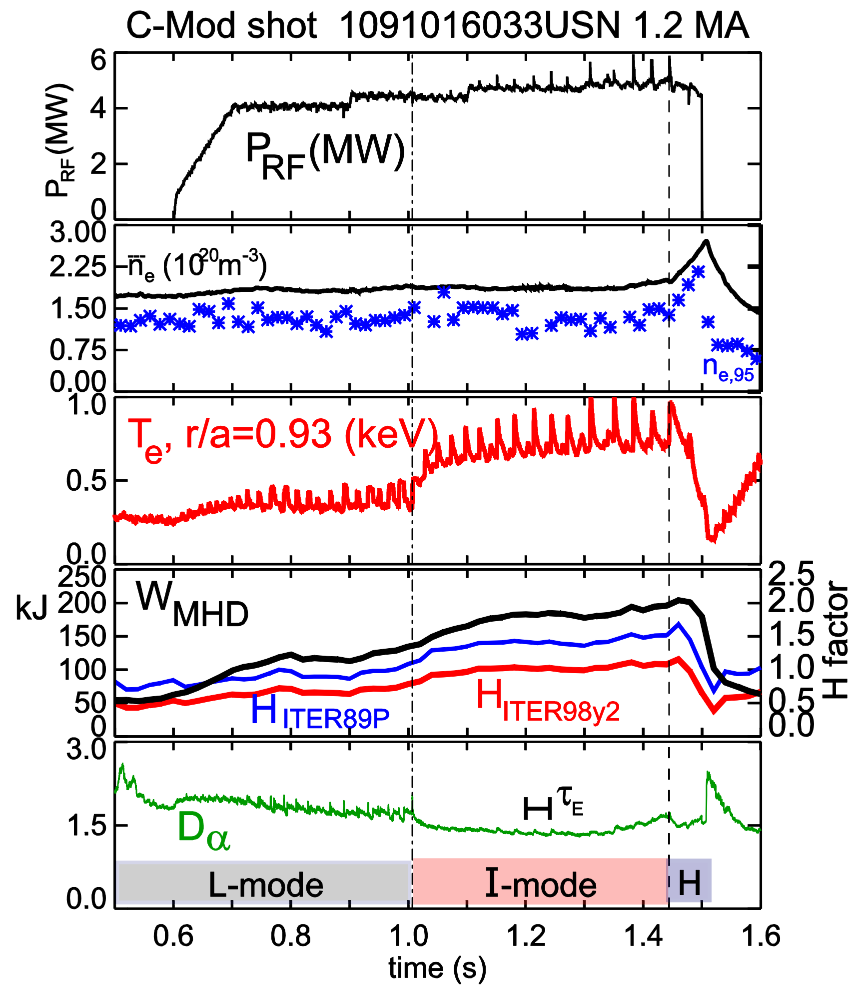


- Steep T_e pedestal
- L-mode density profile with broad SOL.



Details of C-Mod I-mode regime in D. Whyte *et al*, Nucl Fusion **50** (Aug 2010) 105005

Another example, new "Enhanced H-mode" on NSTX, seems to change T more than density pedestals. *R Maingi, next talk.*

So, how to treat different barriers?

Experimentalists:

- US experiments can all now independently resolve the different pedestal structures to sufficient resolution! So, we need to **use** this information, collate and report individual width and height scalings in our past databases and, better, in controlled experimental scans! We no longer need to infer a pressure width from the height, though this can be a useful cross-check.

- Design experiments to elucidate apparently different dependences. Eg, for C-Mod,
  - Larger scans in upper and lower triangularity.
  - Scans in density from large to small neutral penetration.
  - Up-down magnetic balance.
  - Vary magnetic shear.

Theory and Simulation

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- Given we know that transport barriers in different channels can be, and often are, different in structure, width and strength, a complete model and prediction will have to take all channels into account, should give predictions for n, T_e, T_i pedestals. Ideally also rotation, which is complicated by pedestal "source".
  - This doesn't mean that 'pressure only' predictions are not useful!

- In my view, they will have to include both neoclassical and turbulence models, plus neutral fuelling. All likely to be important!
- Cannot neglect, or assume, the particle profile shape
  - Even though the core transport folks often do, it's kind of cheating…
  - As Stacey, Groebner, Callen et al have shown, changes in both D and V can be very important in barriers, and are hard to separate.

- **Testable predictions, even qualitative, as to which channels are likely to have strongest suppression, widest barriers etc will be useful in guiding experiments.**

Specific questions for transport barrier physics raised by "I-mode".

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- I-mode regime clearly separates transport channels.
  - Strong, H-mode-like thermal barrier, but with L-mode-like particle transport.
- Poses a number of questions
  - L-H transition conditions (and dependence on configuration!)
    - Do different SOL flows vs configuration play a role?
  - Mechanism for L-I transition – reduced χ without fluctuation suppression.
    - Change in relative phases of T_e, n_e, ϕ fluctuations? (c.f. Terry, Newman et al)
    - Type and role of high-*f* fluctuations
  - Separate effects on χ and D. Reminiscent of many ITBs. WHY?
    - Different effect of $V_{//}$ and $V_{\perp}$ shears on heat vs particle transport, perhaps via effect on phases?
    - Different turbulent modes (k_{pol}, freq) responsible, only some suppressed?
    - Different ratios of turbulent and residual χ, D? (c.f. Malkov, Diamond)
    - Why NOT a particle transport bifurcation with an E_r well?
  - Generation of 'intrinsic rotation', without density gradient.

Summary

- Edge transport barriers ("pedestal") involve multiple transport channels; e-, ion thermal, particle, momentum….
- The degree of transport suppression, and radial extent of the suppression, can vary significantly between channels.
- Both experiments and theory/simulation need to take them into account to develop a more complete understanding and prediction.
- Experiments already largely have the tools/resolution to study this. We need to use and report them more systematically.
- Models are also being developed which should be able to predict different channels. Comparisons/validation are key! Individual profiles may give more direct validation than pressure, which is a composite.