Two-phase L-H transitions in unfavorable configurations in Alcator C-Mod

Alcator
C-Mod

Presented by Amanda Hubbard

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OUTLINE

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- **Introduction:** Influence of magnetic configuration on L-H threshold, brief review of SOL flow results.

- **Experiments with reversed field and current.**
  - SOL flows.
  - **Evolution of profiles**
  - **Changes in edge thermal transport and fluctuations prior to "L-H" transition.**

- **Discussion:**
  - *What can we learn about L-H transitions? What more information do we need?*
  - *How do these experiments relate to other 'slow transitions'*
  - *Opportunities for joint research? For comparisons with models?*

L-H power threshold is well known to depend on magnetic configuration

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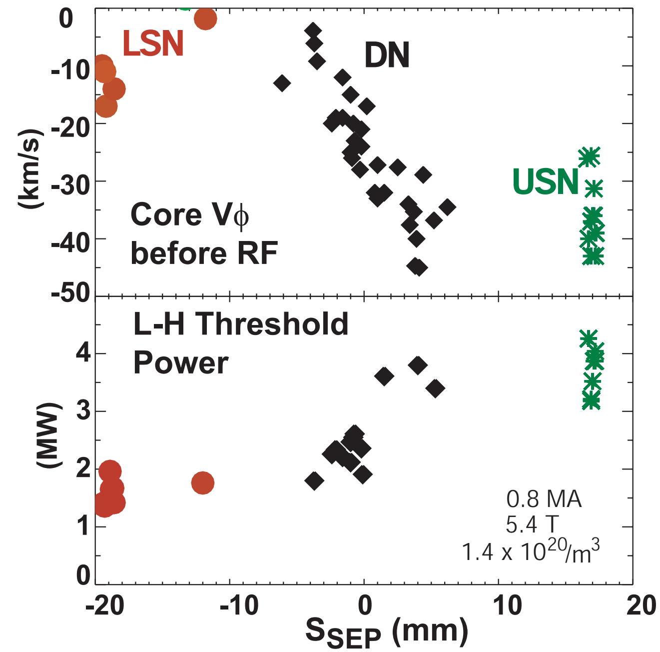
- Higher thresholds with ion Bx∇B drift away from active X-point, seen since earliest ASDEX H-modes.
- Very sensitive to S_{sep}, which may explain variable results in “DN”
- Several studies ~2000 (C-Mod, AUG, DIII-D) showed edge *temperatures* at L-H also ~2X higher – i.e. not just a difference in edge transport.

- C-Mod experiments ~2003 showed a likely connection to SOL flows and related core rotation.
  - HFS flows reverse direction LSN to USN, affect core rotation.

LaBombard,
Nucl. Fus. 2004, PoP 2005



Results appear consistent with SOL flows causing the *differences* in P_{thresh} with configuration (not the transition itself).

Reversing B and I_p removes ambiguities in comparing different magnetic configurations

C-Mod has only one (lower) "divertor" structure. This means:

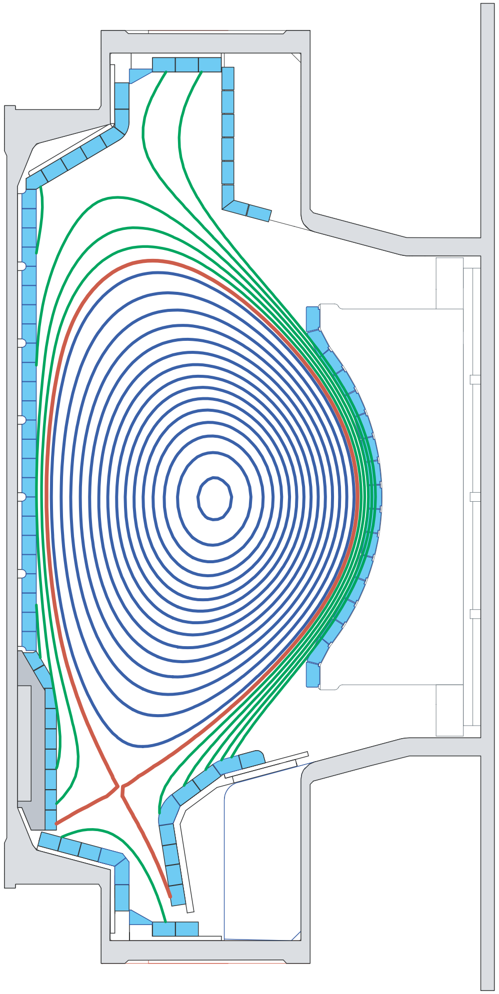
- Upper tile configuration is more open than lower, not designed for high heat flux.
- LSN and USN shapes were not exactly symmetric.

Do these effects contribute to the observed differences in SOL, flows/rotation, profiles, threshold?

To find out, reversed I and B to compare in SAME configuration:

"Reverse B" has ion Bx∇B drift **upward.** ↑

"Normal B" has drift **downward.** ↓



Key results confirmed by field reversal:
Inner SOL flows are unaffected by I, B direction

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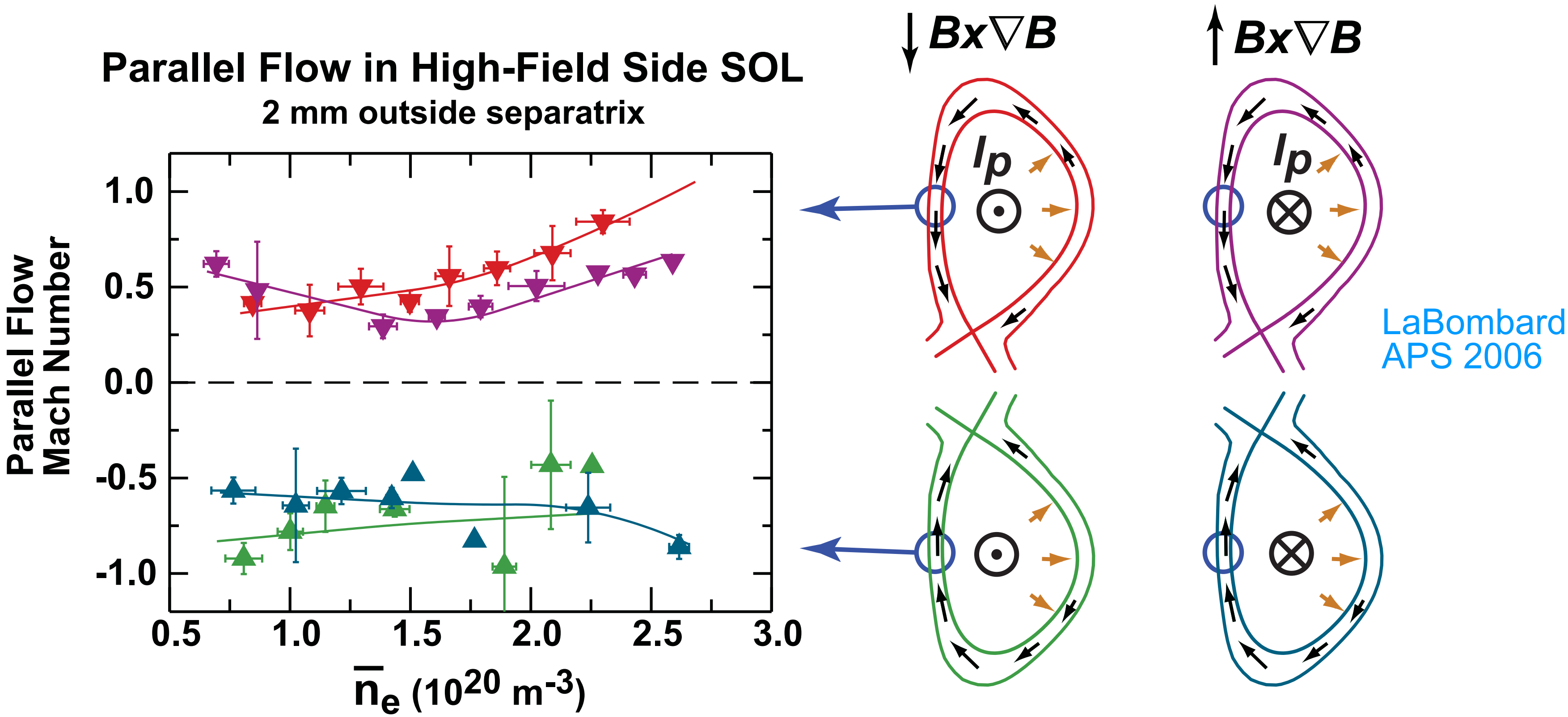

- **Flow direction depends only on X-point location, NOT Bx∇B.**
  Consistent with transport-driven flux. Similar Mach No. in forward, reversed B.

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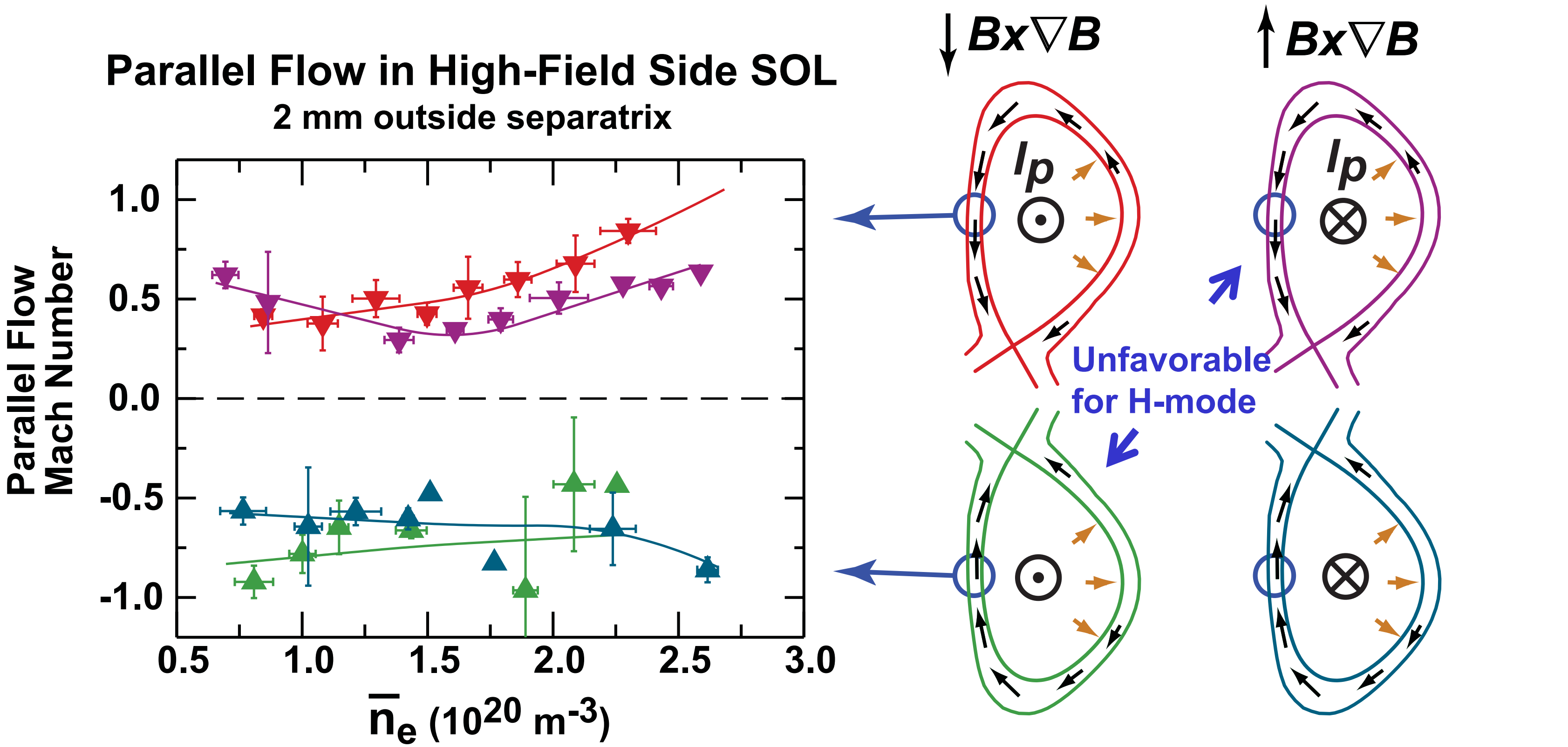

- **Flow direction depends only on X-point location, NOT B×∇B.** Consistent with transport-driven flux. Similar Mach No. in forward, reversed B.
- But, since I_p is also reversed, flows are *counter*-I_p when B×∇B is away from the X-point ('unfavorable'), *co-I_p* in favorable cases.

Key results confirmed by field reversal:
L-H Thresholds higher in Reversed B LSN

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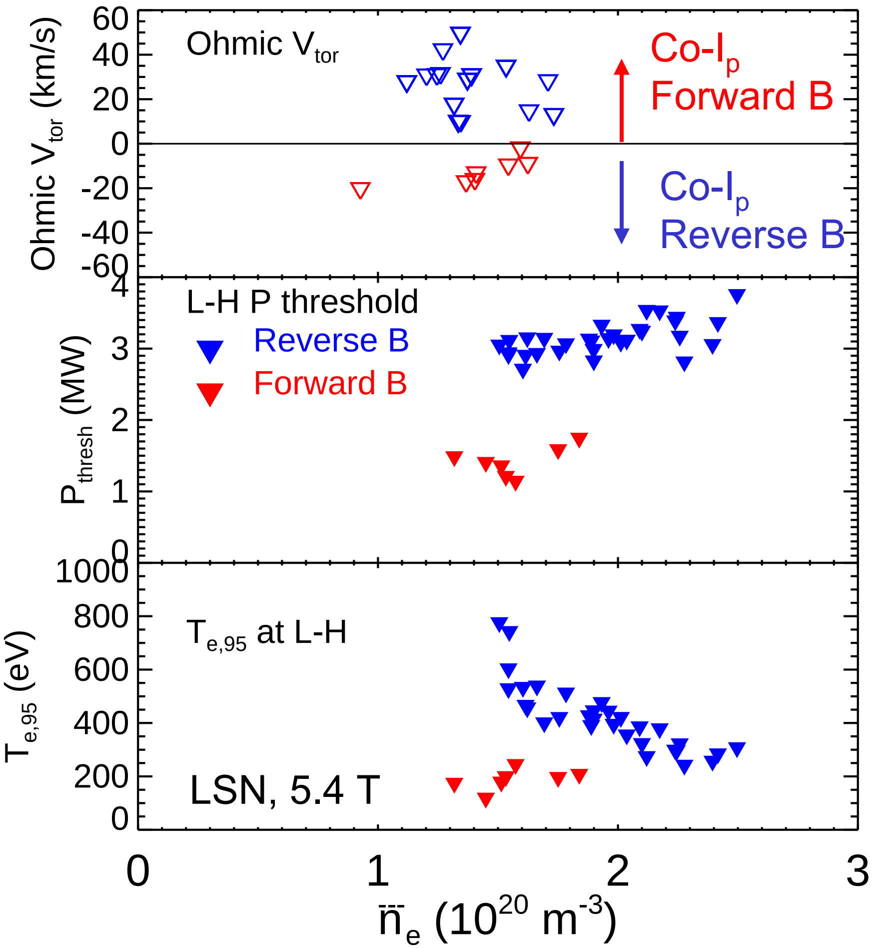
- **Ohmic core rotation is more counter-I_p in reversed field LSN.**
  - Co-I_p increment when power, pressure increase.
- LSN **power thresholds** are much higher (2.7-3.7 MW) - "unfavorable"
  - Usual variability with wall conditions.
- **Threshold temperatures and gradients are also much higher** (>400 eV), particularly at low n_e.
  - This has varied between campaigns.



Edge $T_e(r)$ with unfavorable drift shows interesting evolution *before* L-H transition

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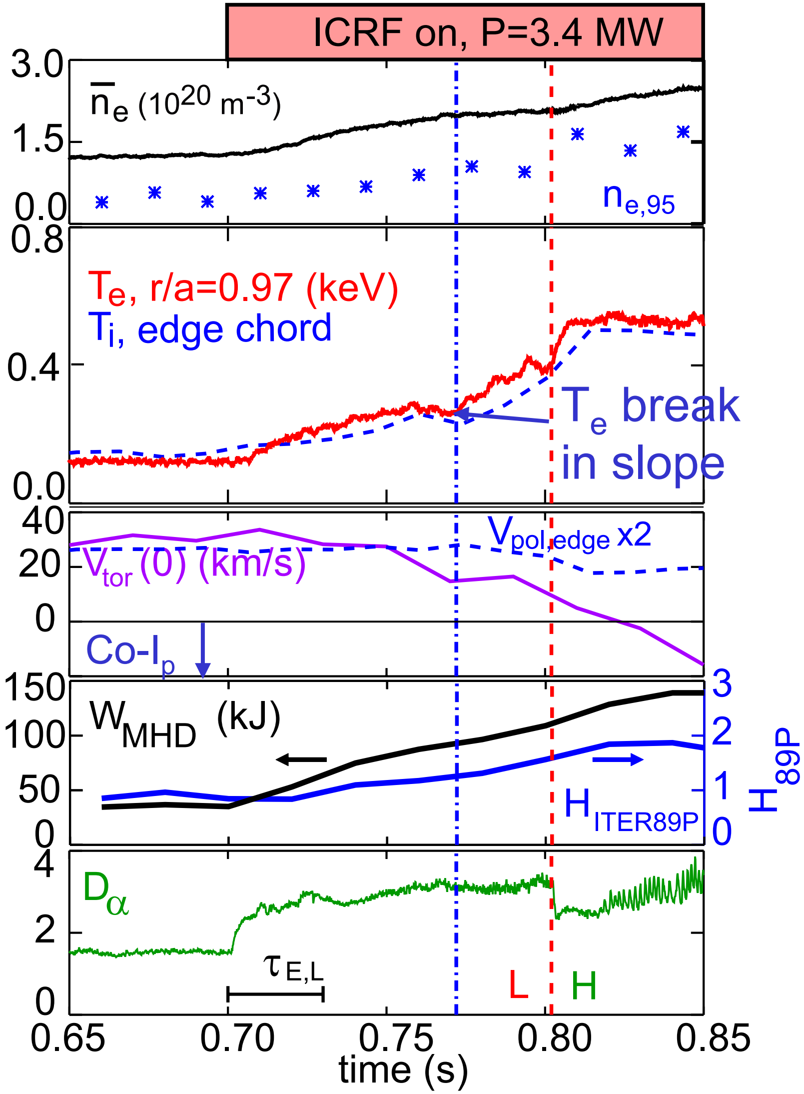

- Edge T_e profiles evolve on a slow time scale, 3-4 τ_E.
- Often a "break-in-slope" in $T_e(t)$, ∇T ~40 ms before L-H.
  - Two-phase H-mode transition?
- Steep T_e gradients develop, *before* changes in ∇n_e & D_α (the classic "L-H") transition.
- $V_{tor}(0)$ steadily reduces.
  - Smaller change in edge V_{pol}.
- Stored energy W, H-factor also increase gradually, H_{89P} to 1.6 in L-mode.
- This L-mode evolution is also seen in Normal B USN, but is NOT seen in favorable drift direction, even with high L-H thresholds (eg, 8 T).

"Pedestal" in T_e develops prior to L-H transition

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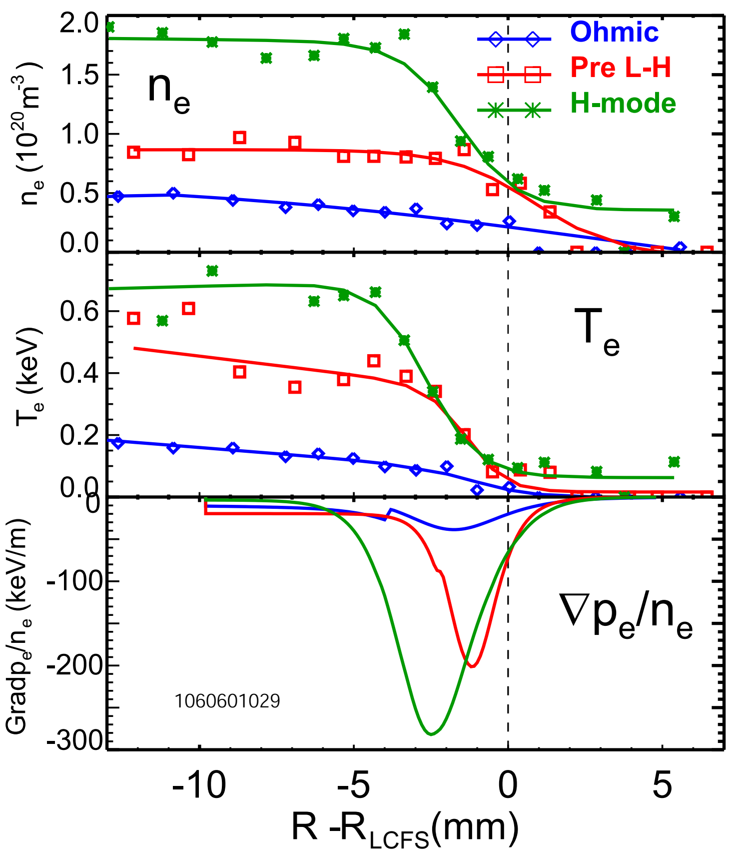
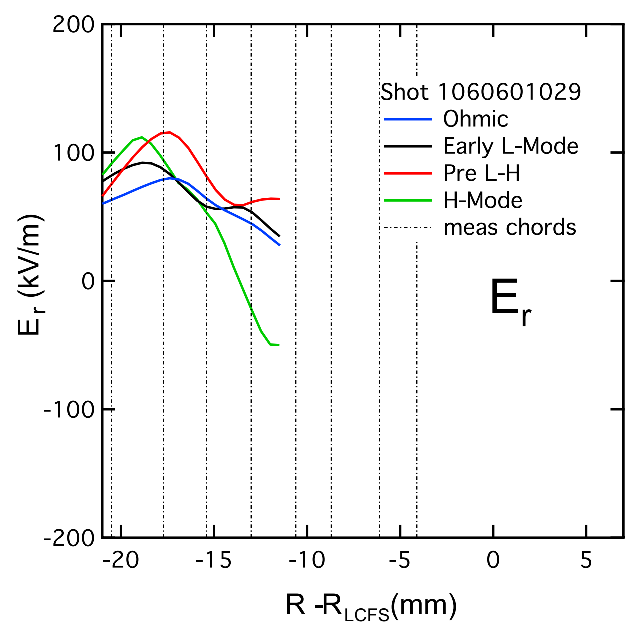
- T_e, p_e gradients develop before L-H over a narrower region (~2 mm) than in later H-mode.
  - $\nabla p_e/n_e$ up to 200 keV/m!



- Preliminary measurements from ambient B^{+4} spectroscopy just *inboard* of pedestal indicate that total E_r does not change substantially until the L-H transition.
  - However, do not resolve the region of steep ∇T_e.
  - New high active CXRS arrays, and x-ray diagnostics, promise improved V_{pol} and V_{tor} measurements in 2007.



Steady decrease in edge χ_{eff} is accompanied by changes in turbulent fluctuations

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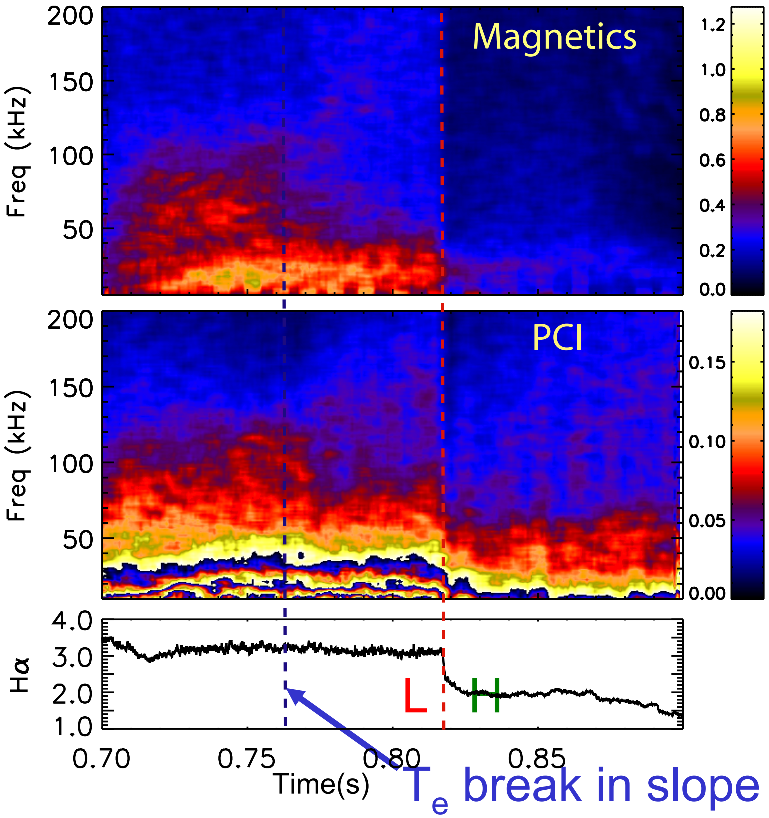
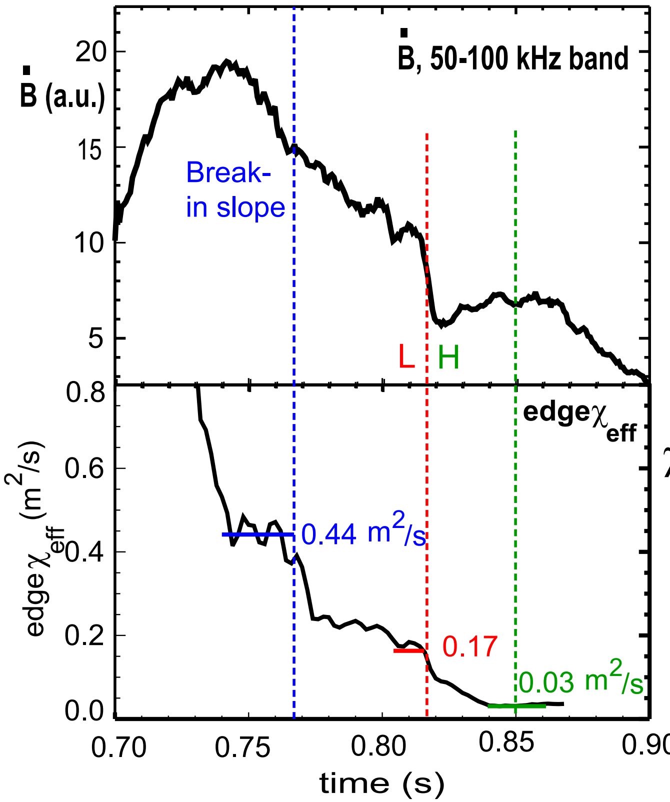
- Gradual decrease in magnetic fluctuations at outboard side, strongest in ~50-100 kHz band, accompanies 60% drop in edge χ_{eff} from power balance.
  - *Net* decrease in integrated $\tilde{B}$ (5-250 kHz) during evolution is ~46%
  - Upshift but little change in net n_e fluctuations by PCI (top view).
  - Further sharp decreases in all fluctuations, and in χ_{eff} , at L-H transition.





Power Balance:

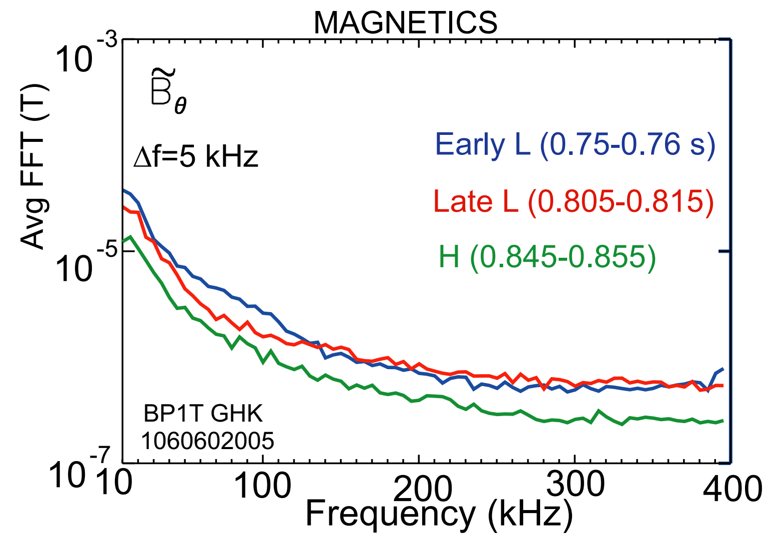
$$\chi_{eff} = \frac{P_{cond}}{2kn_e \nabla T_{eff}}$$

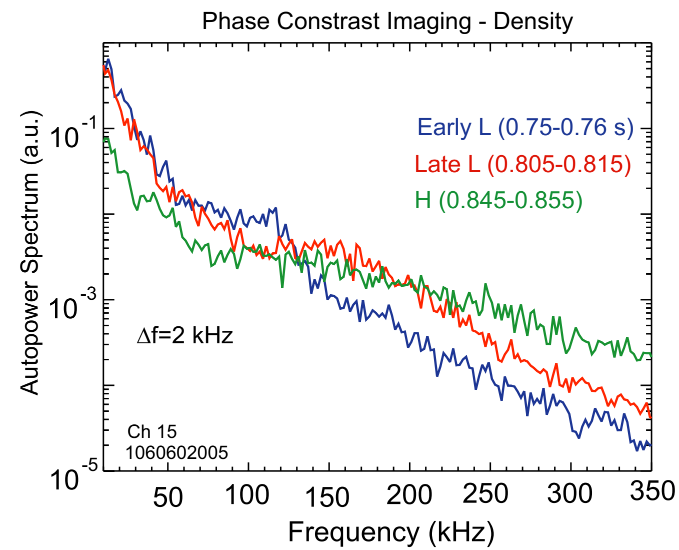
$0.97<\psi<1.0$

Fluctuations in n_e and B respond differently

- Decrease in mid-range (~30-120 kHz) fluctuations Early to late L-mode is consistent and clear on magnetics.- TOP
- Decrease much less visible (sometimes not at all) on Phase Contrast Imaging – BOTTOM.
  - Both see changes in H-mode.
- Possible reasons:
  - δn_e vs δB perturbations?
  - OR poloidal location? (PCI measures along vertical chord at mid-R, magnetics near outboard midplane where we expect ballooning transport).
  - AND/OR k_θ range? (PCI 0.5-7 cm^{-1}, magn <2.5 cm^{-1})
- This campaign, we will use lower f reflectometry (δn_e, outer midplane) to get more information.

- As always, hardest to establish **causality** between fluctuations and transport.

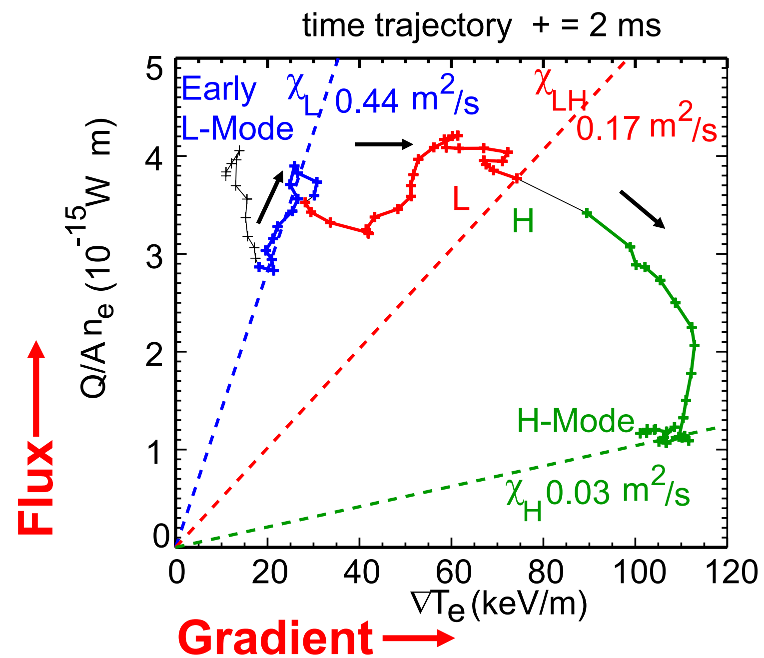


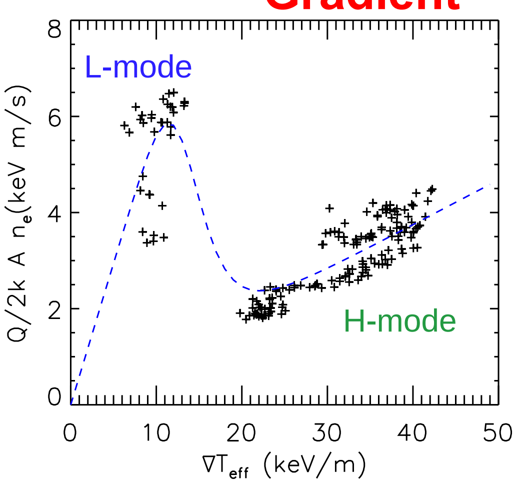


Pre-LH evolution is consistent with a "soft" transition

- Edge flux-gradient plot shows gradual increase in ∇T with near-constant Q, n_e, after 'break-in-slope',
  - Appears to be a 'soft', second order transition, as would result from –ve dependence of χ on T or ∇T.
  - Consistent with the gradual decrease in turbulence.

- Contrasts with the usual L-H transition, which is a rapid first order bifurcation.





Hubbard, Carreras *et al*, PPCF 44, A359 (2002)

Discussion

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- **How does this phenomenon relate to other 'slow transitions'?**
  - Seems most similar to (likely the same as) 'Improved L-mode' on AUG with unfavorable drifts. (Ryter, PPCF 1998).
  - Globally similar features to the 'Intermediate Mode' regime seen on DIII-D but no evidence of "bursty" fluctuations or fluxes. (Colchin, PRL 2002).
  - What about 'slow transitions' on DIII-D with MARFE? (Moyer, PPCF 1999).

- **What can it tell us about edge transport and L-H transition mechanism?**
  - Slow decrease in certain fluctuations accompanies rising T_{edge}, decreasing χ_{eff}. *Do these fluctuations dominate edge thermal transport in L-Mode?*
  - *Why does thermal but not particle transport decrease?? Different modes?*
  - *What exactly is delaying L-H transition in unfavorable case, with high $\nabla p_e/n_e$?*
- **Practical applications/implications of unfavorable magnetic configurations.**
  - 'Improved L-mode' might be attractive for advanced scenarios: H~1.6, but low density. *Can it be maintained for long periods?*
  - Subsequent H-modes have higher T_{ped}, lower n_{ped} and ν^* - control knob. *Can this help us understand pedestal evolution and scaling?*
- **Ideas for joint experimental and/or model comparisons?**

H-mode **pedestals** in unfavorable configuration also have higher T, and lower n_{ped}, ν^*

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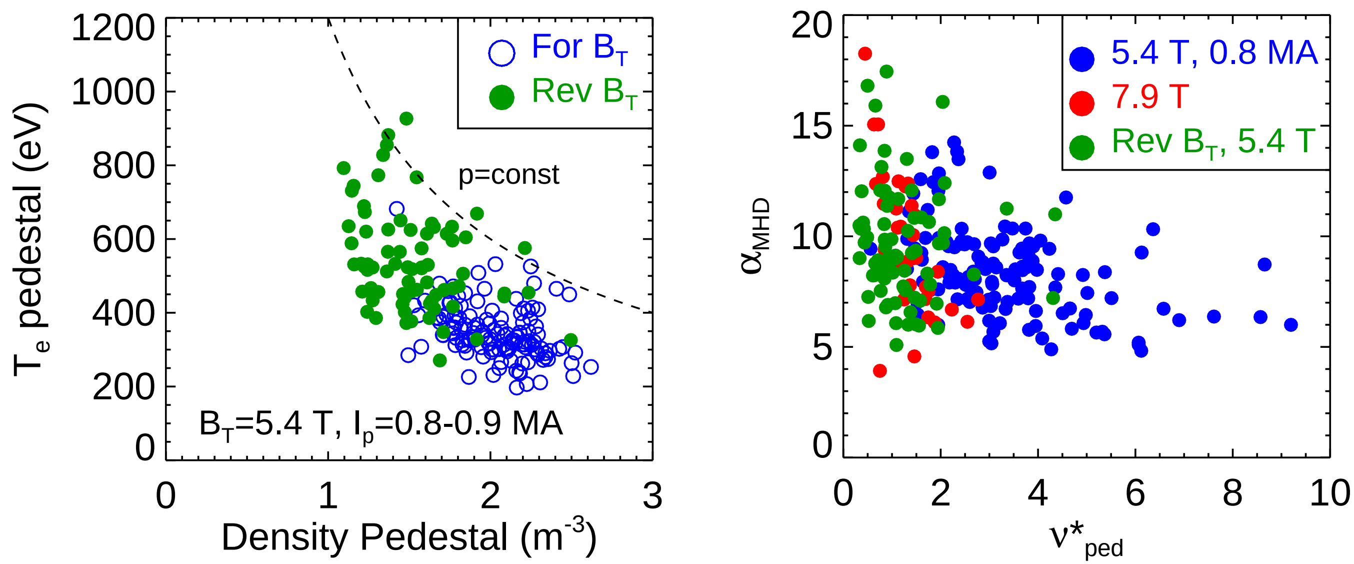
- In fully developed H-mode, pedestals in Reverse B LSN (unfavorable drift) tend to have lower n, higher T (up to 900 eV) than Forward B LSN with similar I, B, target n_e. Pedestal widths, pressures are similar.
  - This leads to lower collisionality pedestals, $0.25 < \nu^*_{ped} < 2.5$



- Similar results for high field (Forward B 8 T) pedestals. Common feature in both cases is a high power and temperature (lower ν^*) at the L-H threshold.

  Is the threshold condition determining the final operating point?