ITB Transport Studies in Alcator C-Mod

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Transport Task Force

March 26th

Boulder, Co

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Supported by US DoE

Alcator C-Mod

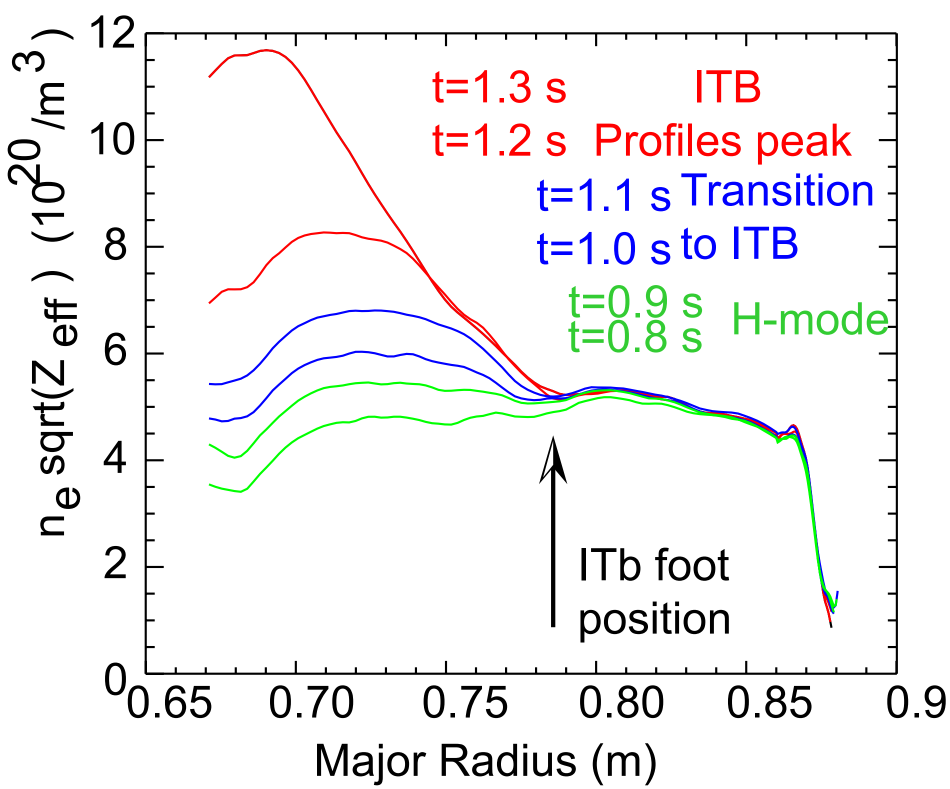
Introduction: ITBs in Alcator C-Mod

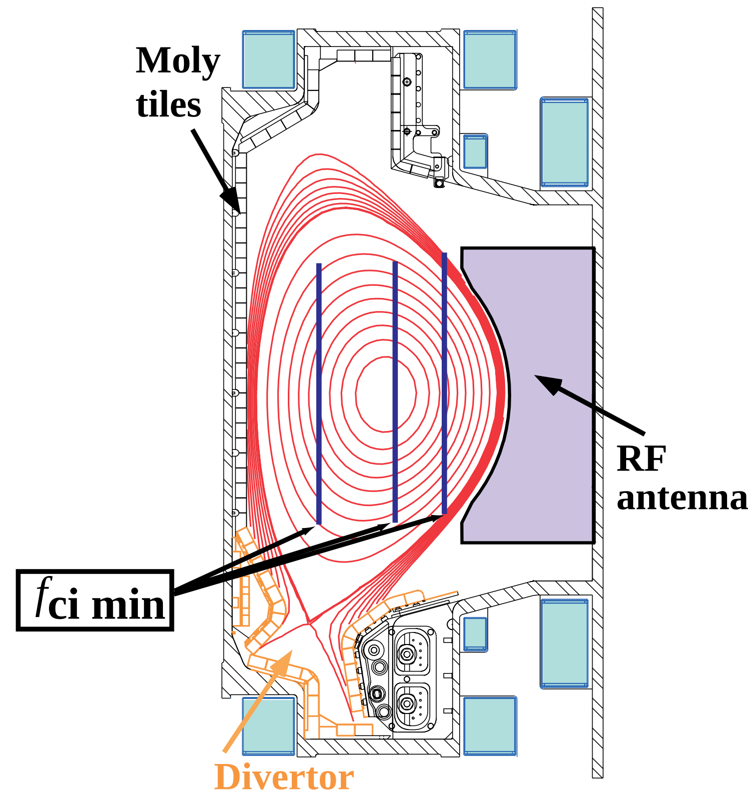
What's New:

- Gyrokinetic stability study at ITB onset
- Improved ion temperature profile measurements
- Localization of fluctuation measurements
- Impurity transport at the ITB foot
- Ohmic H-mode ITBs
- LHCD effects

Features of C-Mod ITBs

Internal Transport Barriers (ITBs) in C-Mod arise from steady H-mode plasmas lasting 2 or more energy confinement times when the central power input is low: they are seen in both Ohmic and Off-axis heated ICRF plasmas





Features of C-Mod ITBs

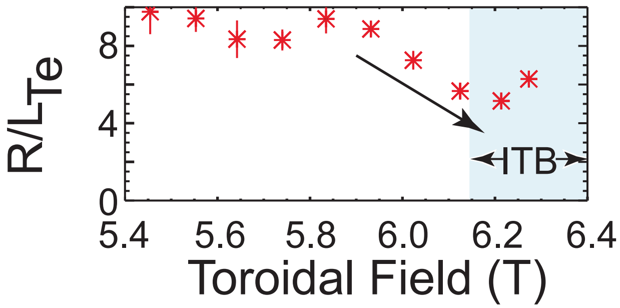
C-Mod plasmas are a unique platform for ITB study:

- No particle or momentum input
- Monotonic q profiles
- Collisionally coupled ions and electrons with $T_i \approx T_e$

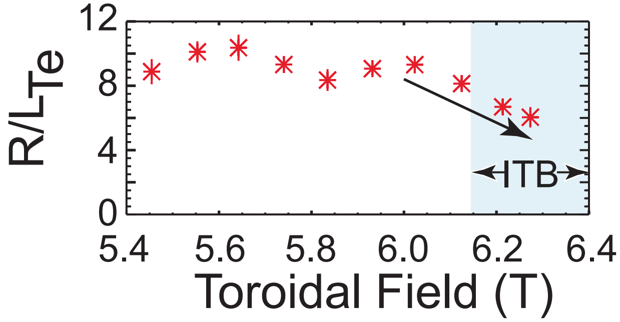
Reduction in particle and thermal transport in the barrier region and core allows the Ware pinch to dominate the transport. This results in strongly peaked pressure and density profiles. Ion thermal transport is reduced to neoclassical

Control of particle and impurity accumulation is achieved through application of central ICRF heating: TEM stability plays a role. ***Ernst, IAEA 2004, 2006***

Increasing magnetic field moves ICRF resonance off-axis on low field side. ITBs form when Bt > 6.2 T with ICRF at 80 Mhz

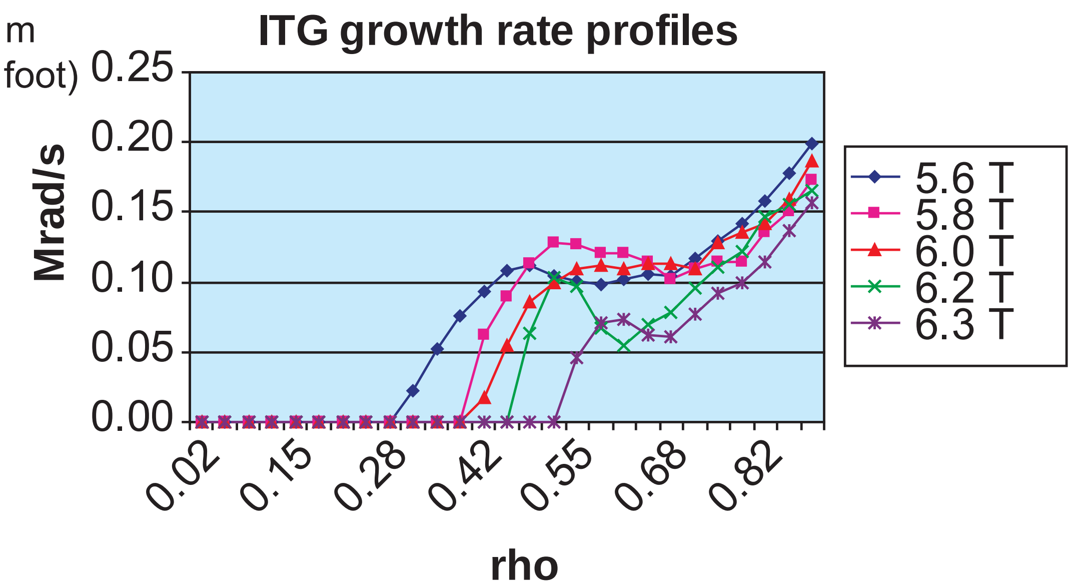


R=0.78 m (near barrier foot,inside)



R=0.80 m (barrier foot)

The region of stability to ITG modes widens with increasing magnetic field.



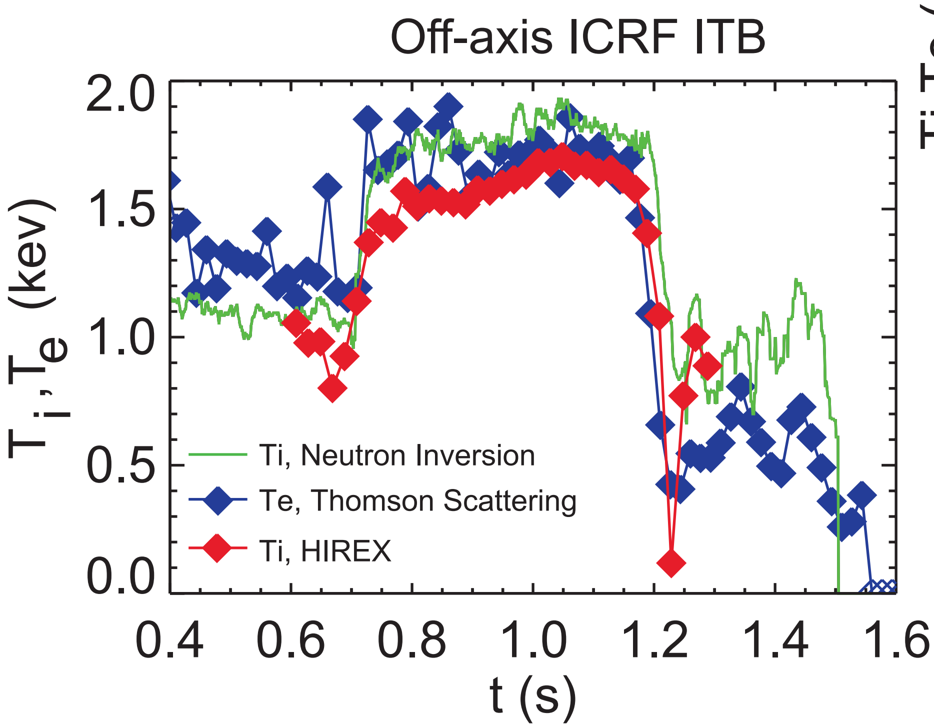
R/L_{Te} decreases in the region near the ITB foot at the time of onset.

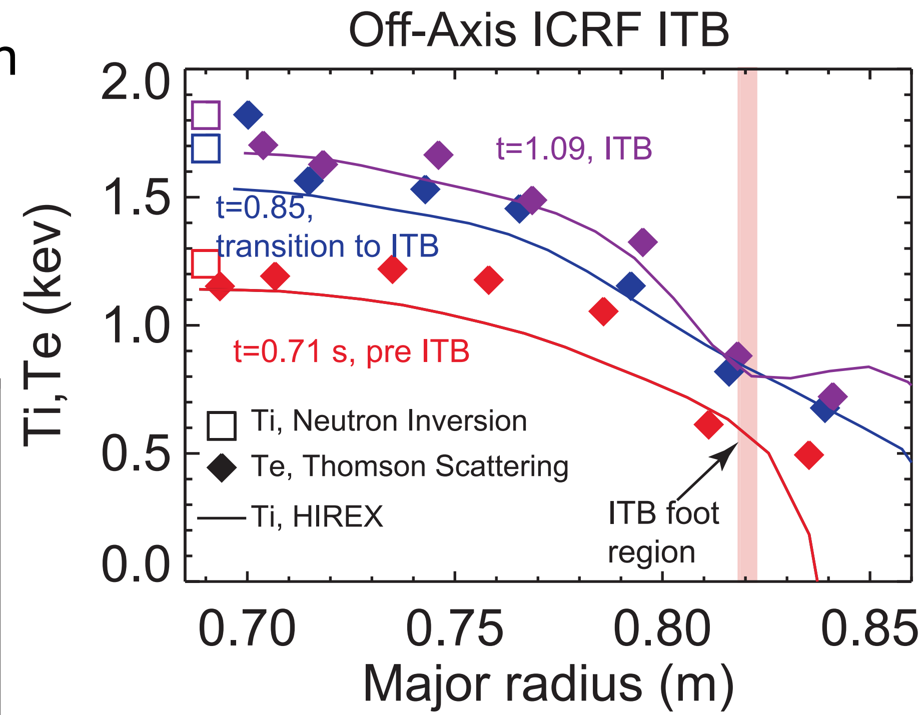
K. Zhurovich, et al, NP8.00073

K. Zhurovich *et al* 2007 *Nucl. Fusion* **47** 1220-1231

Upgraded high resolution x-ray spectrometer measurement of Ti profile shows barrier in temperature during ITB

Excellent agreement is found between T_i from HIREX, central Ti from neutrons, and T_e from Thomson Scattering.



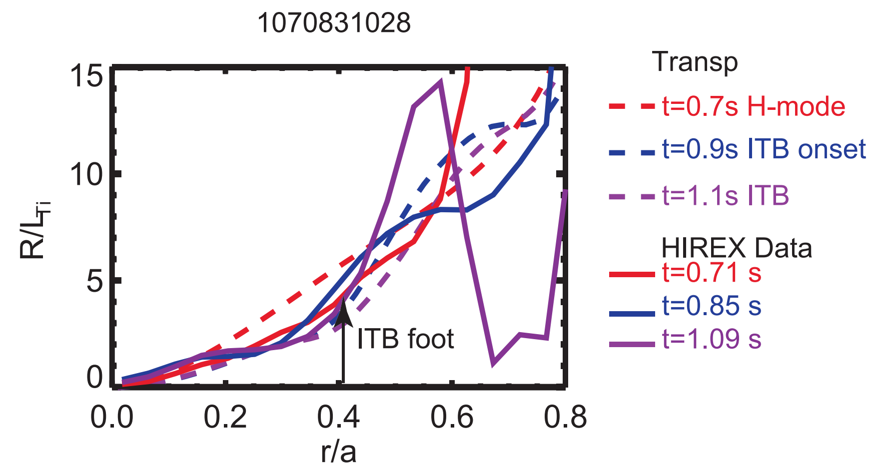


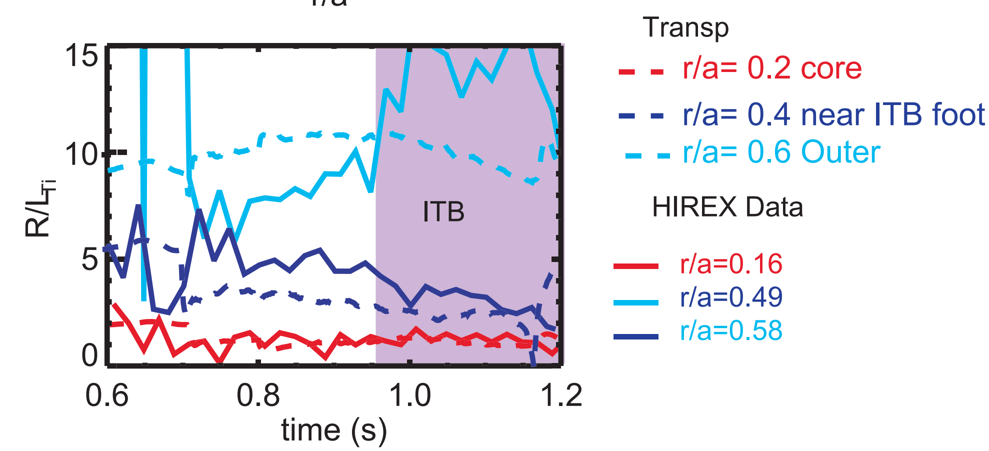
- •A temperature barrier was found previously with sawtooth heat pulse measurements and inferred from pressure profile increase
- •Ion temperature profile from HIREX confirms T_i transport barrier.

R/L_{Ti} can be obtained from HIREX can be compared with that obtained from TRANSP

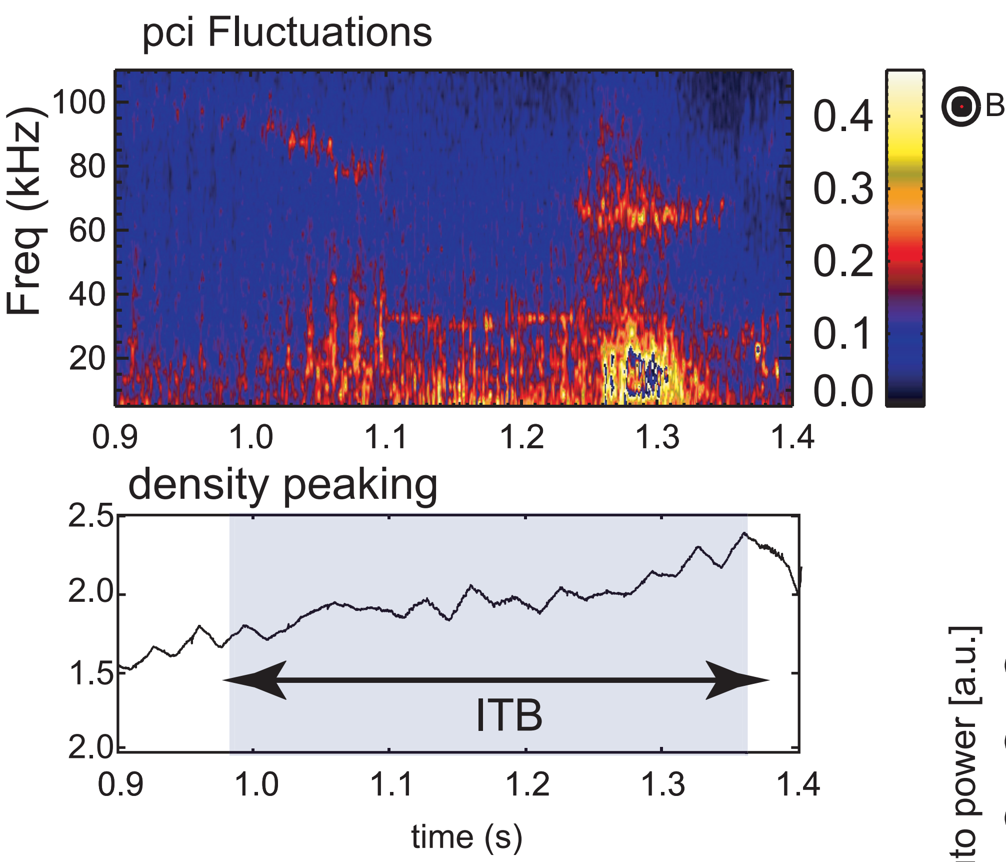
R/L_{Ti} from TRANSP increases from the center for all times; drop outside of core is not seen

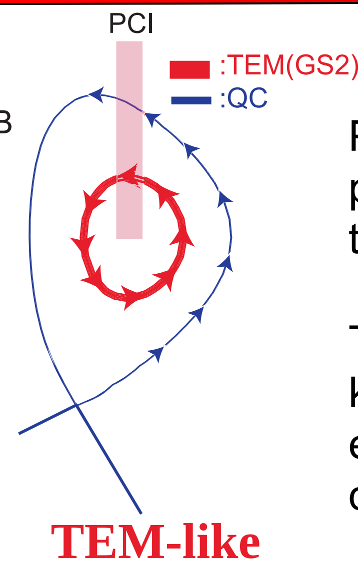
R/L_{Ti} from TRANSP is comparable for core channels; shows discrepancy at larger radii.





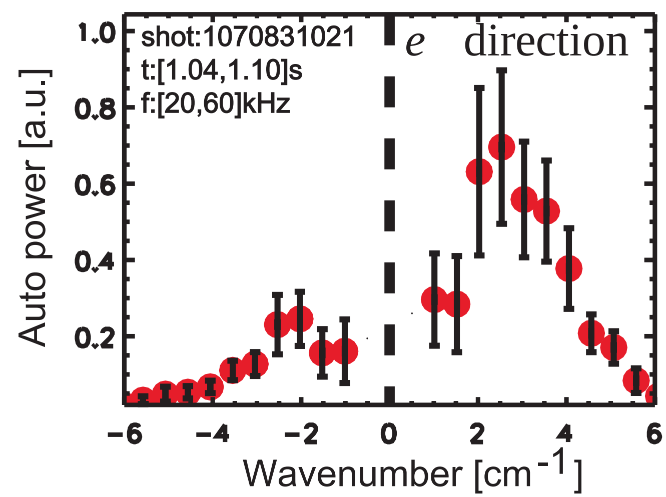
Fluctuations arising during ITB density peaking propagate in electron diamagnetic direction (Lin, P12)





PCI was configured to preferentially view half of the plasma

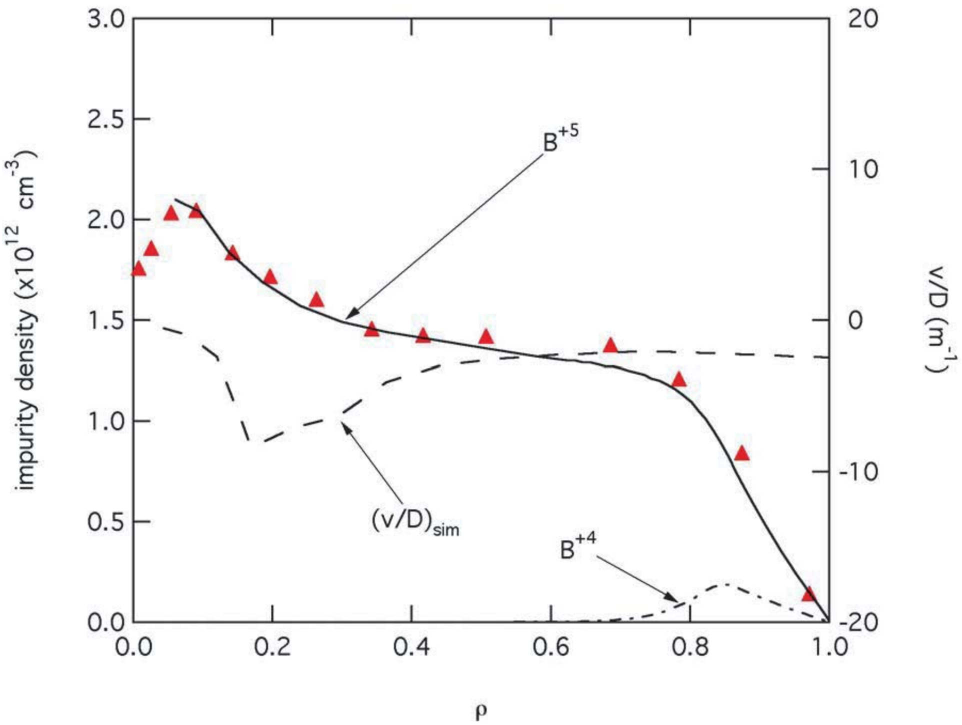
The fluctuations in 20-60 kHz propagate in the electron diamagnetic direction



Caveat:

Neither non-linear GYRO nor linear GS2 has predicted TEM fluctuations in this plasma.

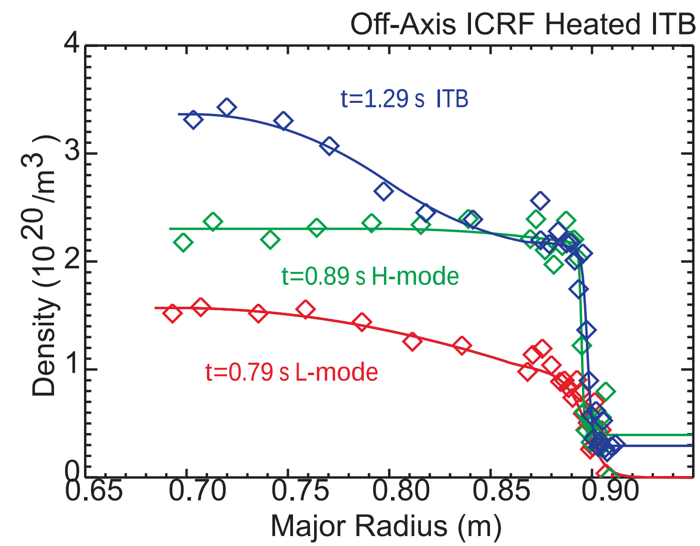
Measurement of Boron impurity behavior in C-Mod ITBs have been obtained with the CXRS diagnostic (Rowan, Bespamyatnov, Fiore: P18)

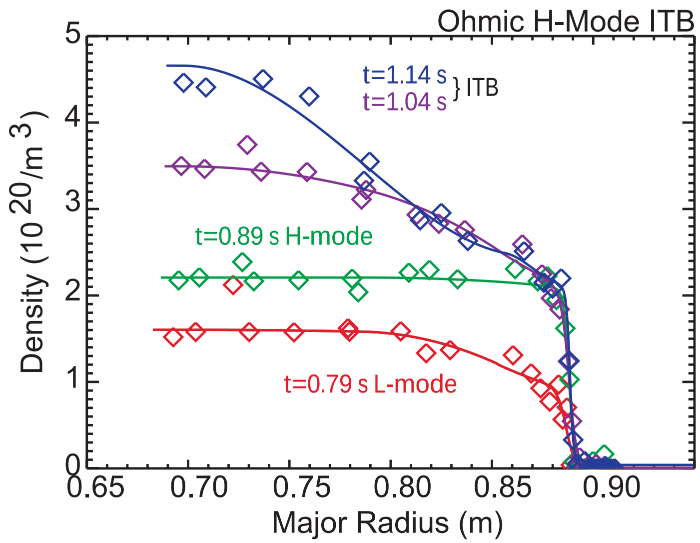


Here is shown a simulation of B^{+5} density (solid line) and B^{+4} density (dash-dot line) compared with the measured B^{+5} density (▲). v/D (dashed line) required in the simulation is plotted on the right axis.

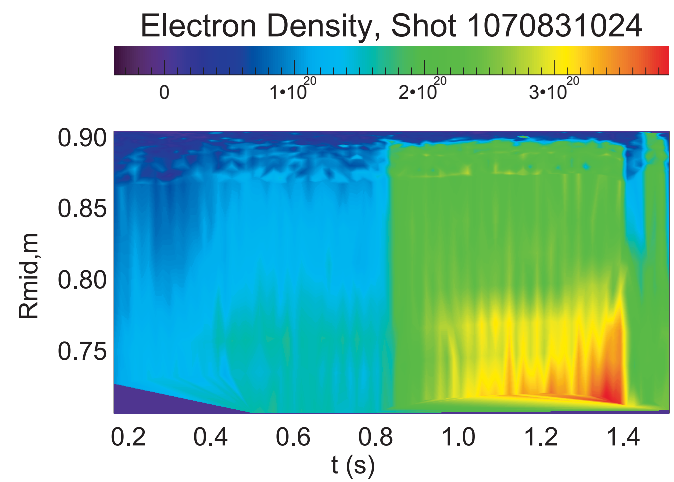
It is found that light impurity confinement is improved in the ITB. Light impurities accumulate in the ITB region but transport does not reach neoclassical levels.

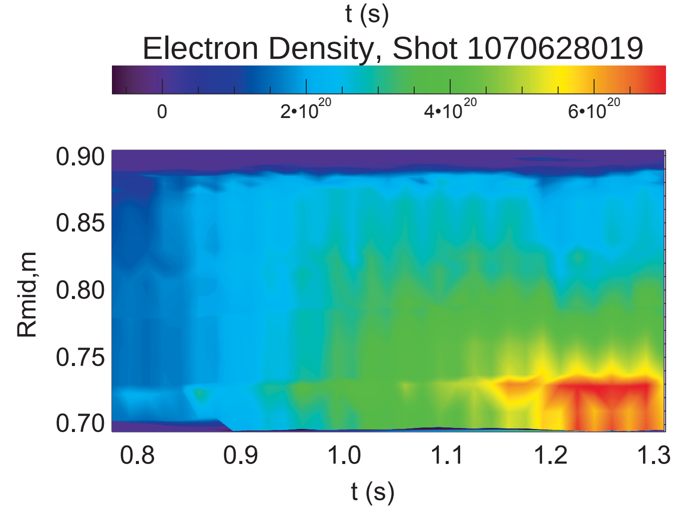
Density peaking in an ITB begins shortly after an EDA H-mode develops for both Ohmic and Off-Axis ICRF ITBs



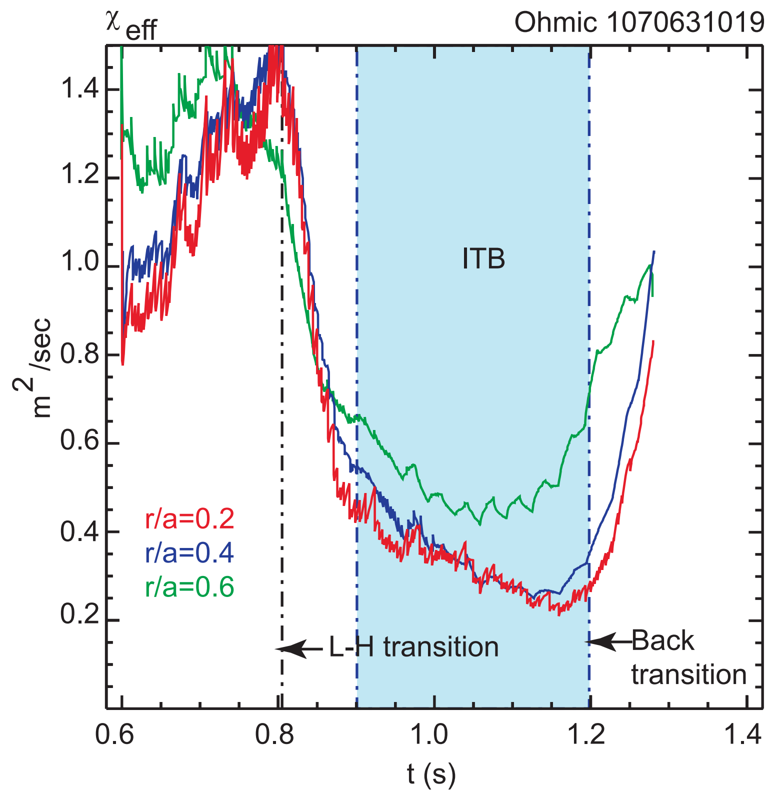


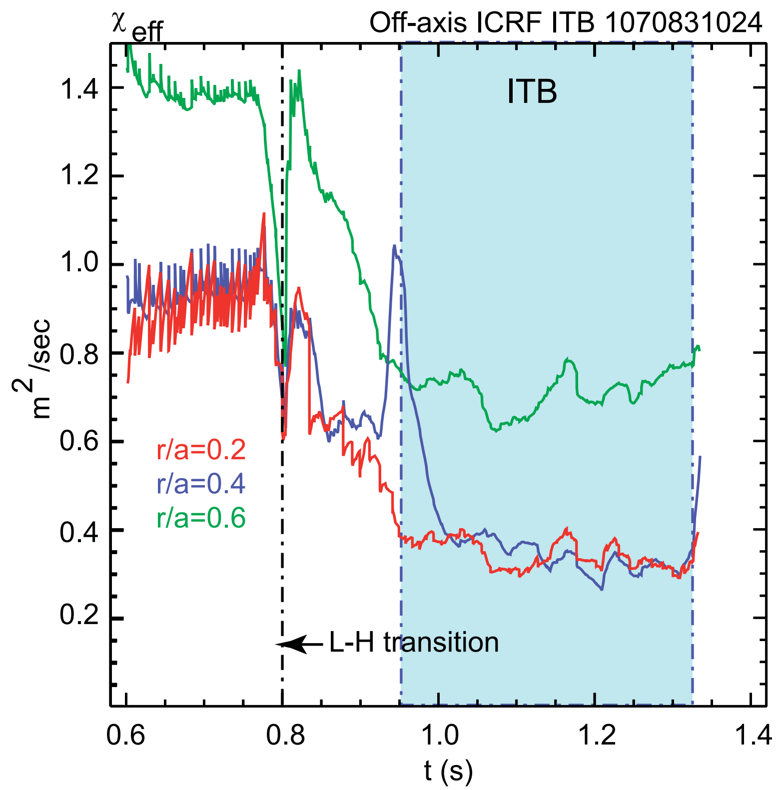
Density contour plot shows that the peaking time and intensity are similar



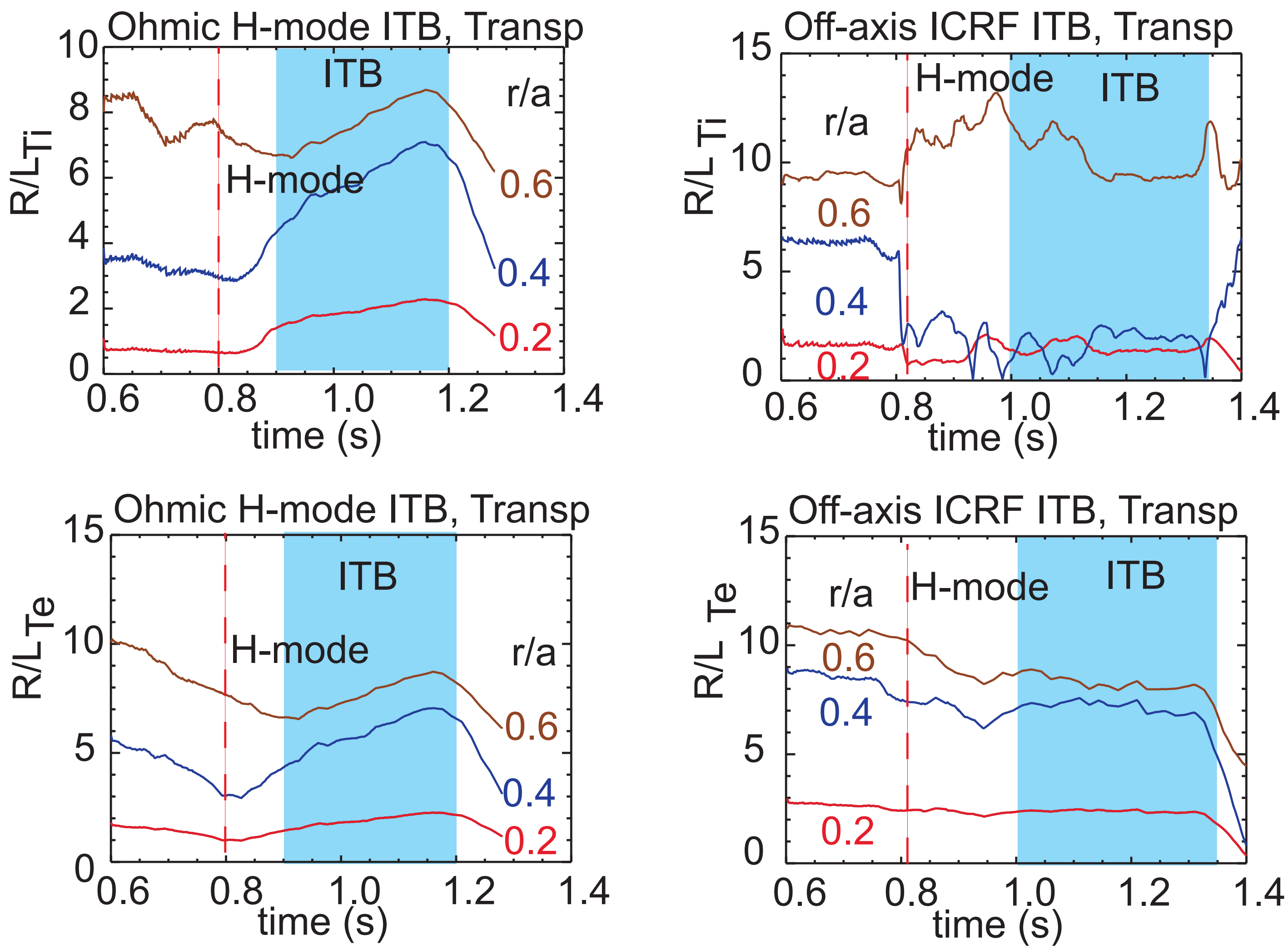


Thermal transport characteristics are similar for off-axis RF induced and Ohmic H-mode ITBs

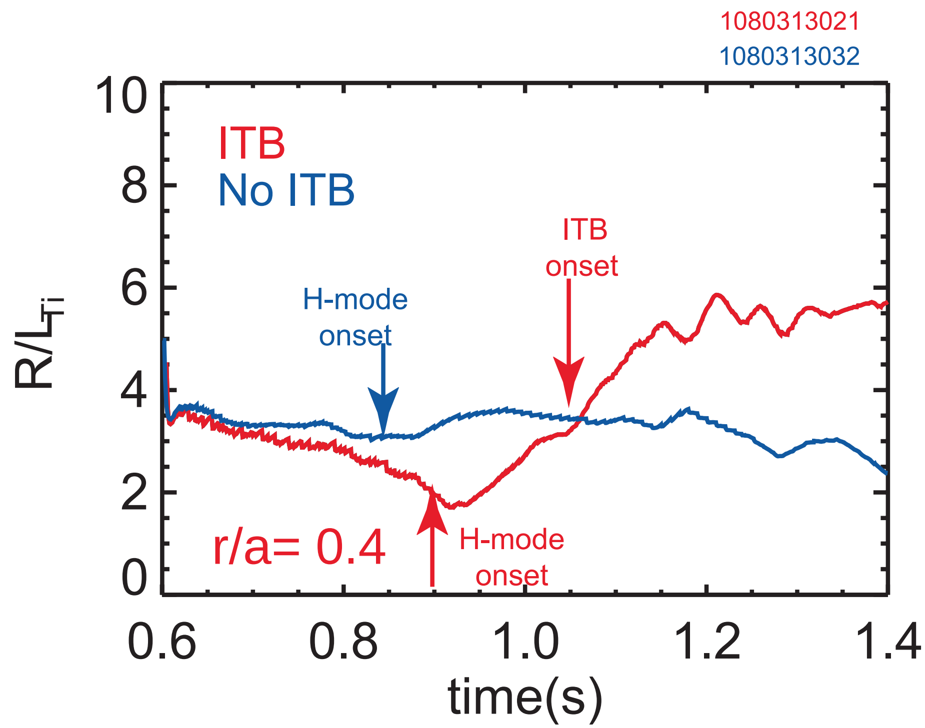




R/L_T appears to have different trend in Ohmic H-mode ITB than in off-axis ICRF ITB

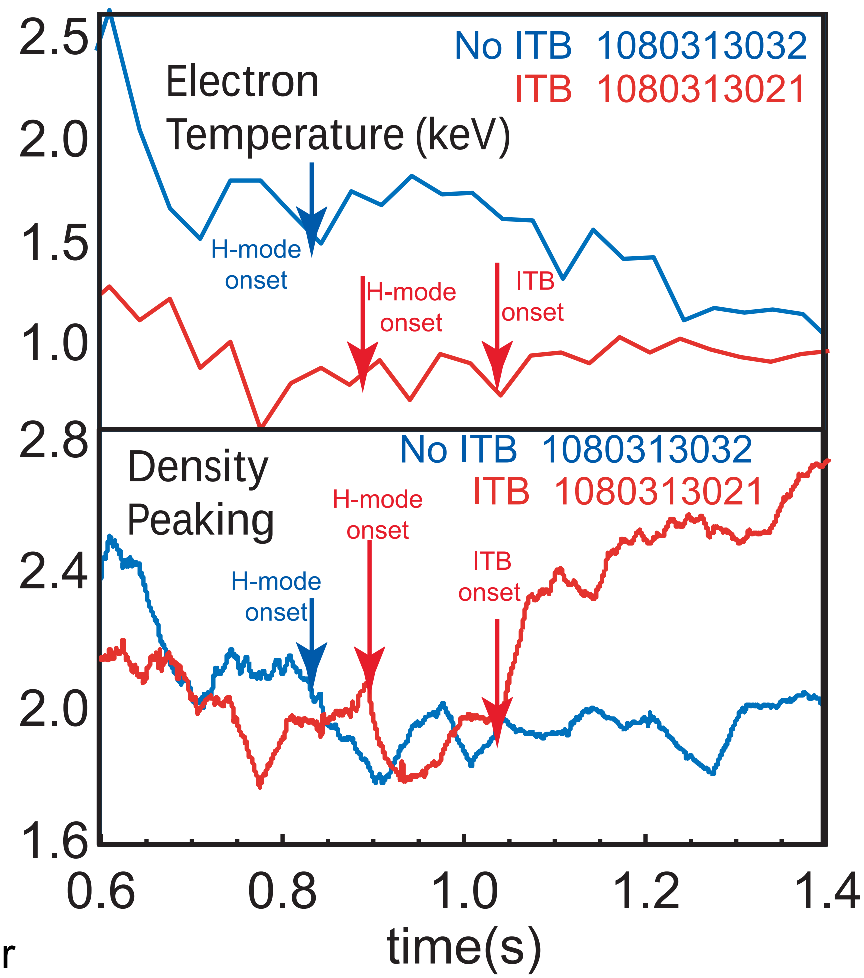


R/L_T in the barrier region dips as H-mode forms in Ohmic plasmas with ITBs

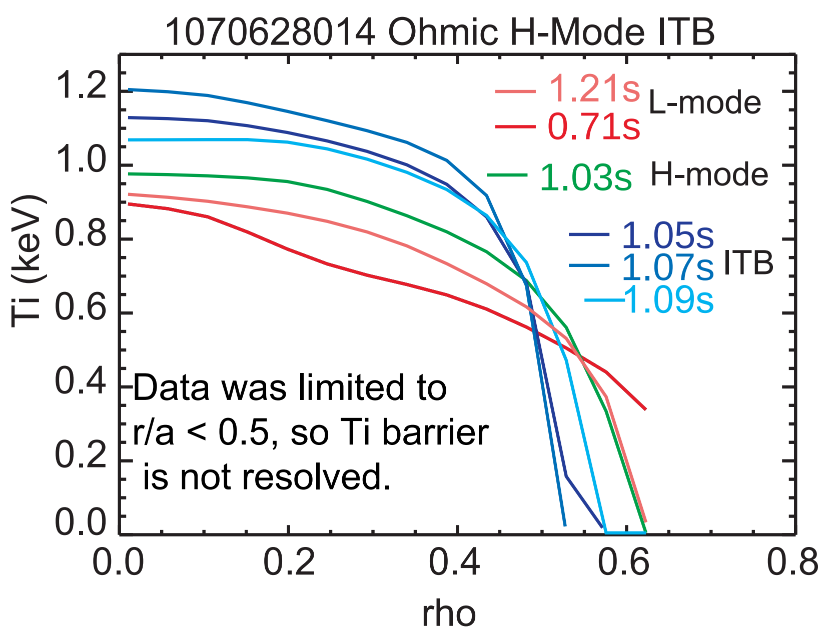


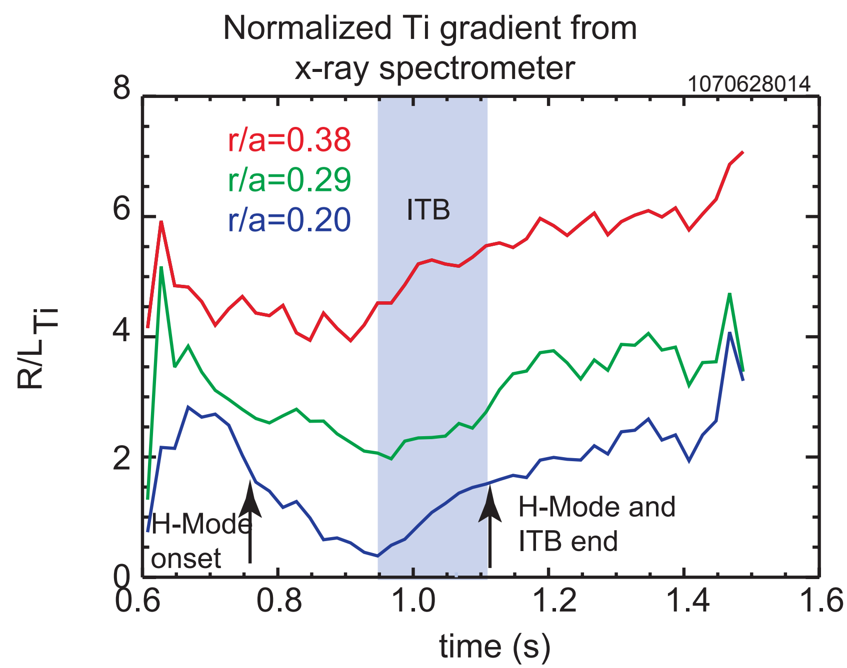
Ohmic H-mode plasmas from the same day are compared. One developed an ITB and the other did not.

- $R/LT_{i,e}$ drops in the barrier region just after the H-mode forms in the case that generates an ITB, and recovers to a higher level after the ITB onset.
- The discharge that did not develop an ITB had higher current, temperature, and toroidal field



Normalized temperature gradients obtained from high resolution x-ray measurement (R/L_{Ti}) show same trend with time in Ohmic H-mode ITBs as that seen from TRANSP calculation





Measured R/L_{Ti} decreases with time after plasma enters H-mode.

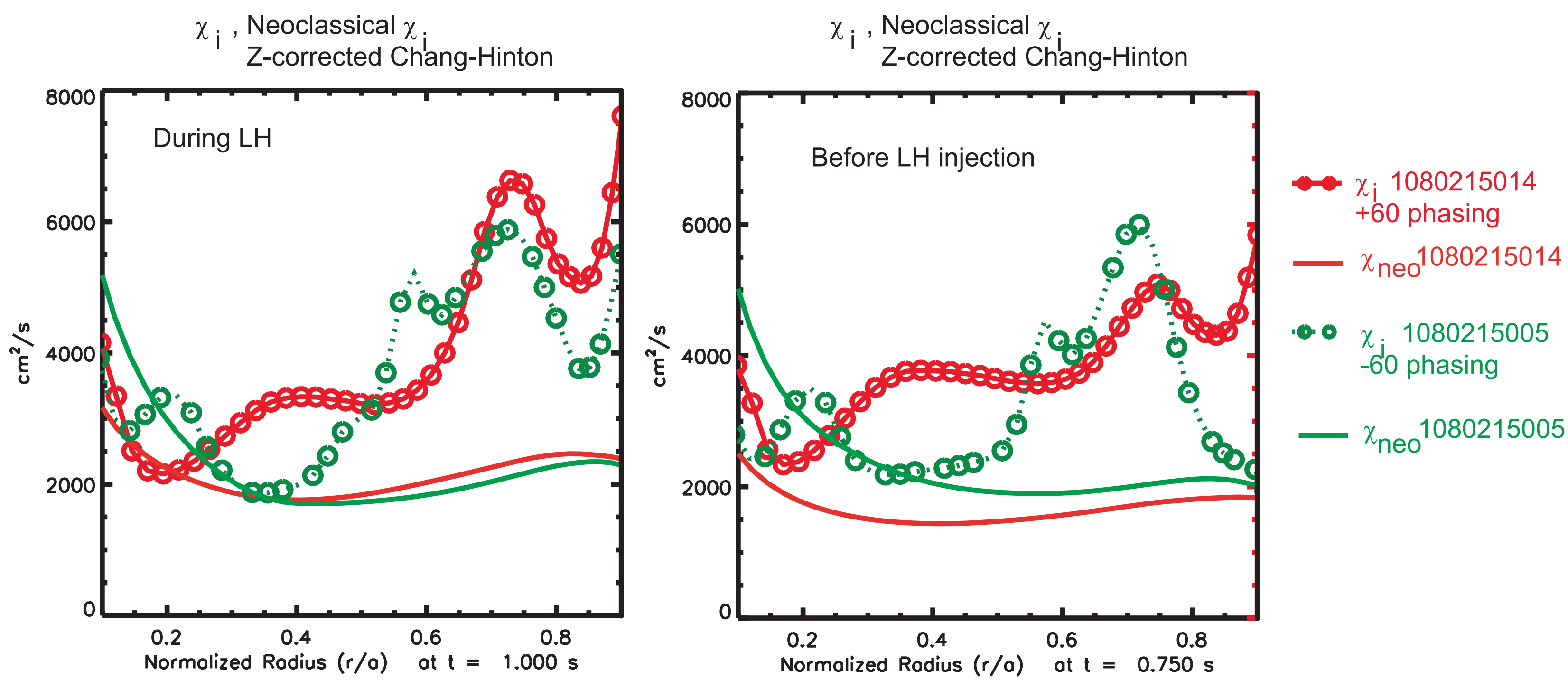
It rises with ITB onset and as ITB grows in the barrier region.

Is there an ITB with LHCD?

Counter toroidal rotation develops during LHCD, suggesting barrier formation.

Central pressure increases.

χ_i decreases slightly in core with LHCD off-axis. More power is needed to obtain stronger effect for definitive analysis



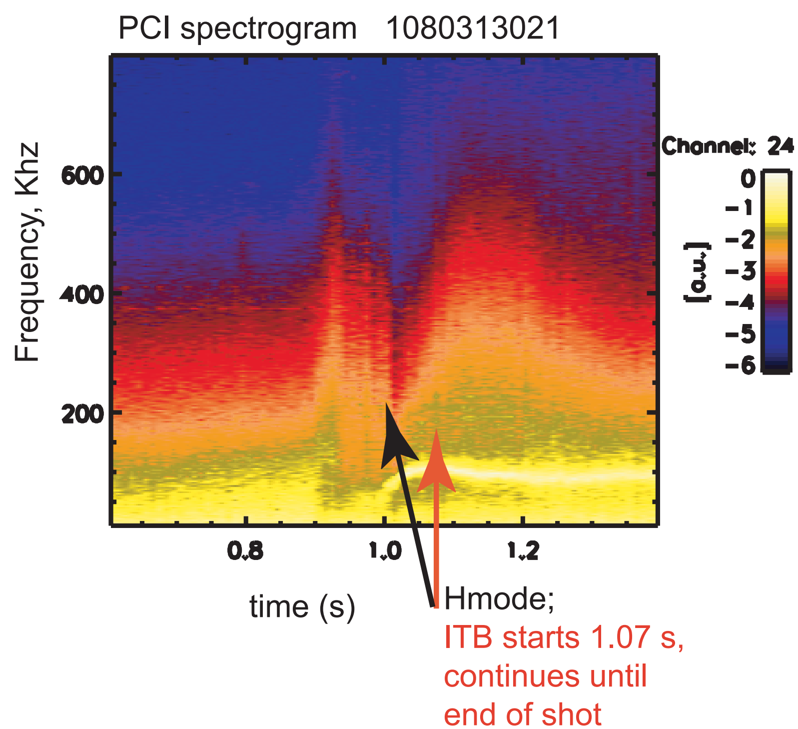
Conclusions

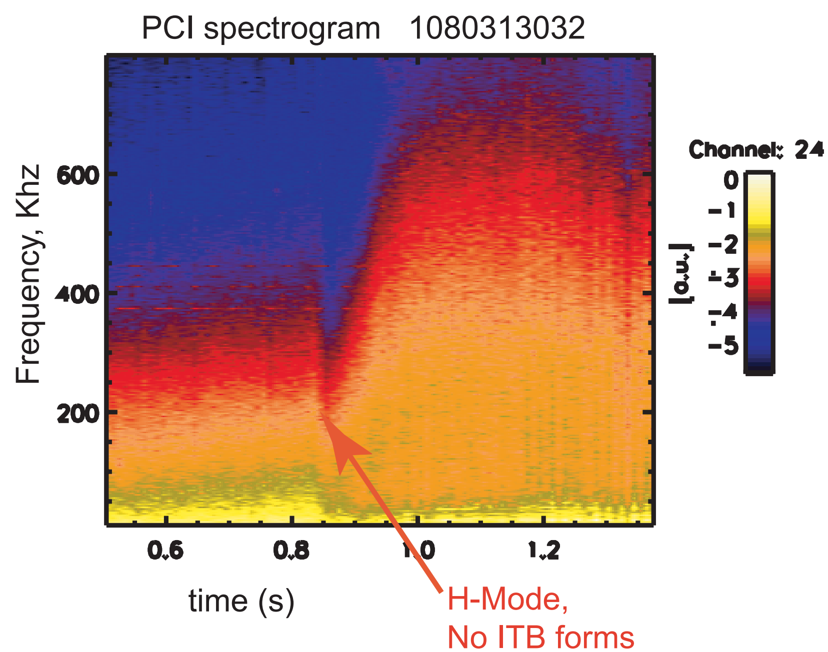
- Non-linear gyrokinetic modeling shows that broadening of the temperature profile with off-axis ICRF injection increases the size of the core-stable region of the plasma, reducing the outgoing particle flux, allowing Ware pinch to dominate particle transport.
- Improved temperature profiles establish that a thermal barrier exists at or near the particle barrier seen in the density profile. These profiles will improve data for stability analysis.
- Density fluctuations that arise and strengthen during ITB growth propagate in the electron direction. However, gyrokinetic modeling does not find TEM in the weak ITB case that shows this fluctuation. We will be working to reproduce strong ITB and to obtain localized PCI measurements of this instability.

Conclusions (cont.)

- Light impurity confinement is improved in the ITB. Light impurities accumulate in the ITB region but transport does not reach neoclassical levels.
- ITBs arising in Ohmic H-mode plasmas appear identical to those forming in off-axis ICRF heated cases. R/L_T decreases following H-mode onset indicating that the ITB trigger is likely the same mechanism as that determined for the off-axis ICRF ITBs. Stability analysis is needed.
- LHCD plasmas show development of counter current rotation (See Ince-Cushman, et al. this morning) Slight temperature peaking suggests possibility of ITB development.

PCI sees fluctuations arising during ITB density peaking also in Ohmic H-mode ITBs





Chordal view, no masking