Intrinsic Plasma Rotation in C-Mod Internal Transport Barriers

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TTF-2011

April 6, 2011, San Diego, CA

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Outline
- ITBs in C-Mod
- Toroidal rotation with ICRF
- E_r and EXB shear
- Gyrokinetic analysis
- Magnetic field scan results
- Conclusions and Future Work

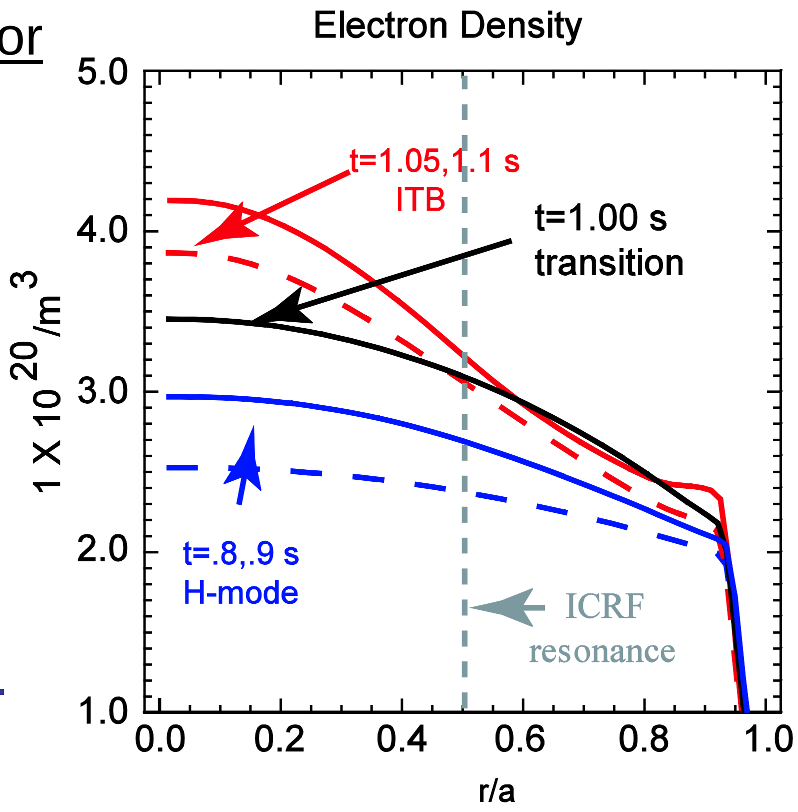
Alcator
C-Mod

Features of C-Mod ITBs

<ins>C-Mod plasmas provide unique platforms for ITB study:</ins>

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

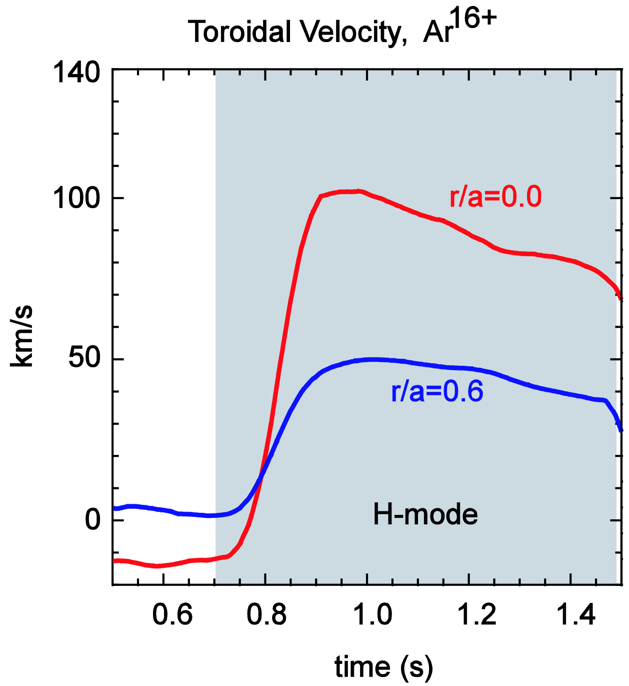
<ins>Reduction in particle and thermal transport</ins> in the barrier region and core allows the Ware pinch to dominate the transport. This results in strongly peaked pressure and density profiles. Ion thermal transport is reduced to neoclassical levels



<ins>Intrinsic toroidal rotation, slows, often reverses as ITB develops</ins>. Initially co-going after the H-mode, the rotation at the plasma center decreases throughout the ITB phase of the plasma. Rotation at the half radius does not change significantly.

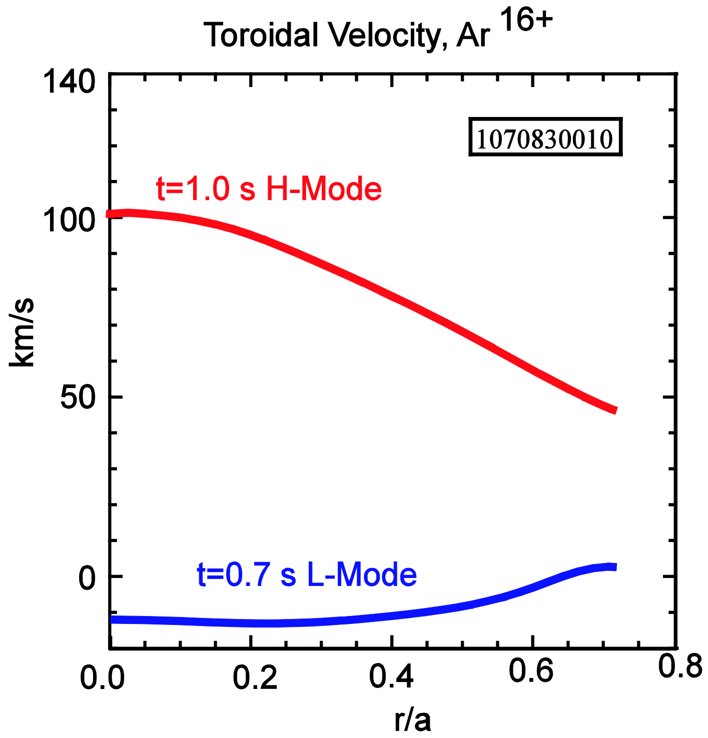
Toroidal rotation increases in the co-current direction after the H-mode transition

On-axis ICRF heating:



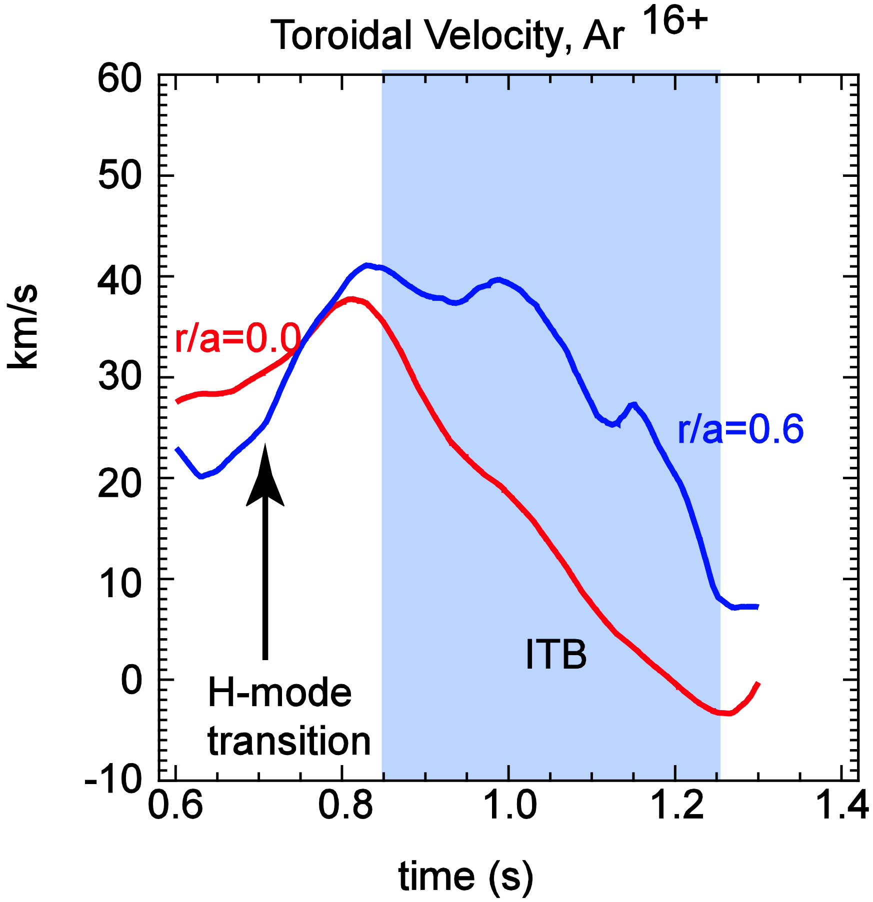
Counter current toroidal rotation in L-mode shifts strongly to the co-current direction at the H-mode transition

The toroidal rotation profile is strongly peaked on axis in H-mode.



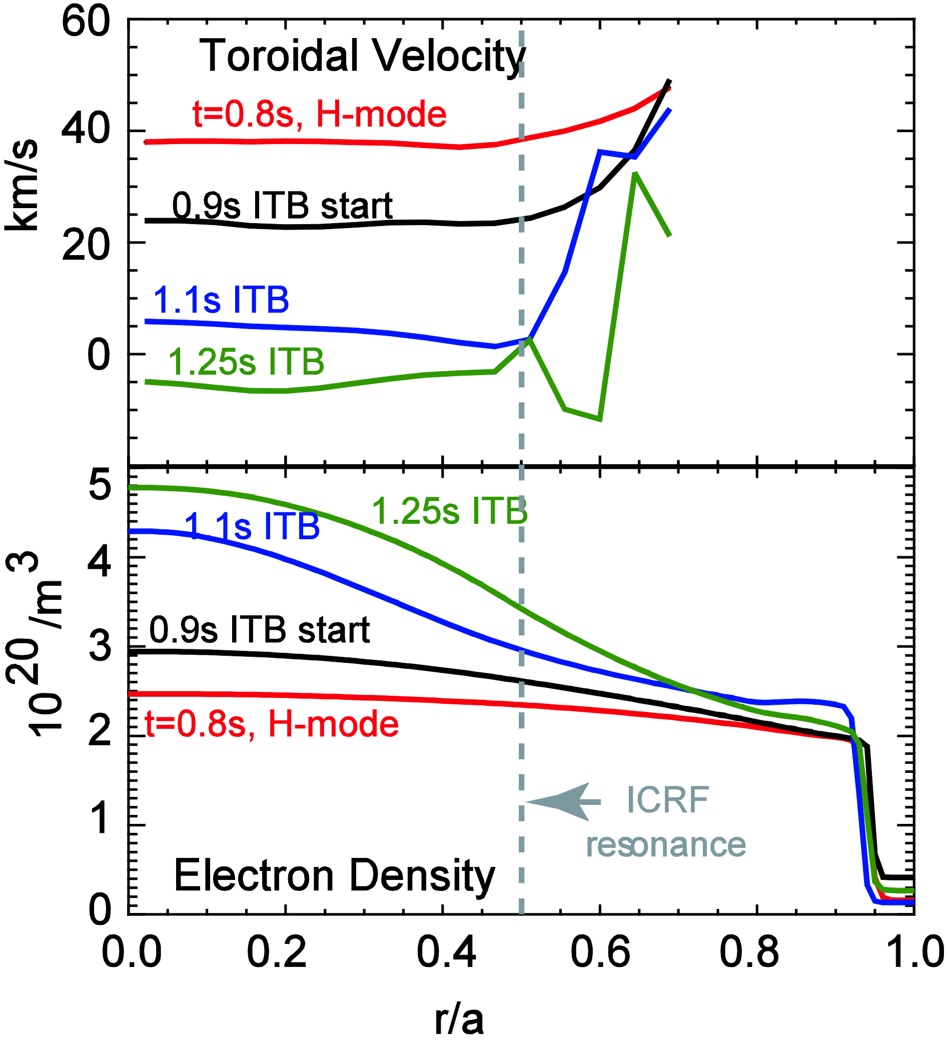
Toroidal rotation profiles are obtained from the Doppler shifted x-ray emission of the argon impurity

With off-axis ICRF heating, the central toroidal rotation decreases, often reverses direction; an ITB usually develops



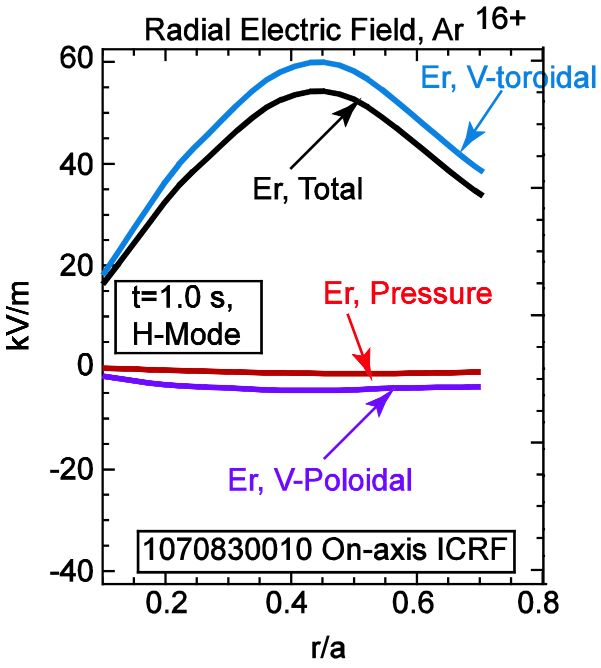
Rotation increases in co-current direction at the H-mode transition. As ITB develops, core rotation decreases, moves in counter current direction.

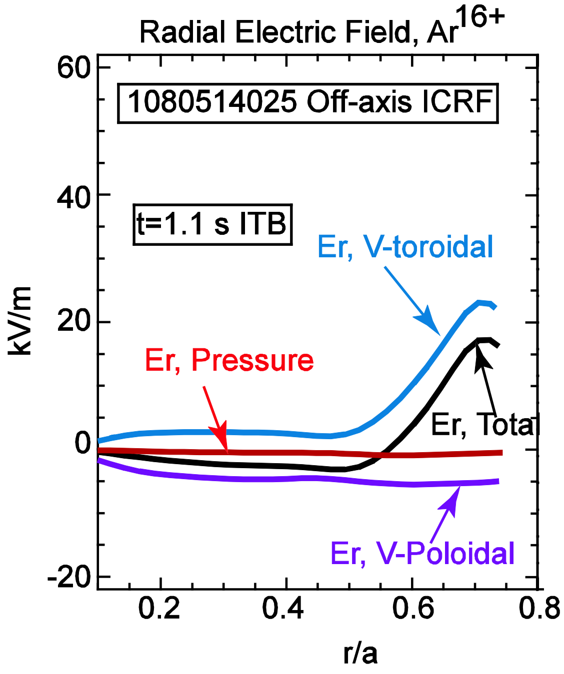
As density peaks, a well in the toroidal rotation develops inside of the ITB foot region.



The radial electric field profiles are different for on-axis, off-axis ICRF heated discharges

In the centrally ICRF heated discharge, E_r is broad with peak of 55 kV/m at r/a=0.45



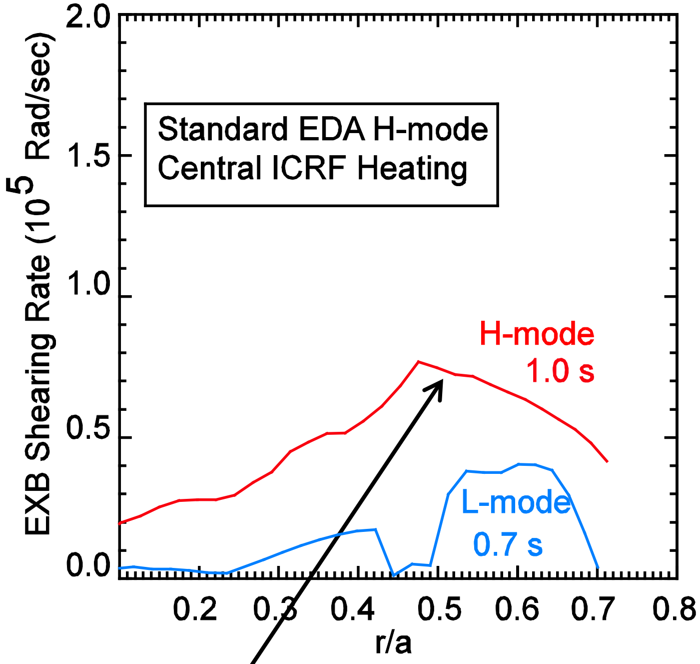


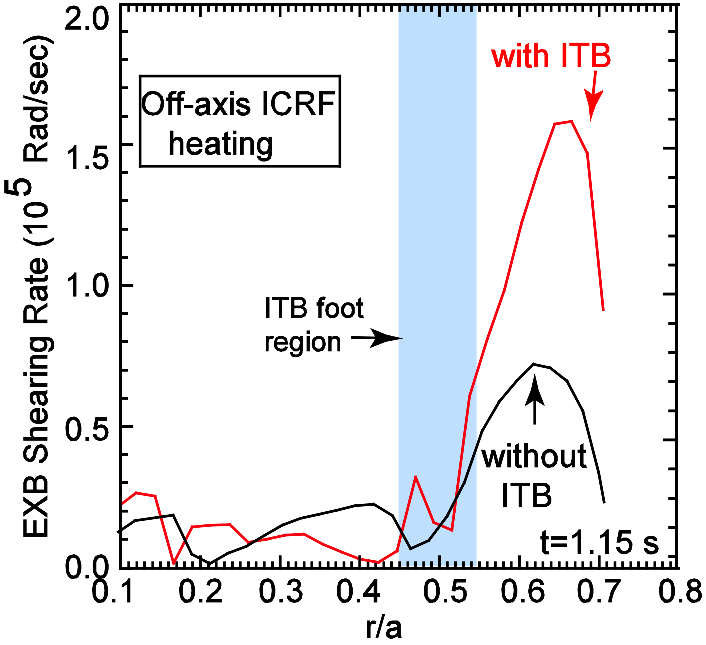
Off axis ICRF heating leads to an E_r profile that is flat in the core, then rises beyond r/a=0.5. An ITB is observed in the density and temperature profiles in this plasma

Toroidal rotation data are used in TRANSP calculation to determine the radial electric field; Contributions from toroidal rotation, poloidal rotation, and pressure profile are shown. Toroidal rotation is the largest contribution to the radial electric field.

EXB shearing rate is 2-3 times higher in ITB foot region in plasmas where ITB develops

In the case of off-axis heated H-mode the shearing rate is peaked to the outside, r/a>0.6.

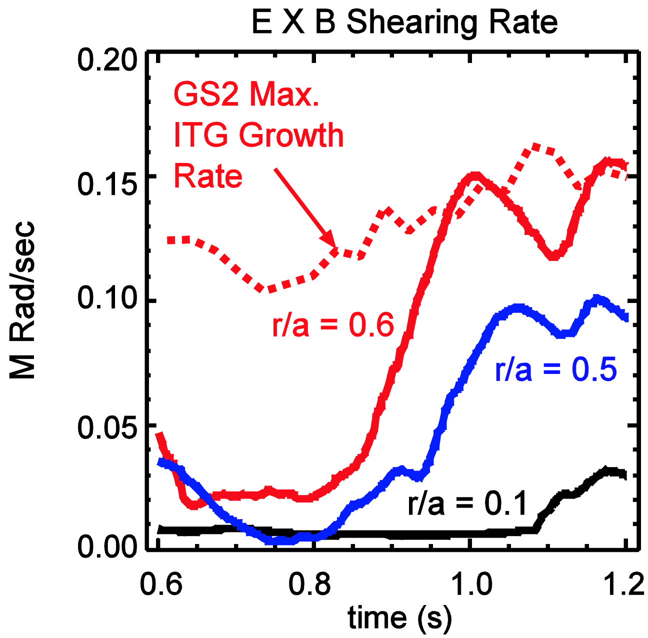




Centrally heated H-mode has shearing rate peaked off-axis; the magnitude is lower than ITB case

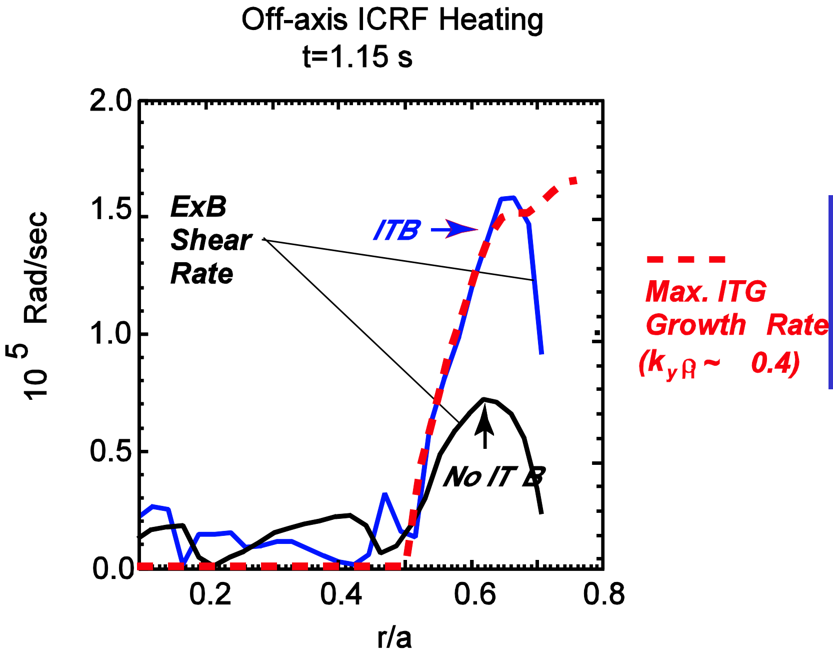
The shearing rate is lower **at r/a=0.6 if an ITB does** not form

ITG growth is comparable to EXB shearing rate in ITB foot region



Linear GS2 growth rate calculation, courtesy D. Ernst

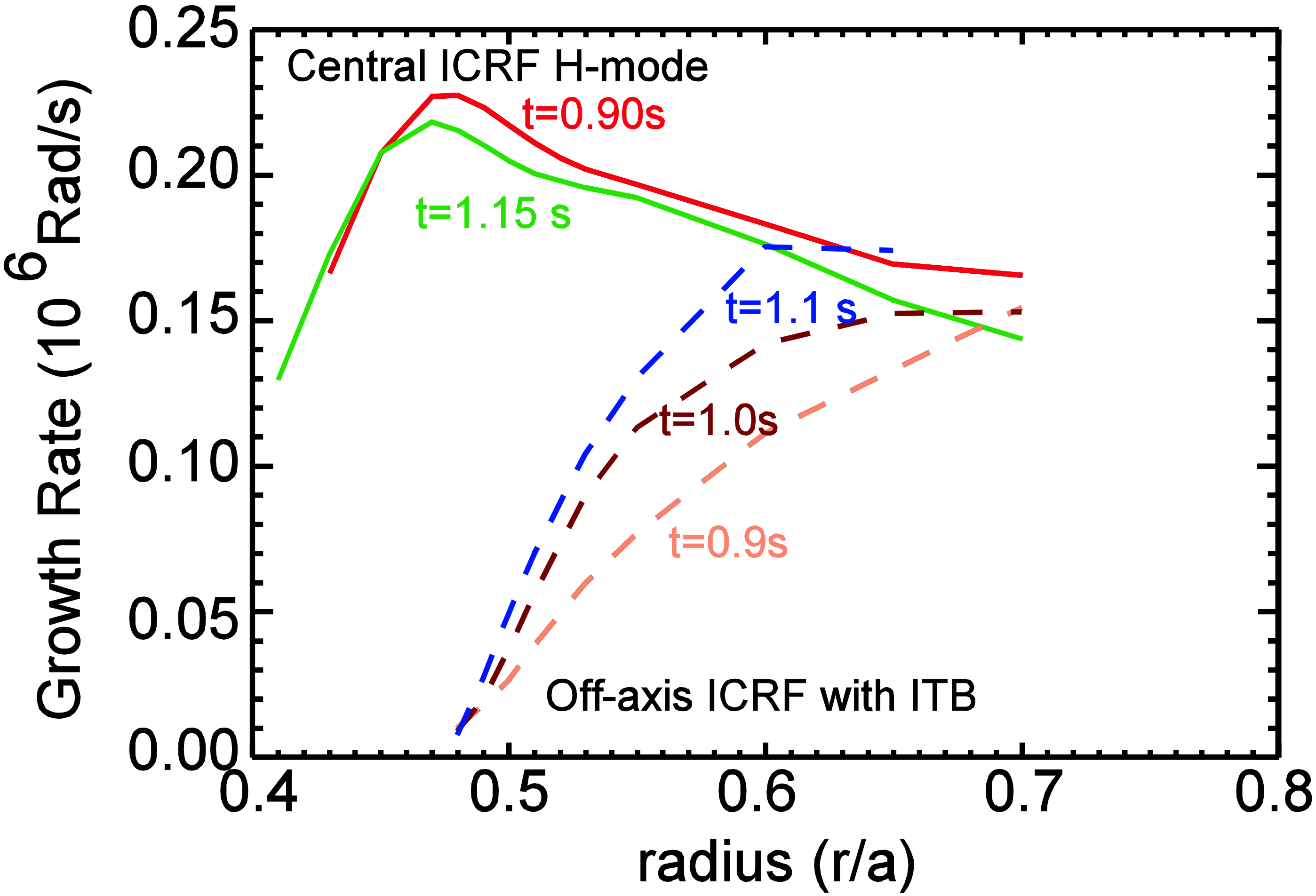
Maximum ITG growth rate is at $k_\perp\rho_i$=0.4. Beyond r/a=0.5, persists from L-mode into H-mode



ITG growth rate is 1.5 x 10^5 Rad/s near the ITB foot in the off-axis ICRF heated case with ITB

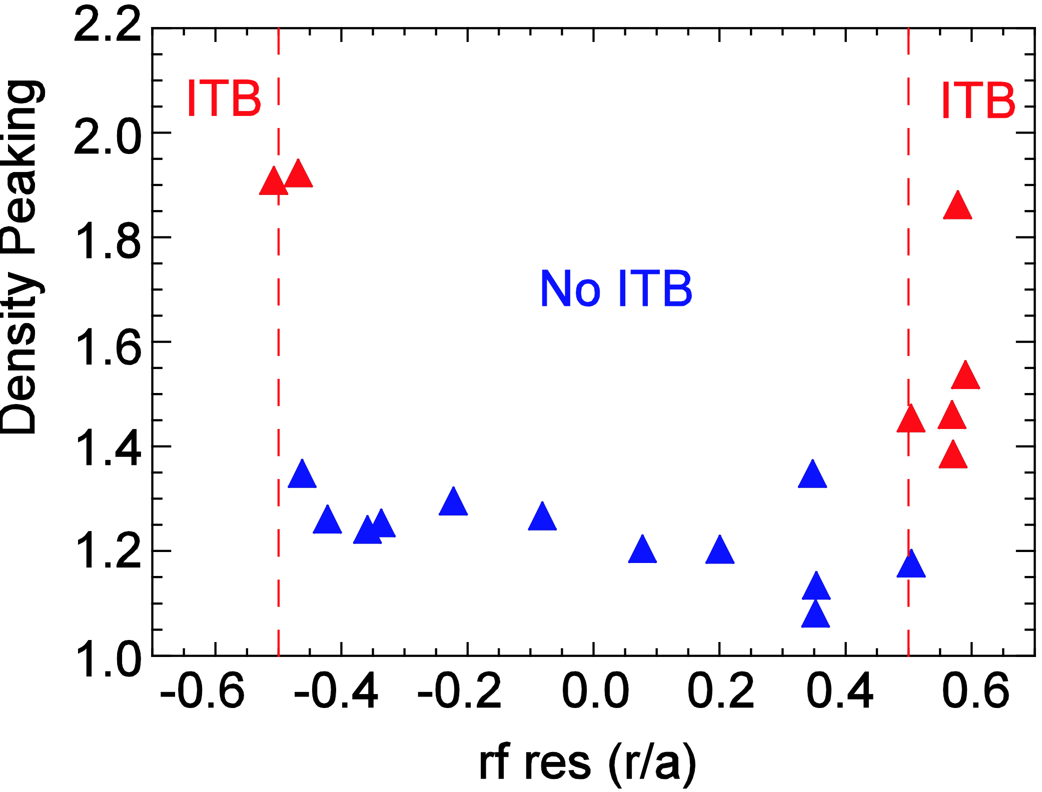
Linear GYRO calculation of the ITG growth rate echoes GS2 result

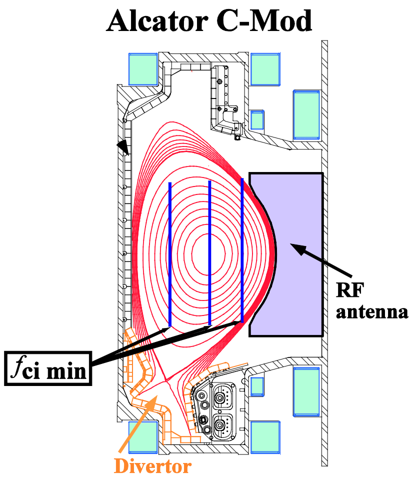
Maximum ITG growth rate at $k_\theta \rho_i \approx 0.4$, plotted with radius peaks at 1.5 x 10^5 Rad/s outside ITB foot in the off-axis heated plasma that developed an ITB

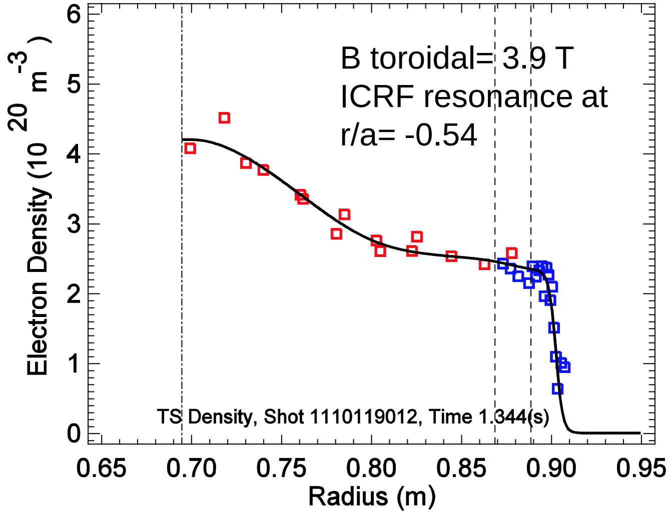


Maximum ITG growth rate is higher in the core for centrally heated ICRF plasmas with no ITB.

Using the toroidal magnetic field to scan the ICRF resonance position to the half radius usually causes the central density to peak and an ITB to develop

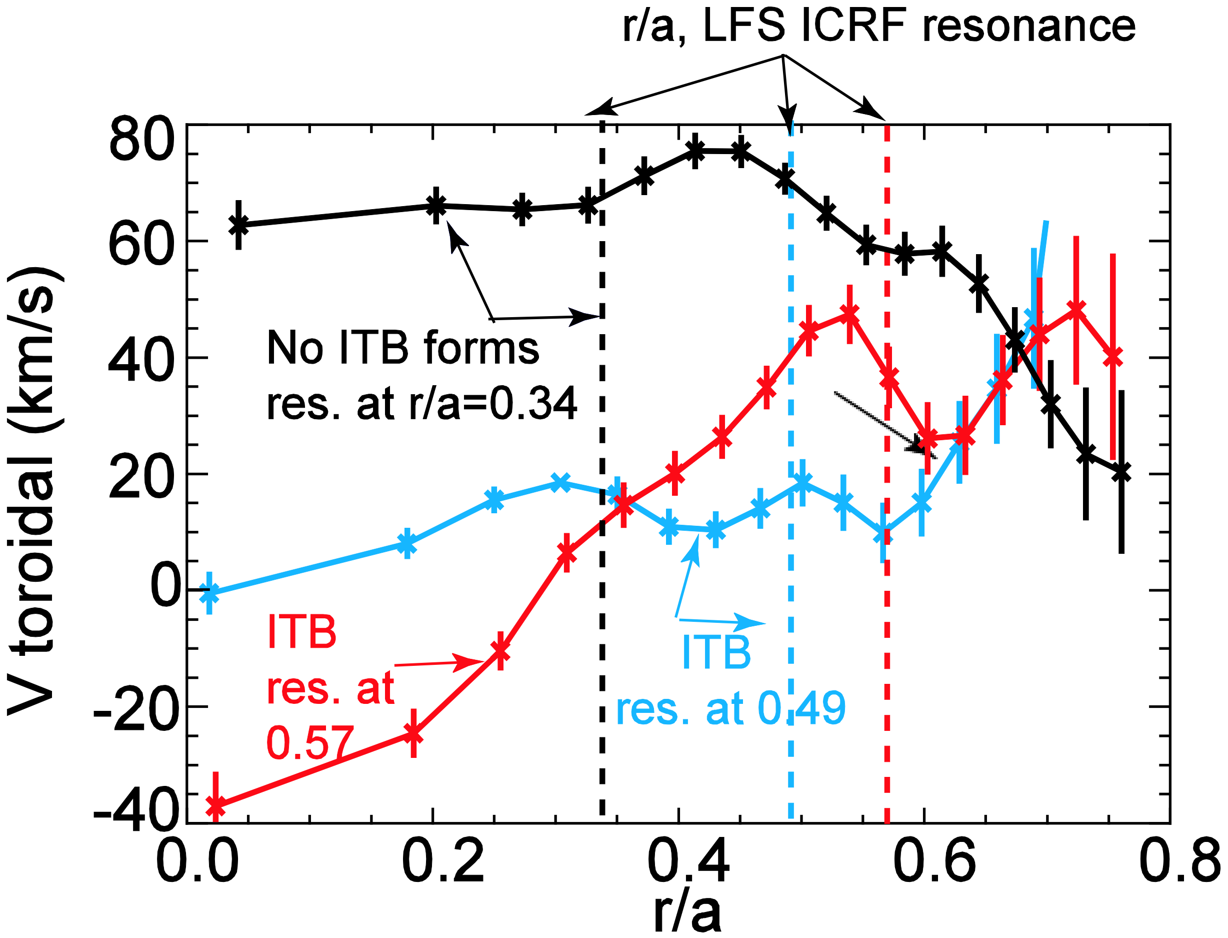


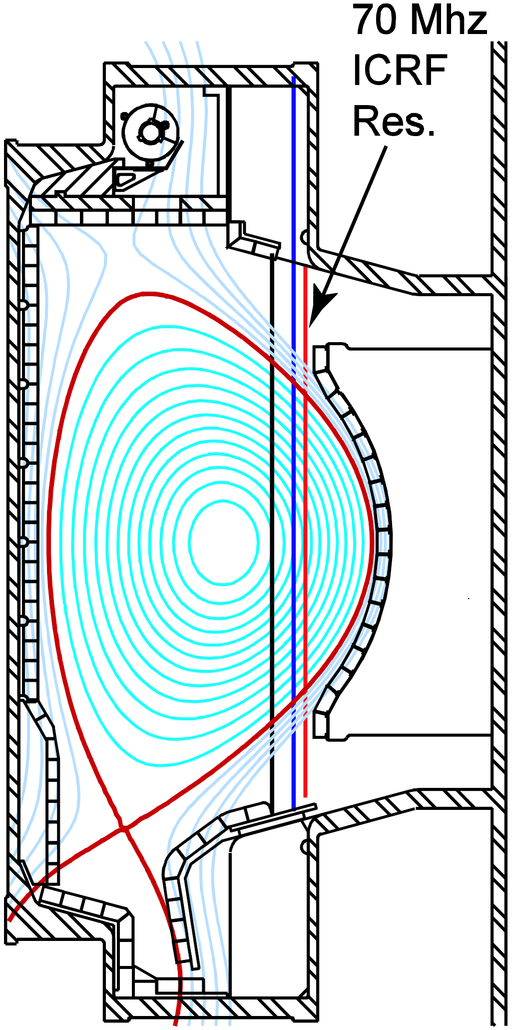




1/18/11: Scanning the toroidal field from 3.9 T to 5.5 T moves the 70 Mhz ICRF resonance across the plasma. ITB density peaking is seen at the extremes of the scan.

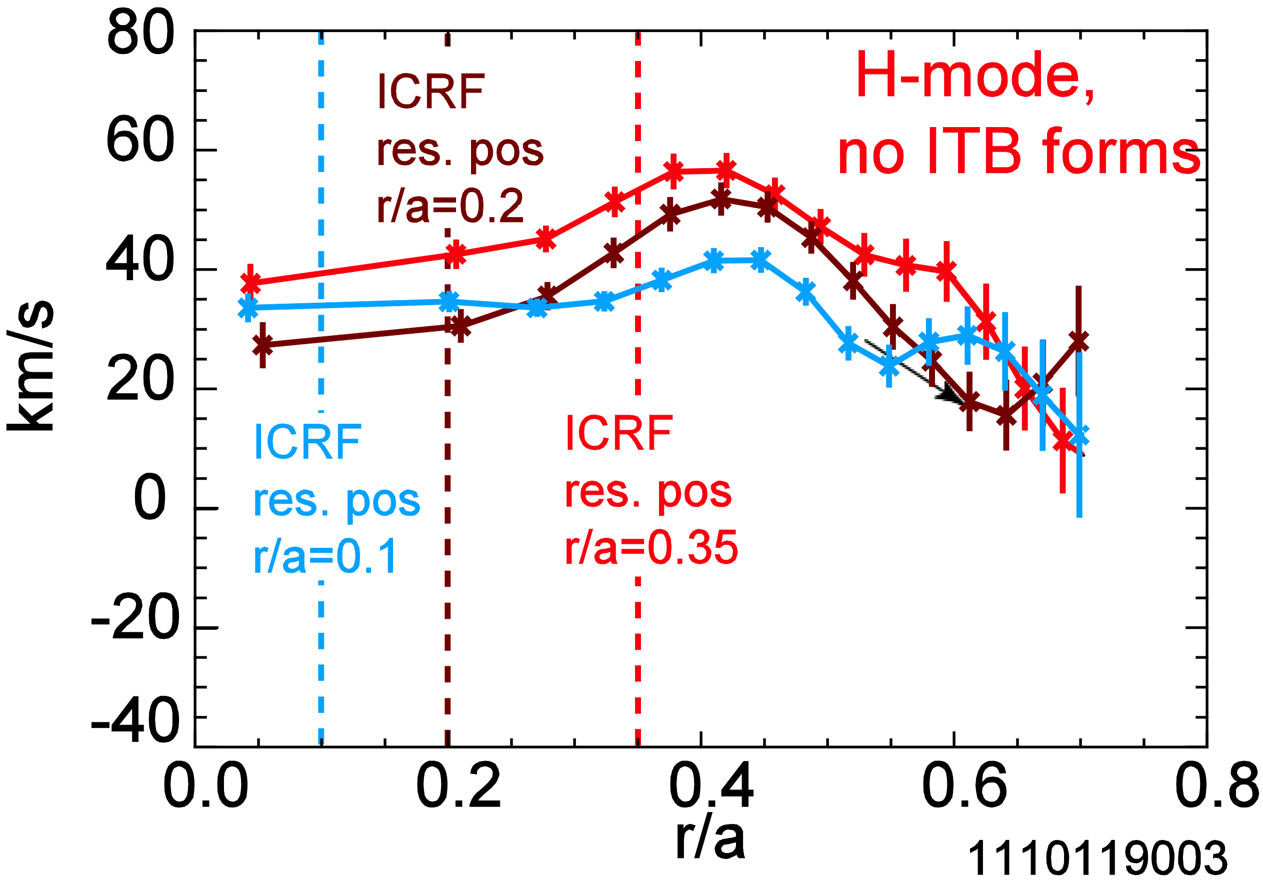
The toroidal velocity profile changes as the magnetic field is scanned: The ITB develops when there is a central well in the velocity profile.

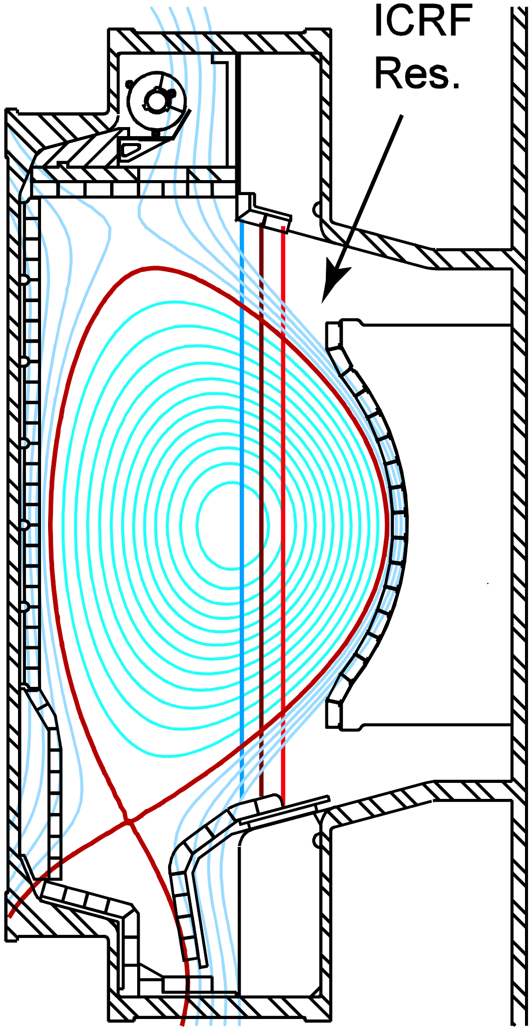




ICRF resonance positions are on the low field side of the plasma.

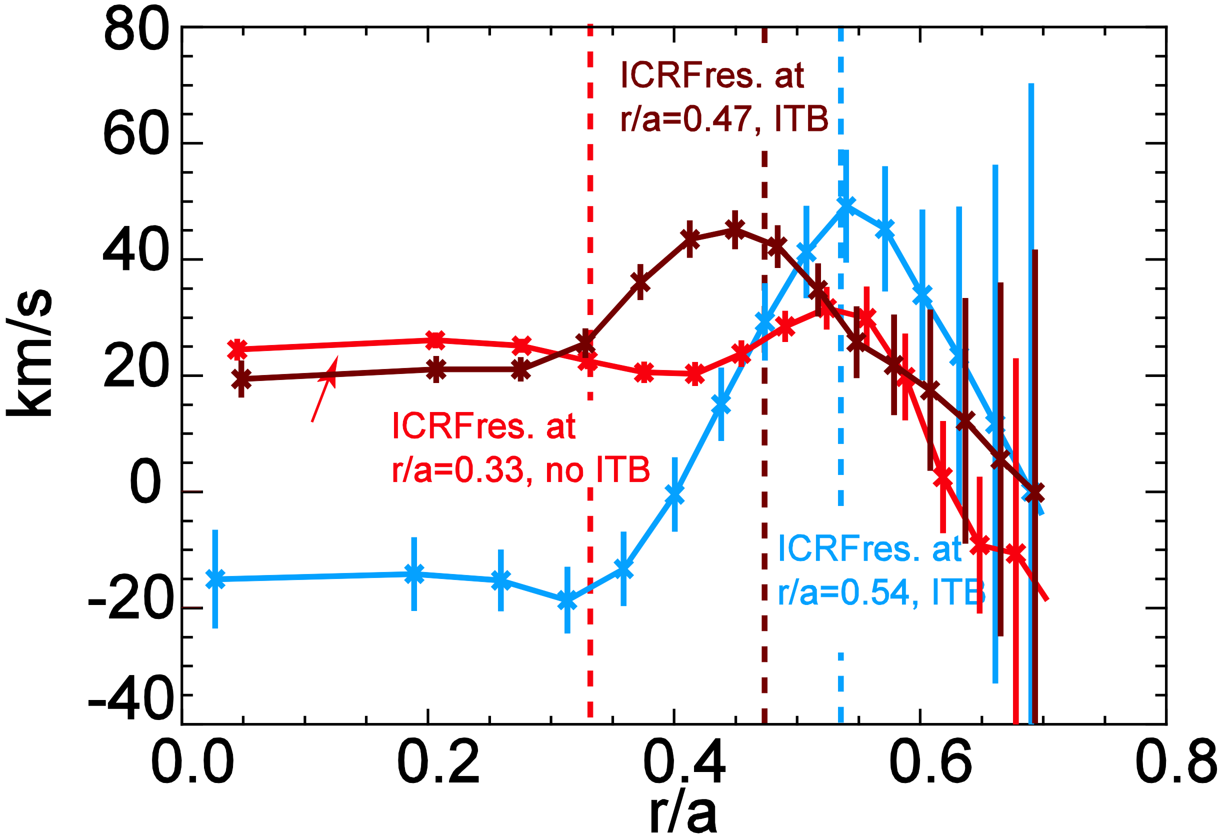
Inside the half radius, toroidal velocity profiles were flat or slightly peaked off access. No ITBs formed.

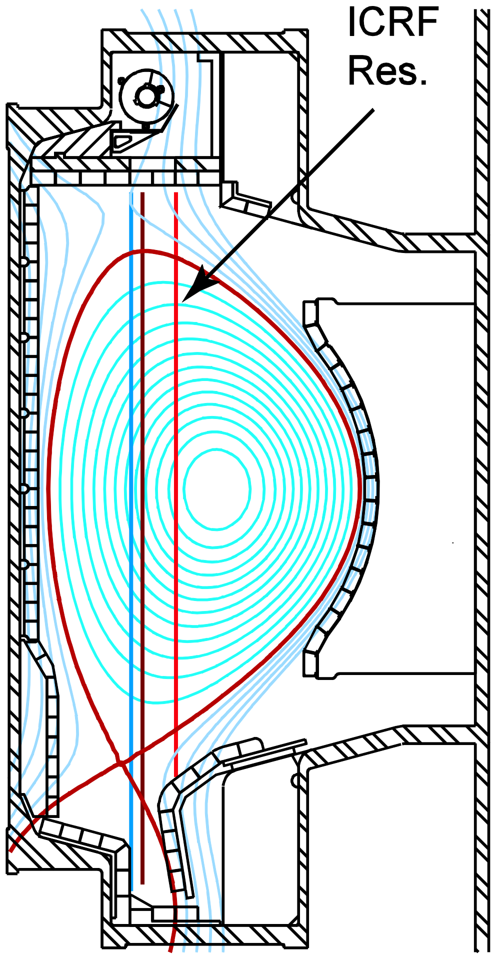




Toroidal velocity shows weak or no central well when ICRF resonance is closer to axis, no ITB forms.

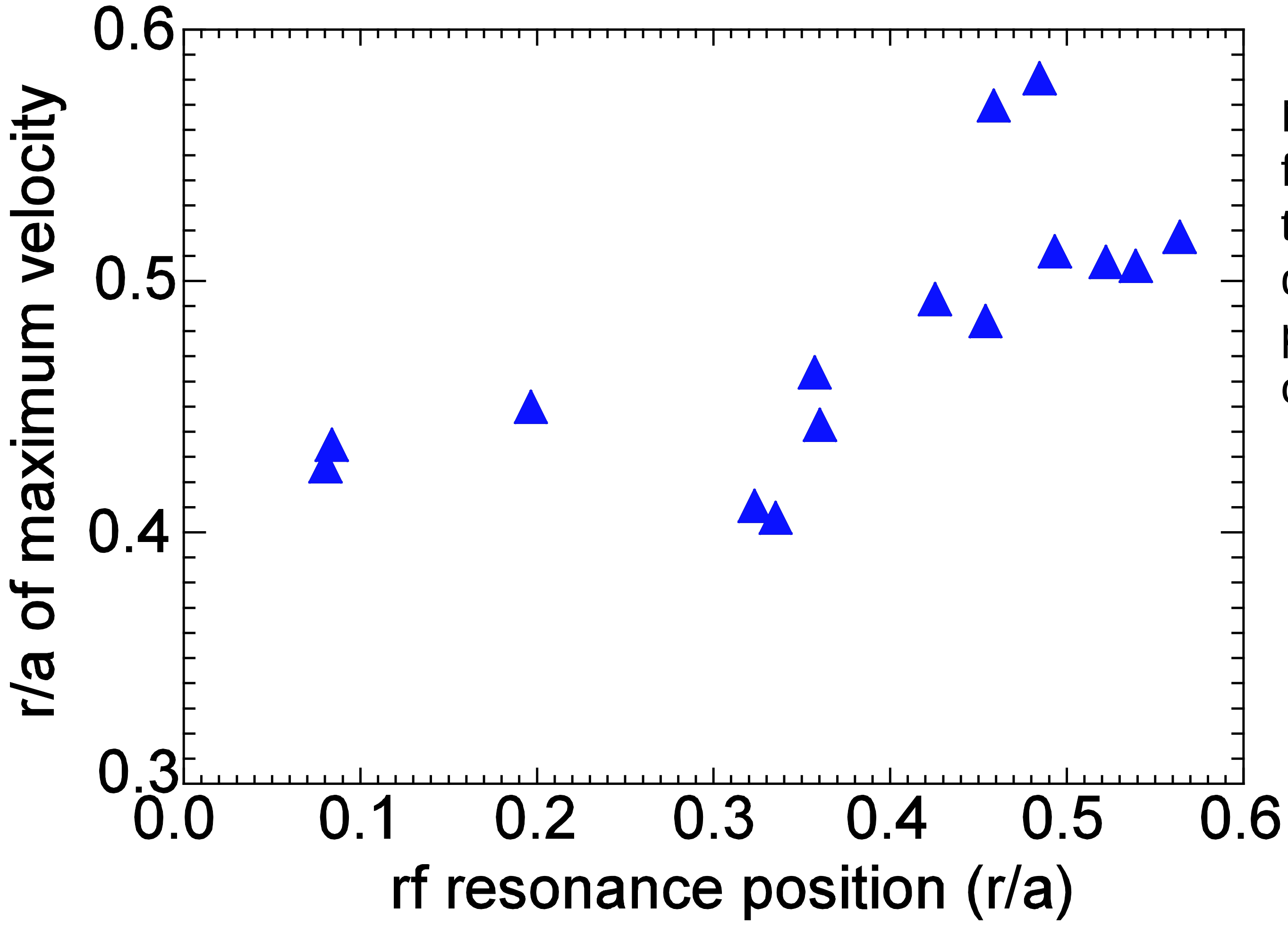
A deep well in the toroidal velocity appears as the ICRF resonance reaches the half radius on the high field side (HFS) of the plasma and an ITB forms





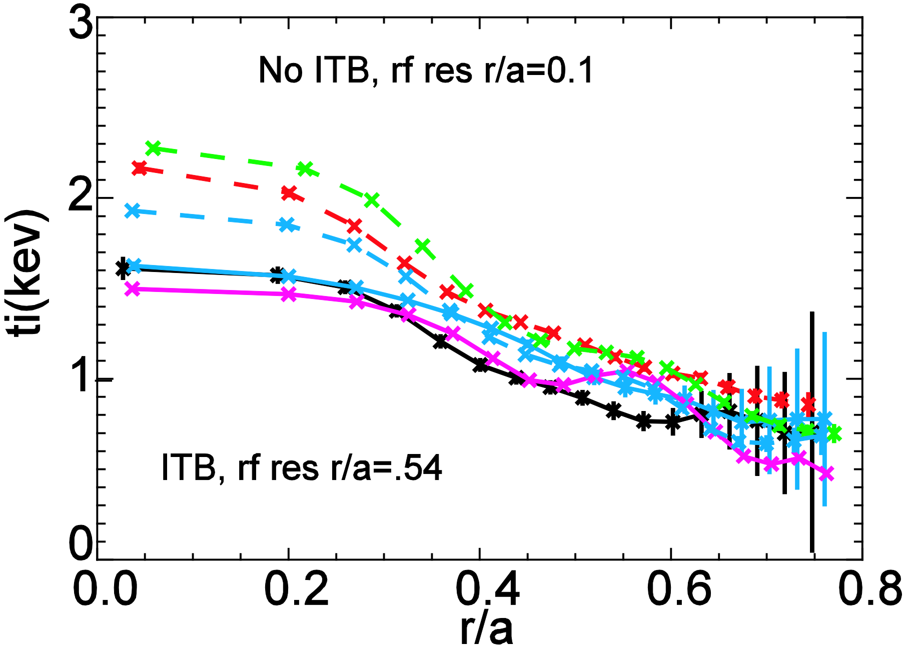
Toroidal velocity shows central well when ICRF resonance is off axis and an ITB forms.

The location of the peak in the velocity profile increases as the ICRF resonance moves further off-axis

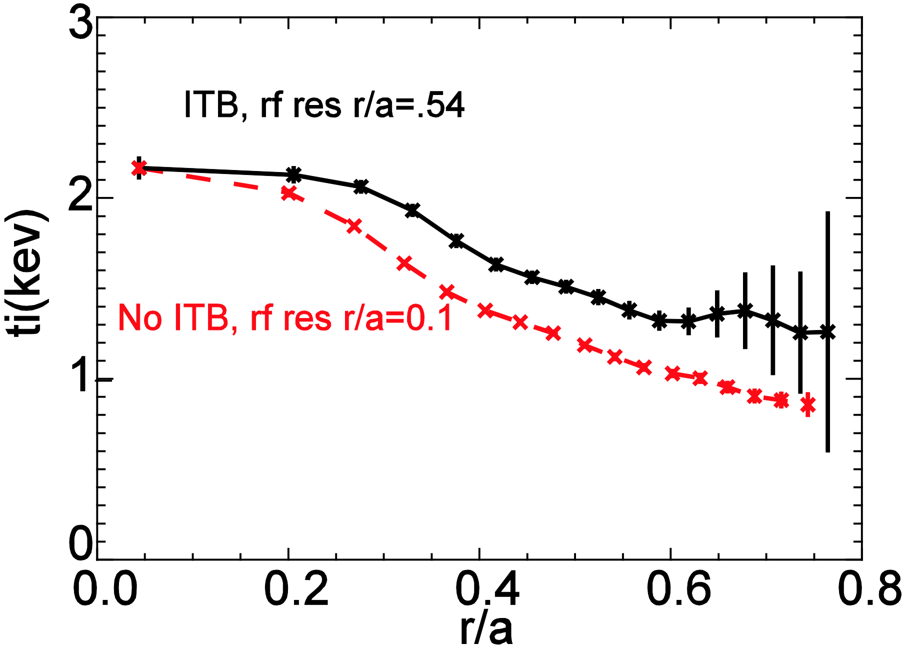


Note that it is frequently found that the toroidal velocity during H-mode is peaked on axis for on-axis ICRF heating

Ion temperature profiles are flatter with the ICRF resonance off-axis



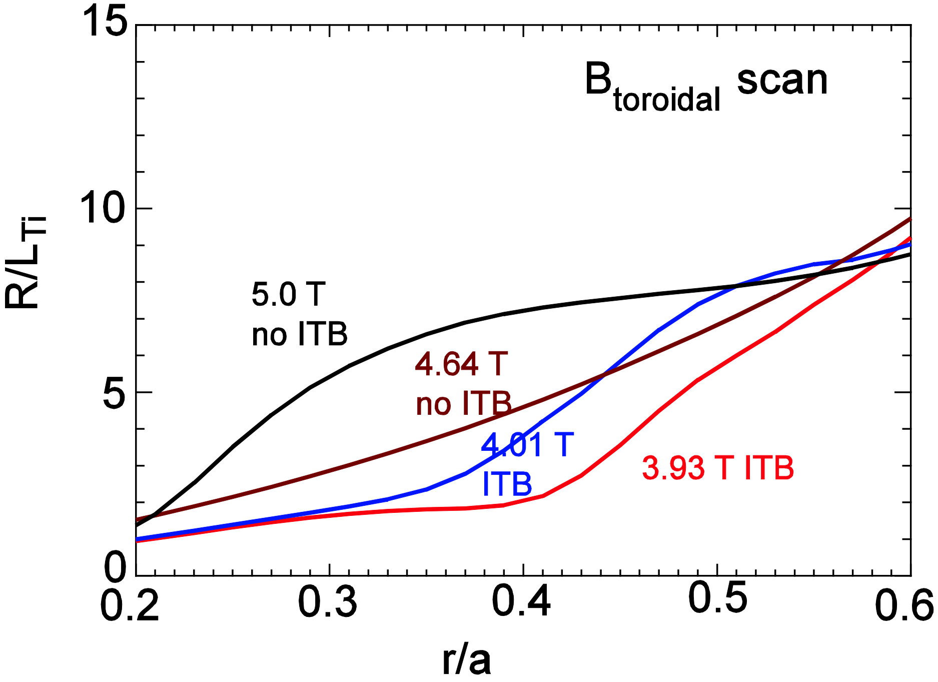
Data from 2 shots, 3 time points each are shown. Solid lines are from an ITB case, dashed lines from a centrally heated H-mode plasma.



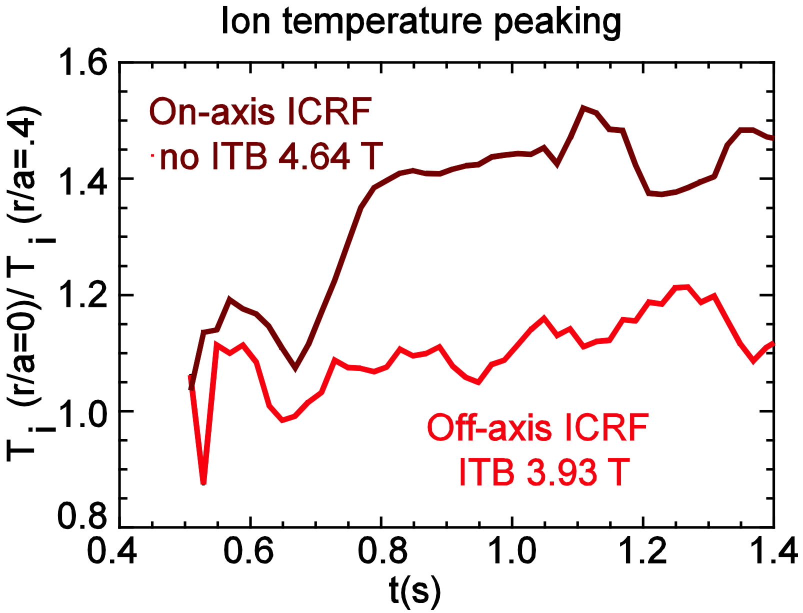
Two profiles (left) are normalized to the center point to show the difference in shape.

Flattening of the Ti profile and decreasing of R/L_{Ti} have been credited with increasing the stability of the plasma to ITG and decreasing turbulent diffusion

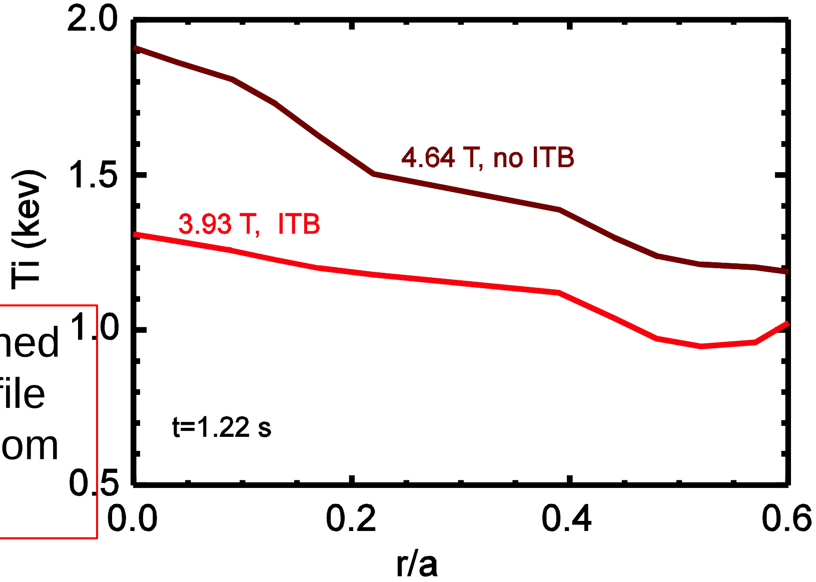
Calculation of Ti profile and R/L_{Ti} using the heating profile and neutron rate in TRANSP shows that the profile flattens as the magnetic field is scanned to move the rf resonance position off-axis



Ion temperature peaking

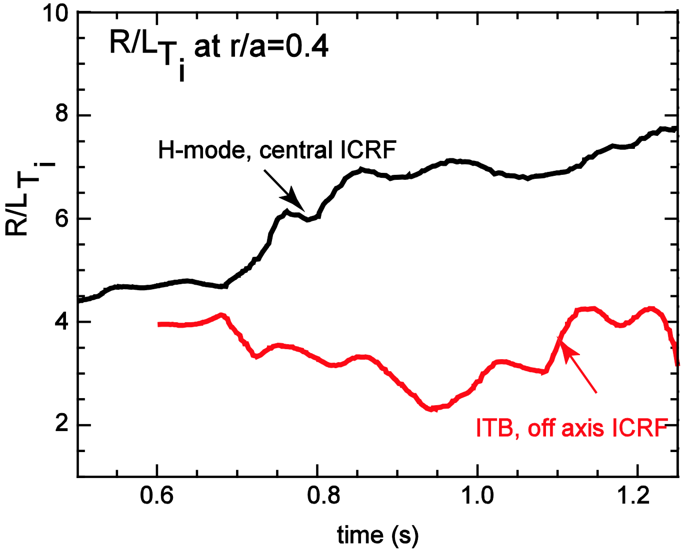


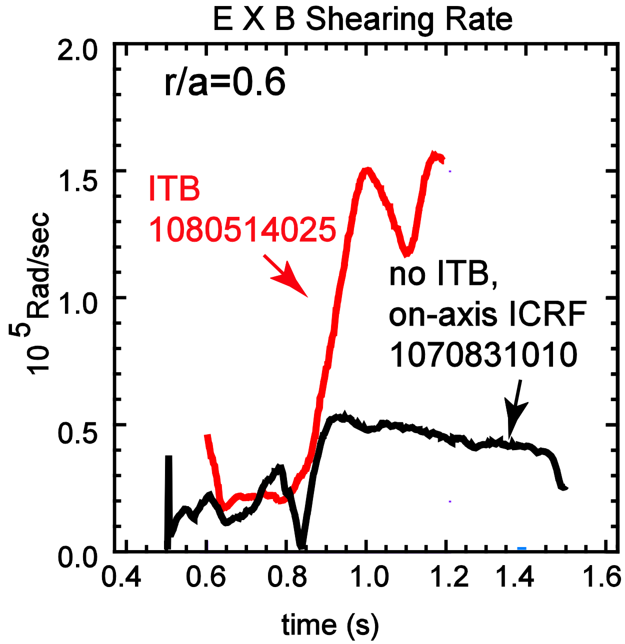
Ion temperature measurement from Doppler broadened Argon emission verifies that the ion temperature profile is flattened as the ICRF resonance is moved away from the plasma center.



Which is more important for ITB formation in Alcator C-Mod: R/L_{Ti} decreasing after H-mode transition or EXB shearing rate increase in the ITB foot region?

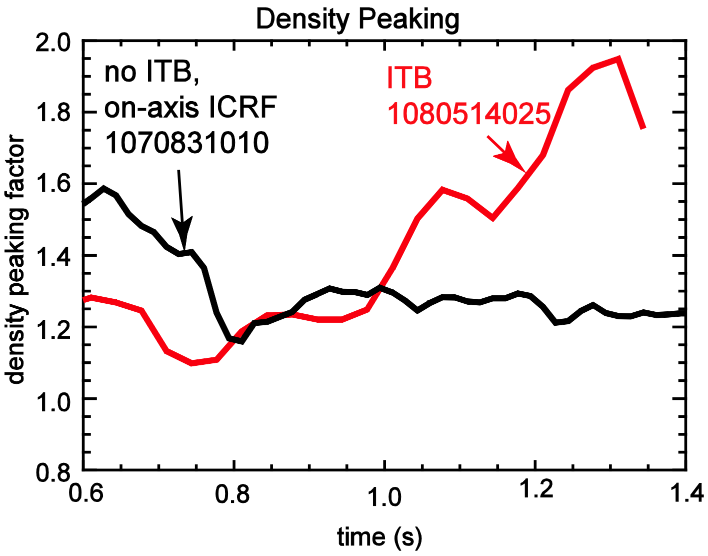
R/L_{Ti} decreases slowly after H-mode transition when ITB forms—no sudden transition





Shearing rate in the outer part of the plasma increases abruptly after the H-mode transition

Density increase with time is similiar to R/L_{Ti} change



Conclusions and Future Work

- Measurements of spontaneous toroidal rotation on Alcator C-Mod are allowing examination of the radial electric field and E X B shearing rate characteristics in C-Mod ITB plasmas.

  - ❖The rotation profiles change between plasmas that have on-axis versus off-axis ICRF heating.

  - ❖A radial electric field well is calculated in the off-axis ICRF heated cases using toroidal rotation data obtained from x-ray Doppler measurements and is significant in ITB plasmas

  - ❖The location of the peak in the rotation velocity appears to move with the ICRF resonance

- The self generated EXB shearing rate increases rapidly after the H-mode transition outside r/a=.5 in off-axis ICRF heated discharges, before evidence of ITB density peaking appear.

  - ❖EXB shearing rate is significantly higher (2 to 3 times) in the region outside r/a=0.5 in ITB plasmas than in non-ITB cases.

- The gyrokinetic calculation of the ITG growth rate shows that it is comparable to the experimental EXB shearing rate near the ITB foot

- Detailed profile measurements of ion temperature and plasma rotation have been obtained as a function of ICRF resonance position. Data are being studied and prepared for gyrokinetic analysis (GS2 and GYRO, linear and nonlinear)