DEPENDENCE OF TURBULENCE AND TRANSPORT ON THE ELECTRON TO ION TEMPERATURE RATIO

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MOTIVATION & OVERVIEW

- $T_e/T_I$ is a critical dimensionless parameter for confinement and transport
- Present large beam-heated plasmas typically have $T_I > T_e$
- Next-step, burning plasma, or reactor scale devices will operate with $T_e/T_I \approx 1$
  - Higher density, better confinement $\Rightarrow$ higher collisionality, thermalization
  - Direct alpha heating of electrons, limited beam heating
- Previous experimental work in H-mode (Petty, et al.): $\tau_E \sim (T_e/T_I)^{-2}$
- Theoretical predictions that transport increases as $T_e/T_I \Rightarrow 1$
  - Simulations suggest $\chi_I \sim (T_e/T_I) + (0.8-1.1)$ (Kotschenreuther, Dorland)
- Critical gradient for ITG modes, $R/L_{TI}$, is reduced as $T_e/T_I$ is increased

Goal: Understand fundamental physics of the dependence of turbulence & transport on $T_e/T_I$
OUTLINE

• Experimental conditions

• Profile Measurements

• Turbulence analysis

• Transport (TRANSP) analysis

• Conclusion
Experimental Investigation of Turbulence and Transport Dependence on $T_e/T_I$

- $B_T = -2.0$ T, $I_P = 1.0$ MA
- Inner Wall Limited
- L-mode plasma
- $a=0.63$ m.
- $\kappa=1.54$
- $P_{Beam} = 4.8$ MW
- $P_{ECH} = 2.4$ MW (4 gyrotrons)

GOAL: Scan $T_e$ while other parameters ($T_I$, $\Omega$, $n_e$) held nearly constant -->
Measure turbulence and transport characteristics

BES array: scanned radially on repeat shots
Experimental Investigation: $T_e/T_I$ Varied using ECH

- $B_T = -2.0 \, \text{T, } I_P = 1.0 \, \text{MA}$
- Inner-wall limited L-mode
- $a = 0.63 \, \text{m, } \kappa = 1.54$
- $P_{\text{BEAM}} = 4.8 \, \text{MW}$
- $P_{\text{ECH}} = 2.4 \, \text{MW}$

- $T_e$ increased by 20%
- $T_I$ and $V_{\text{tor}}$ reduced in response to increasing $T_e$
- Density (not shown) essentially unchanged
**$T_e / T_l$ VARIED USING ECH**

- $T_e$ increased by 20%
- Density unchanged
- $T_l$ and $V_{tor}$ reduced in response to increasing $T_e$

![Graph showing $T_e$ and $T_l$ over time with comments on ECH effects and profile time slices.]
**$T_e$ Uniformly Increased as Other Profiles Held Similar**

Electron Temperature Raised by 20%, Self-Similarly

- Rotation reduced modestly, potentially affecting $E_xB$ shearing rate
- Intrinsic impurity (carbon) increased about 60% with ECH
Turbulence Amplitude Increases with $T_e/T_i$

Measureable increase in fluctuation across profile, except in edge region (little or no change)

- Average frequency of fluctuations decreases with ECH as a result of rotation reduction

(Local turbulence properties measured with BES)
Turbulence Correlation Lengths and Decorrelation Time Exhibit Little Dependence on $T_e/T_i$

- Radial and Poloidal (not shown) correlation lengths virtually unchanged as $T_e$ is varied.

- Decorrelation time (eddy turnover time) exhibits little change, except near edge; suggests a stronger "churning" near edge region.

  \[ D_{\text{TURB}} = \frac{(L_{c,r})^2}{\tau_c} \]

- Poloidal flow velocity (eddy $v_\theta$) is reduced for $r/a < 0.9$ with higher $T_e$, but increases near edge (higher radial electric field?)
Ion, Electron, and Particle Diffusivity Increase with $T_e/T_I$

- Ion thermal diffusivity increases somewhat uniformly across profile
- Electron thermal diffusivity increases dramatically at and outside of deposition region, decreases inside
- Particle (Helium) transport increases
- $\tau_E \approx (T_e/T_I)^{-1.5}$

Magnitude of $\chi_I$ and $D_{He}$ increase is similar to that of turbulence ($\bar{n}/n$) increase, while change in $\chi_e$ increase suggests different transport mechanism
TURBULENCE ALSO INCREASES WITH $T_e/T_I$ WHEN $T_I$ INCREASED AT CONSTANT $T_e$

ECH and Beam Power Exchanged to maintain $T_e$ and increase $T_I$

\[ T_I \approx T_e \]
\[ T_I > T_e \]

\[ T_I \approx T_e \]
\[ T_I > T_e \]

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20-60% increase in $\tilde{n}/n$ across profile as $T_I/T_e$ approximately doubled.

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GROWTH RATES MODESTLY HIGHER WITH INCREASED $T_e/T_I$ WHILE SHEAR RATES REDUCED IN CORE

- Carbon level increased ~60% when ECH applied which reduces calculated growth rates: competition between $T_e/T_I$ and $n_{\text{IMP}}$
- Shear rates not significantly different over outer half-radius, where turbulence measurements obtained
- Can’t make quantitative conclusions yet, given uncertainty
CONCLUSIONS

- Turbulence and transport properties studied as a function of $T_e/T_I$, with $T_e$ increased by 20% relative to $T_I$ as other parameters held roughly constant.

- Long-wavelength turbulence increases as $T_e/T_I \Rightarrow 1$
  - $\tilde{n}/n$ increases about 10-20% ($0.45 < r/a < 0.9$)
  - $v_\theta$ is reduced, except at edge ($r/a \sim 0.95$)
  - $L_{c,r}, L_{c,\theta}, \tau_c$ exhibit little change.

- Transport increases significantly as $T_e$ is uniformly increased via ECH heating:
  - $T_e$ increased; rotation and $T_I$ decrease
  - $\chi_I$ increases in response to increasing $T_e$; $\chi_e$ increased outside $\rho_{DEP}$
  - $\tau_E \approx (T_e/T_I)^{-1.5}$

- Magnitude of turbulence increase consistent with ion and particle transport increase ($\sim 20\%$); electron transport increases substantially ($\sim 2.5$), likely resulting from an separate or additional mechanism.