DEPENDENCE OF TURBULENCE AND TRANSPORT ON THE TOROIDAL MACH NUMBER

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TRANSPORT TASK FORCE
SAN DIEGO, CALIFORNIA
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OVERVIEW AND MOTIVATION

- Examine the dependence of turbulence and transport on toroidal rotation and rotational shear by varying toroidal Mach Number while maintaining other dimensionless parameters nearly constant:
  \[ M = v_{\text{TOR}}/(c_s) \ (0.2 < M < 0.45) \]
  - L-mode and H-mode plasmas examined

- **Obtained comprehensive fluctuation data set:**
  - 2D turbulence measurements obtained over radial profile (0.4 < r/a < 1.0)
  - BES measured $n/\bar{n}$, $v_\theta$, $L_c$, $L_{c,\theta}$, $\tau_c$ (focus of this discussion)
  - FIR, Doppler Refl., PCI, Langmuir probes, high-k backscattering
  - L-mode and H-mode (focus here is L-mode)

- **Provide turbulence & transport data set for comparison with 3D simulations**
  - Contribute to V&V process, discussed this morning
  - C. Holland poster, this meeting

- **Preview:**
  - Not a large variation in turbulence parameters in L-mode
  - Subtle effects in correlation properties
**DIMENSIONLESS PARAMETERS WELL-MATCHED FOR MACH NUMBER SCAN**

- **I_p = 1.0 MA**
- **B_T = 2.0 T**
- **L-mode: 1.5-2.5 s**
- **H-mode: 2.7-4.0 s**

- Significant complications with LH transitions at low power (see talk by Schlossberg (McKee) tomorrow)

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**Graphs and Data Points**

- \( I_p \) (red and black lines)
- \( T_e \) (keV) plots for ECE30 and density
- \( n_e \)
- \( T_i \) (keV)
- \( V_{tor}(r/a=0) \)
- \( V_{tor}(r/a=0.8) \) for LH Transition
- \( \beta_N \)
- \( q_{95} \)
- \( \tau_E \)
- \( D_\alpha \)

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**Notes:**

Profiles Reasonably Well-Matched for Mach Number Scan

Density PROFILE

Thomson Data

= Core

= Tangential

dte126285.01500

Normalized shot: 126296, time: 1500.00

Mon Apr 16 18:49:05 2007

CerFit: Ti vs rho shot: 126299, time: 1500.00

Mon Apr 16 18:55:37 2007

Minor Radius (r/a)

Co-Injected

Balanced

Te vs rho shot: 126296, time: 1500.00

Mon Apr 16 18:52:10 2007

CerFit: Toroidal Rotation shot: 126299 time: 1500.00

dtro126285.01500

Ω (rad/s)

Te (keV)

Mon Apr 16 19:01:20 2007

n_e (10^{19} \text{ cm}^{-3})

T_e (keV)

T_i (keV)

Co-Injected

Balanced

Minor Radius (r/a)

Mon Apr 16 18:49:05 2007

FLUCTUATION SPECTRUM EVOLVES DYNAMICALLY THROUGHOUT DISCHARGE

- Measurements obtained in L-mode Discharges:
  \( I_p = 1 \text{ MA}, B_T = -2.0 \text{ T} \)
  \( P_{\text{inj}} = 5 \text{ MW}, \)
  \( n_e, o = 3 \times 10^{19} \text{ m}^{-3}, T_e, o = 2.2 \text{ keV} \)
  \( T_i, o = 2.7 \text{ keV} \)

- Beam source oscillations arise from current or voltage noise in neutral beam source, small amplitude:
  \( \tilde{n}_{\text{BEAM}}/n < 1\% \)

- Common-mode rejection procedures can isolate and subtract

- Fluctuations markedly reduced in core region at LH transition

Cross-Power Spectrum at \( r/a = 0.64 (\Delta Z = 1.2 \text{ cm}) \)
2D MEASUREMENTS OF CORE PLASMA TURBULENCE OBTAINED WITH HIGH-SENSITIVITY BES SYSTEM ACROSS MINOR RADIUS

- 1 MHz sampling
- $k_{\perp} \rho \leq 2.5 \text{ cm}^{-1}$
- 2 common-mode channels

<table>
<thead>
<tr>
<th>$\tilde{\eta}/\eta$</th>
<th>0.4%</th>
<th>0.7%</th>
<th>0.9%</th>
<th>2-10%</th>
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Rotation affects frequency spectra, but has little or no effect on fluctuation amplitude.

Comparison of Density Fluctuation Spectra

- Nearly identical amplitudes, but edge characteristics differ

Integrated Fluctuation level (70 < f < 400 kHz) virtually unchanged with M
TURBULENCE ADVECTS POLOIDALLY AT THE LOCAL 
**ExB VELOCITY**

**Time-Lag Cross Correlation**

Turbulence Velocity determined from poloidal cross-correlation time-lag analysis from BES

**Comparison of \( v_\theta \) (BES) and ExB (from CER)**

No indication of dominant flow direction relative to ExB (e.g., ion vs. electron diamagnetic)
Comparison of Turbulence Advection Velocity Profile (from BES)

Large local shear in $v_\theta$ profile
$(d(v_\theta)/dr \sim 5 \times 10^5 \text{ s}^{-1})$
**Correlation Parameters Show Modest Dependence on Rotation/Rotational Shear**

- $L_{c,\theta} > L_{c,r}$
- $L_{c,\theta}(\text{Co-Inj}) > L_{c,\theta}(\text{Balanced})$
- Super-simple assessment of decorrelation rate:
  \[ 1/\tau_c \approx \gamma \approx \gamma_{\text{lin}} - \gamma_{\text{ExB}} \]

![Graphs showing correlation parameters vs. minor radius](image)
Balanced-Injection Discharges Exhibit Significant Dispersion in Edge Fluctuations: Not Observed in Co-Injection

- Dual-mode behavior in Balanced-injection discharge in edge region (r/a~0.95)
- Counter-propagating low-frequency mode (electron diamagnetic direction)
- How does this affect transport?
**Fluctuation Amplitude Increases with Poloidal (Z) Position**

- $\Delta Z_{\text{BES}} \ll L_{\text{Plasma}}$
- Suggests peak fluctuation amplitude is “rotated” away from outboard mid-plane

![Diagram showing stronger turbulence and fluctuation amplitude data for different $r/a$ values](image)
GYRO SIMULATIONS SHOW EFFECT OF ROTATION AND ROTATIONAL SHEAR ON TURBULENCE

No Shear
\( \gamma_{\text{ExB}} = 0 \)

Shear
\( \gamma_{\text{ExB}} = 0.05 (c_s / a) \)

Fluctuation structure peaks at outboard midplane
"Ballooning-like"

Center of fluctuation structure peaks at finite \( \theta \)

- Measurements and simulations suggest off mid-plane peaking of density fluctuation amplitude in direction of equilibrium poloidal ExB flow

C. Holland, J. Candy

**Core H-Mode Fluctuations Significantly Reduced from Those in L-Mode**

- Large edge fluctuations imprinted on beam: can’t isolate other local core fluctuations in H-mod
**Turbulent Eddy Structures Differ in L & H-mode:**
Elliptical in L-mode vs. Tilted in H-mode

**2D Spatial Correlation Function (Δτ = 0)**

Eddy structures show dramatic differences between L-mode and H-mode: effects of poloidal flow shear?
SUMMARY & FUTURE DIRECTIONS

- Turbulence characteristics investigated as a function of toroidal Mach #
  - Dimensionless scaling study
  - Examine effects of varying ExB shear on turbulence
  - L-mode and H-mode examined
  - Balanced injection plasmas resulted in co-rotating plasmas
  - Data set for V&V study
- Little change in $\tau_E$ with $M$ in L-mode
- No measurable change in fluctuation amplitude profile
  - Poloidal (ExB) velocity varied significantly (~50%)
  - Increased poloidal correlation lengths at high rotation
  - No measurable change in radial correlation length
  - Reduced decorrelation rates in high shear zone (r/a~0.9)
- Increase in turbulence amplitude with distance from plasma midplane
  - qualitatively consistent with rotation of turbulence ballooning structure (GYRO)
- Significant increase in $\tau_E$ with $M$ in H-mode (~30%)
  - Fluctuations amplitude several times smaller than L-mode in Balanced plasma
  - Co-rotating plasmas have large fluctuation structure near pedestal
  - Eddy structure differs in L vs. H-mode