Plasma Fluctuation measurements in Ion Stiffness Experiments using Phase Contrast Imaging

by

A. Marinoni¹

In collaboration with:

J.C. Rost¹, M. Porkolab¹
K.H. Burrell², J. Candy², T.C. Luce²
and the DIII-D Team

¹ Plasma Science and Fusion Center, MIT, Cambridge (MA)
² General Atomics, San Diego (CA)

Presented at the 54th meeting of the APS division on Plasma Physics
Providence, Rhode Island

October 29th - November 2nd, 2012
What is stiffness?

The profile’s resistance to change with the addition of heating power.
High stiffness may affect ITER performance

• TGLF modeling of ITER base case scenario suggest very stiff transport at fixed pedestal beta and no ExB shear
  [J. Kinsey at al., Nucl. Fusion 51, 083001 (2011)]

• Recent JET experimental results indicate that, at low magnetic shear, ion stiffness significantly increases with lowering toroidal rotation, and thus ExB shear

• ITER is expected to rotate slowly due to low external torque and high inertia, thus stiff profiles are predicted

How will the fusion power scale with the coupled power?
Dedicated experiments were performed on DIII-D to test the impact of rotation on ion stiffness

- Goal: vary heat flux at fixed $\beta_{\text{ped}}$ in ITER relevant scenario
- Co and balanced beams provided low and high rotation
- NBI power varied by a factor of 3 at low and at high rotation

- $n_e_0 \sim 5-6 \times 10^{19} \text{ m}^{-3}$
- $T_{e_0} \sim 3.5-5 \text{ keV}$
- $T_{i_0} \sim 4-8 \text{ keV}$
- $B_T = 2.1 \text{ T}$
- $q_0 \sim 1.2$
- $q_{95} \sim 4$
- $P_{\text{NB}} \sim 3-9 \text{ MW}$
- $\beta_p \sim 0.6-1.2$
ExB velocity depends primarily on torque

Little dependence is observed on input power in the entire dataset

Low torque shots
High torque shots

Does a larger ExB (shear) reduce transport and fluctuations?

A. Marinoni/APS-DPP/October 2012
Plasmas at high rotation show lower transport consistent with a larger ExB shear quench

Larger difference between the two scenarios at outer radii

Linear relationship between fluxes and gradients

A. Marinoni/APS-DPP/October 2012
Fluctuations were measured by the Phase Contrast Imaging diagnostic

Details on the system:
J.C. Rost, GP8.00090
Fluctuations were measured by the Phase Contrast Imaging diagnostic

Details on the system: J.C. Rost, GP8.00090

Optics table enclosure

CO₂ beam

parabolic mirror

CO₂ laser

phase plate

lens

detector

16 element LN cooled HgMnTe

λ/8

A. Marinoni/APS-DPP/October 2012
Fluctuations were measured by the Phase Contrast Imaging diagnostic

- Sensitive to the line integral of density fluctuations
- Large bandwidth
  - $f$: 10 kHz - 10 MHz
  - $k$: 1 - 20 cm$^{-1}$
- Sensitive to horizontally directed wave-vectors:
  - $k_\rho$-$k_\theta$ components change along the beam-path
- $k_\theta$ induces a net Doppler shift

Details on the system:
J.C. Rost, GP8.00090
Intrinsic frequency and Doppler shifts are captured by the PCI.
Intrinsic frequency and Doppler shifts are captured by the PCI.
Doppler shift in PCI spectra is consistent with CXRS measurements

Primary dependence is observed on coupled torque
Difference in Doppler shift localizes the signal in the region $0.5 < \rho < 0.8$.
Difference in Doppler shift localizes the signal in the region $0.5 < \rho < 0.8$

A difference in Doppler shift of 200 kHz is compatible with standard turbulence spatial scales in $0.5 < \rho < 0.8$

Innermost radii and the pedestal are to be excluded
The intensity of fluctuations decreases at high rotation.

Comparable intensities at same torque and different power.

High torque plasmas show similar Doppler shifts.

Spectra are coherently averaged in inter ELMs phases.
The intensity of fluctuations decreases at high rotation.

Comparable intensities at same torque and different power.
Correlation lengths do not seem to depend on either torque or power.

The impact of torque is within the PCI resolution.

Correlation lengths are coherently averaged in inter ELMs phases.
Conclusions and future work

**Intensity of fluctuations:**
- **Strong torque** dependence
- **No power** dependence

**Correlations lengths:**
- **Independent** of torque and power

Based on Doppler shifts, the bulk of the signal comes from the region $0.5 < \rho < 0.8$, where the effect of torque on transport is the largest.

Nonlinear GYRO simulations and comparisons via a synthetic diagnostic are **in progress**.
What is stiffness?

- The sensitivity of the gyro-Bohm normalized ion heat flux to the driving $R/LT_i$. [J.Citrin, ITPA 2012]

- The ratio between the diffusivity and the difference between the logarithmic gradient of the temperature and its critical value, using an appropriate normalization. [X.Garbet, PPCF 2004]

- Marginal stability, i.e. profiles whose gradients are close to the instability threshold everywhere

- The profile’s resistance to change with the addition of heating power... i.e. the fractional increase in the diffusive heat flux divided by the fractional increase in the temperature gradient [J.De Boo, PoP 2012]
Doppler shift in PCI spectra is consistent with CXRS measurements.

Little or no dependence is observed on input power at same torque.