Fluctuation characteristics of micro-turbulence on Tore Supra using Doppler backscattering system

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Outline

1. Shape of the wavenumber spectrum in the intermediate k-range and impact of collisionality
2. Dispersion relation from Doppler measurements
3. Investigation on low frequency oscillations of the density fluctuations velocity
4. State of the DREVE project (Doppler reflectometer in vertical line of sight)

Summary & perspectives
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Summary & perspectives
Shape of k-spectrum on Tore Supra

Example of a ICRH discharge (#45511) @ r/a = 0.8 ± 0.08:

- No clear transition (no knee in the spectrum)
  => 2 regions: “quasi-linear” region $k\rho<0.8$ and a transfer region $k\rho>0.8$
Transition in the $k$-spectrum at high $k$

Faster decrease at higher $k$

=>$\text{Shell model}$

(conserved quantities potential vorticity and potential enstrophy)

\[ h \equiv n - \nabla^2 \Phi \quad \quad W = h^2 \]

Interaction with disparate scales (drift waves – ZF)

\[ |\tilde{n}_k|^2 \approx |\tilde{\phi}_k|^2 \]

\[ |\tilde{n}_k|^2 \approx \frac{k^{-3}}{(1 + k^2)^2} \]

Generalized form :

\[ \tilde{n}_k \approx (1 + i\delta)\tilde{\phi}_k \]

\[ |\tilde{n}_k|^2 \approx \frac{k^{-3}}{(1 + \alpha k^2)^2 + \beta k^2} \]
Shape of k-spectrum on Tore Supra

Example of a ICRH discharge (#45511) @ r/a = 0.8 ± 0.08:

Fair agreement for all cases with the model taking into account interactions between disparate scales (drift-waves-zonal flows)

$L. Vermare et al, CRAS 2011$
Dimensionless scaling experiments in Tore Supra

dedicated $v^*$ scan experiments $\Rightarrow v^* = [0.11 - 0.44]$

$\nu^* \propto n/T^2$

$\rho^* \propto \sqrt{T}/B$

$\beta \propto nT/B^2$

Dimensionless parameters well matched!
\( \nu^* \) dependence of spectrum shape

Decreasing collisionality affect only the quasli-linear part of the spectrum:

- spectrum more peaked at low \( \nu^* \)
- no clear impact in the transfer region

\( \Rightarrow \) In contrast with effect expected from zonal flows damped by collisions!
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Summary & perspectives
Perpendicular velocity profile

Perpendicular velocity in the laboratory frame:

\[ V_\perp = V_{E \times B, \perp} + \left< \frac{\omega}{k} \right>_{\text{fluc}} \]

with usually \( \left< \frac{\omega}{k} \right>_{\text{fluc}} \ll V_{E \times B, \perp} \)

\( \Rightarrow \) direct access to the radial electric field

[E. Trier et al, NF 2008]
Perpendicular velocity evolution with $k$

\[ \mathbf{v}_\perp(k) = I \mathbf{V}_{\text{ExB}} + |V_\phi(k)| \mathbf{V}_\phi \]

\[ V_\phi \equiv \frac{\omega_{\text{dia}}}{k} \]

**High $\nu^*$:**
\[ \omega_{\text{dia}}(k) \propto k^\alpha \]
- $V_\phi > 0$: ion
  - with $\alpha > 1$
- $V_\phi < 0$: e-
  - with $\alpha < 1$

**Low $\nu^*$:**
\[ \omega_{\text{dia}}(k) \propto k \]
- mixed turbulence?

[L. Vermare et al, PoP 2011]
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Summary & perspectives
Motivations

GAMs & zonal flows observations

- direct observation from a single system: as currently observed in AUG during L-mode plasmas

- correlation between independent systems: as planned in Tore Supra using the new vertical system and the old one (equatorial plan)

$\Delta \phi = 120^\circ$

$\Delta \theta = 90^\circ$

[G. Conway et al, PPCF 2005]
Evaluation of the methods using synthetic signal

3 methods:
- Directly from the derivative of the phase
- Using sliding FFT windows (expected value evaluations or fitting of the Doppler component)
- Using pmusic algorithm

Synthetic signal: \[ \sum_j \cos(2\pi F_j t + f_L) + i \sum_j \sin(2\pi F_j t + f_L) \]

\[ f_L = f_{GRMS} \cos(2\pi f_G t) \]

\[ F_j = f_{Dop} + \delta f_j \]
\[ \delta f_j \in [-\Delta f, +\Delta f] \]

Main Doppler component:

\[ f_{Dop} = 300kHz \quad \Delta f = 200kHz \]

Additional low frequency oscillation:

\[ f_G = 14kHz \quad f_{GRMS} = 20kHz \]
Application to synthetic signal

- **phase derivative**
  - fast
  - no parameters choice
  - very noisy
  - Signal length > 100 000

- **sliding FFT**
  - sensitive
  - Signal length > 300 000

- **pmusic**
  - signal length > 60 000
  - high sensitivity
  - parameters choice
Application to experimental data

# 45510 – high collisionality case of the $\nu^*$ scan with specific set-up to acquire longer frequency step

X-mode : $r/a = 0.95$

Oscillations in the fluctuations velocity observed at $F=8.2\text{kHz}$ using all methods
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Summary & perspectives
DREVE project: Vertical Doppler reflectometer

Capabilities of studying the role of turbulence driven flows, long range correlations and GAMs

Characterisation of long-range correlations of density fluctuations and of their velocity in L mode plasmas using correlation between equatorial and vertical reflectometers (toroidal + poloidal)

=> Accessibility of GAMs in vertical line of sight (poloidal structure m=1)

One additional channel identical to the equatorial Doppler system (0-mode, V-band)

Correlations between 2 Doppler reflectometry channels ($\Delta \theta = 90^\circ$; $\Delta \phi = 120^\circ$)
- at a given wavenumber between $3 < k < 15$ cm$^{-1}$
- with localized measurements between $0.5 < r/a < 0.95$
DREVE in operation

First spectra in March 2010

Frequency (kHz)

- V band
  50-75 GHz
  O mode
DREVE in X mode to access high $k$

High magnetic field $B = 3.8$ T, D band, $k$ up to $40$ cm$^{-1}$

$1 < k_{\rho_i} < 6$ to 10 (depends core/edge)

Low magnetic field $B = 2$ T, W band or mixed $k$ up to $30$ cm$^{-1}$

First tests in April 2011 using the TS D-band system
The adventures of DREVE

- Motorized antenna system and synchronized acquisitions are ready on Tore Supra for correlation studies (since October 2010 and waiting for plasmas ...)

- March-April 2011: Implementation of the system on TCV during shutdown of TS => accident with ECRH (TCV safety system not sensitive enough for our system => mixer and multiplier seriously damaged)

- Restart on TS next week using spare components and restart with “full power” beginning of June (waiting of new components)

Next steps:

- first attempts to correlate signal from both systems

- perform dedicated experiments to GAMs study
Summary & perspectives

- Robust features observed in $k\theta$-spectrum: departure from a classical $k$-spectrum power law with fast decrease for $k\rho_i > 1$ and fair agreement with model taking into account interactions between disparate scales (drift-waves-zonal flows)

- Modification of the $k$-spectrum shape by varying $\nu^*$
  -> in contradiction with standard expectations from core turbulence
  ... specific behaviour of the interface area between core and edge ?
  => new experiments are planned to address this point

- Modification of the dispersion relation by changing $\nu^*$

  Set of nice experimental observations to compare with gyro-kinetic codes: challenging simulations !

- Observation of low frequency oscillation in the fluctuations velocity
  => possible GAMs ?

  Deeper investigations are planned during this campaign on long range correlation and GAMs studies
Thank you for your attention!
Ray tracing help

One channel identical to the equatorial Doppler system

⇒ O-mode polarisation, V-band
⇒ Tiltable antenna with Gaussian optics

Same cut-off (O-mode) but poloidal angle will depend on the Shafranov shift:

\[ r/a = 0.87 \]
\[ 2k_0 = 8.78 \text{ cm}^{-1} \]
\[ \theta = 88^\circ \]

\[ r/a = 0.87 \]
\[ 2k_0 = 8.55 \text{ cm}^{-1} \]
\[ \theta = 6.5^\circ \]