The 11th meeting of study on Plasma Science for Young Scientists,
Mar. 17-19 2008, JAEA, Naka, Ibaraki, Japan

Coexistence of the drift wave spectrum and low-frequency zonal flow potential in cylindrical laboratory plasmas

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Plasma Turbulence
Itoh Project 2004-2008

Content

1. **Observation of the drift-wave and the residual zonal flow**

2. **Linear dispersion relation**

   i) Comparison of normalized fluctuation levels

   ii) Wave numbers of fluctuations

   iii) Poloidal velocity fluctuations derived from TDE method

3. **Modulational instability**

4. **Bispectral analysis**

Aim of the Specially-Promoted Research

Quantitative study of "Structural formation and selection rule in turbulent plasma"

Quoted from P.H. Diamond, et al., Plasma Phys. Control. Fusion **47** R35 (2005)

Plasma production:

i) ***exitation of turbulence***

ii) ***excitation of zonal flow***

iii) **Saturation of turbulence with zonal flows**

Observation:

i) ***Spatio-temporal structure of the drift wave-zonal flow system***

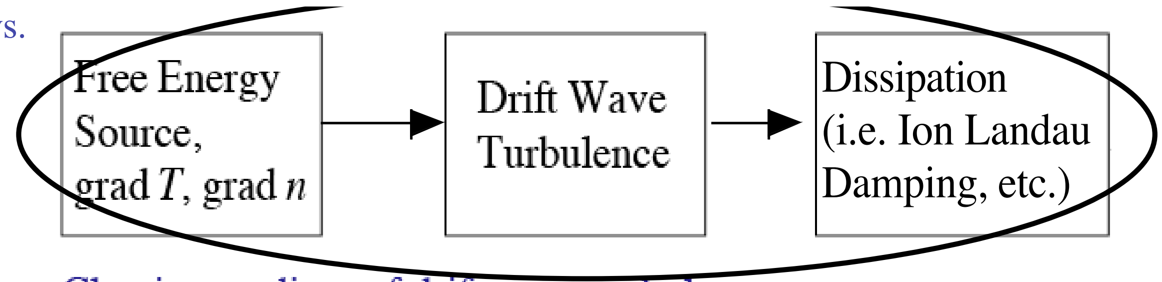
ii) **Comparison of intensity between the zonal flow and turbulent Reynolds stress**

iii) ***Nonlinear energy transfer***

Red: Completed now!

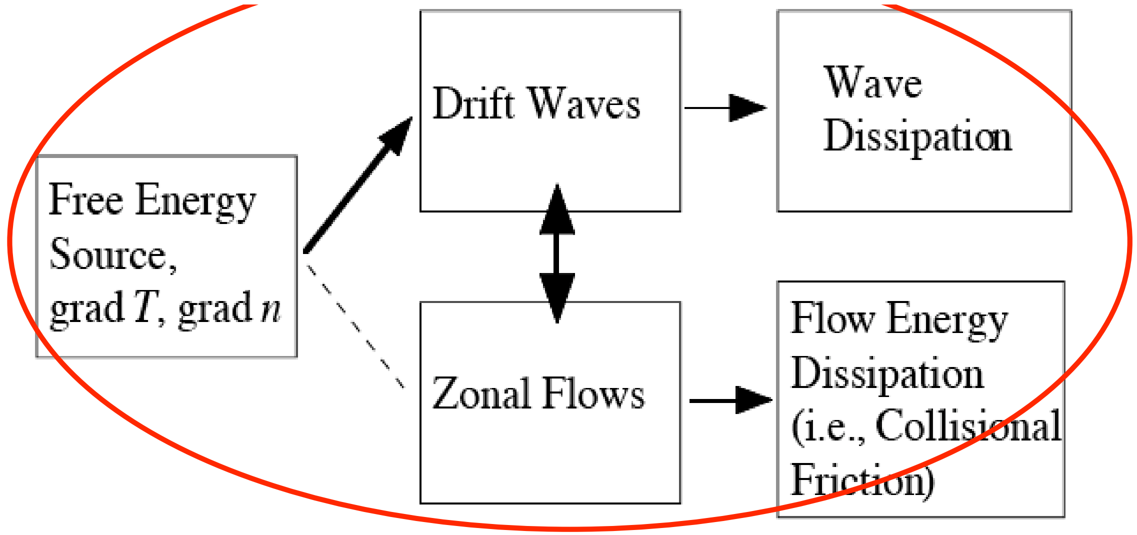
Orange: Progress

Conventional picture of drift-wave turbulence



Classic paradigm of drift wave turbulence

Picture of the drift wave-zonal flow system



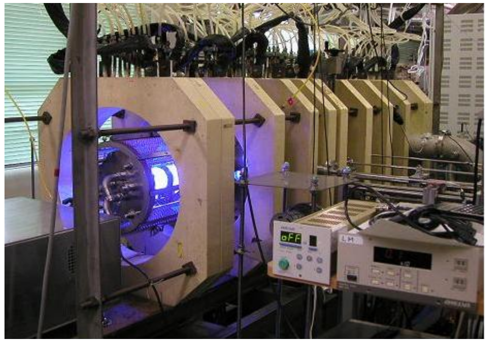
New paradigm of drift wave-zonal flow turbulence

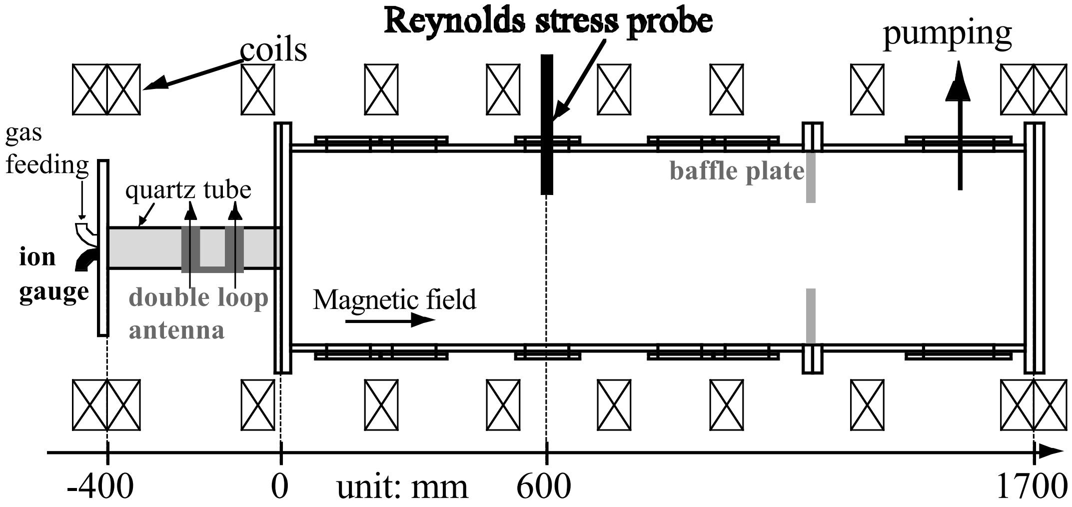
Figure 1. Newparadigm fortheplasmaturbulence.

Experimental devices

The Large Mirror device (LMD [1])

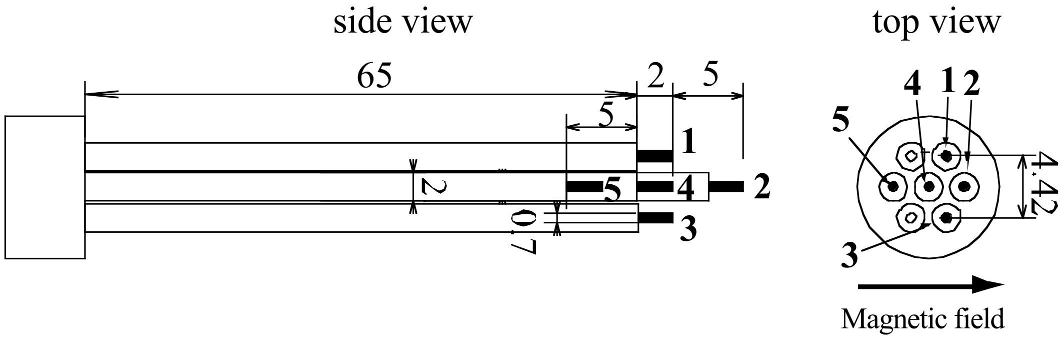
[1] Y. Saitou, et al., Phys. Plasmas **14** (2007) 072301





Helicon source (2kW, 7MHz)
Ar gas

The Reynolds stress probe

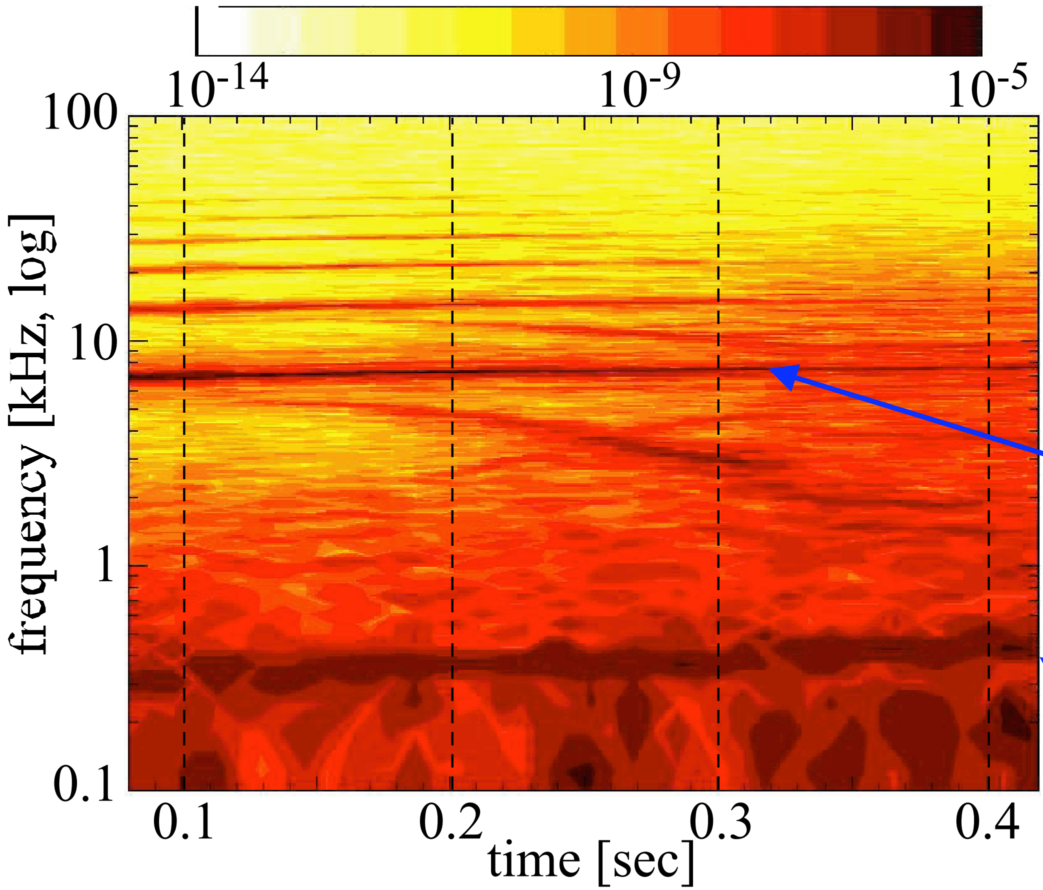


$$\tilde{E}_\theta = \left(\tilde{\Phi}_1 - \tilde{\Phi}_3\right) / d_\theta \; (k_\theta) \qquad \tilde{E}_r = \left\{\tilde{\Phi}_2 - \left(\tilde{\Phi}_1 + \tilde{\Phi}_3\right)/2\right\} / d_r \; (k_r)$$

Reynolds stress per mass density $\langle \tilde{v}_r \tilde{v}_\theta \rangle = \langle \tilde{E}_\theta \tilde{E}_r \rangle / B^2$

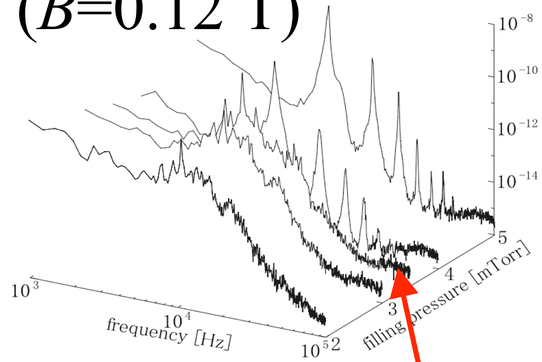
Drift wave and residual zonal flow

Time evolution of the potential spectrum during a single discharge



Measured at r=3.5 cm (a=~5 cm)

Filling pressure scan (B=0.12 T)



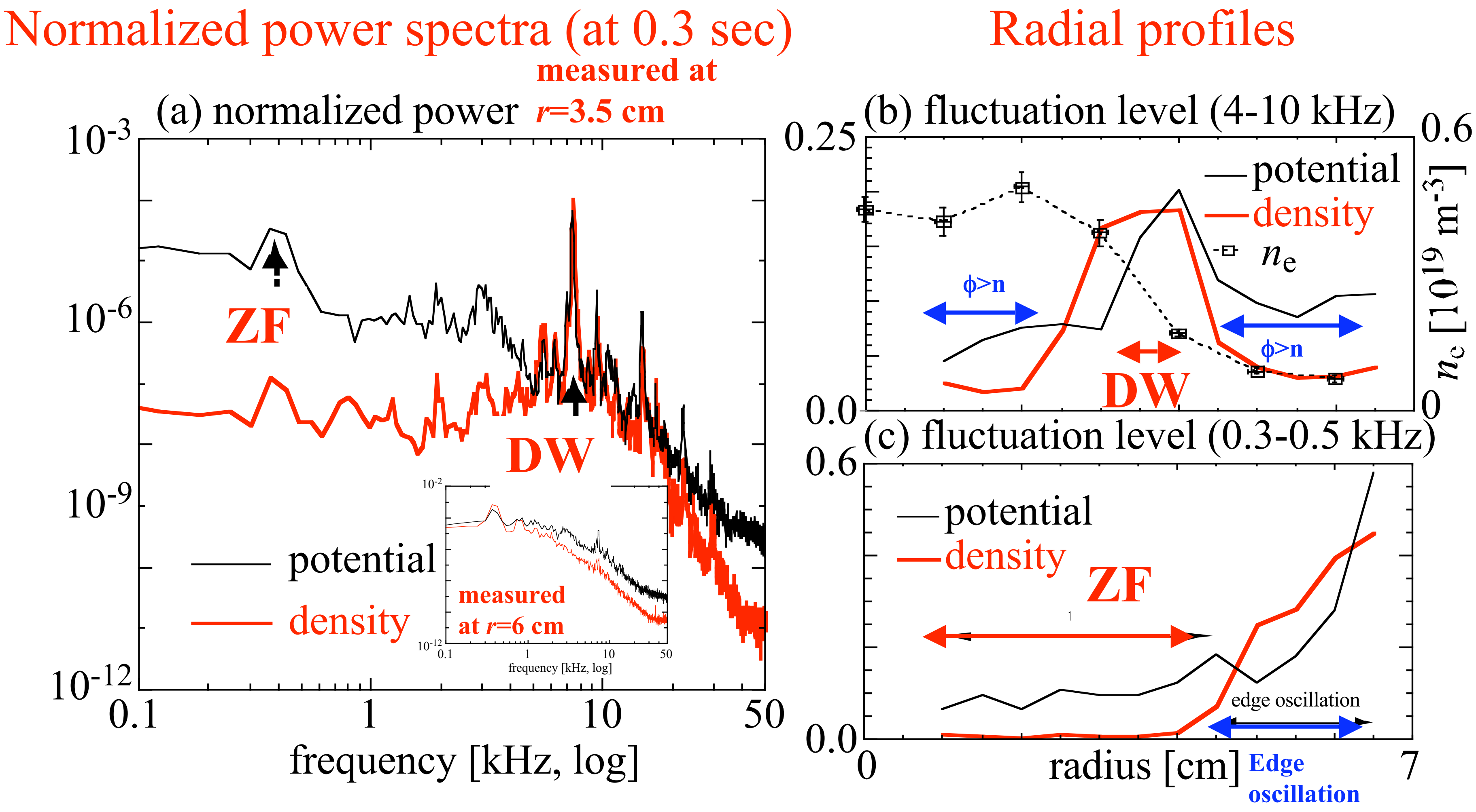
Marginal transition to strong turbulence at 3.5 mTorr

the drift-wave (DW)

the residual zonal flow (ZF)

DW (7-8 kHz) and residual ZF (~400 Hz) are observed.

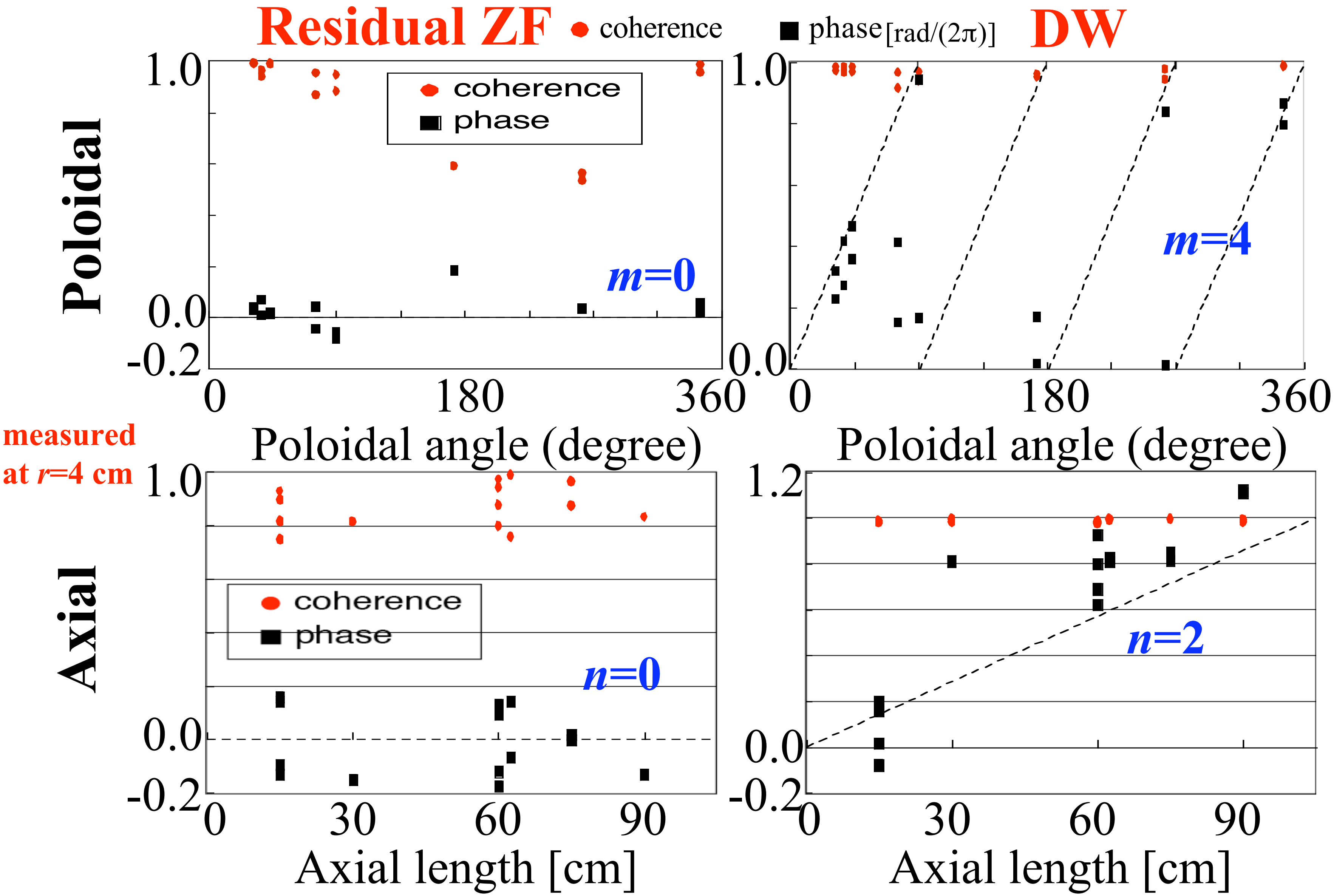
Normalized fluctuation spectra



DW (density ~ potential) is located at r=3.5-4cm.

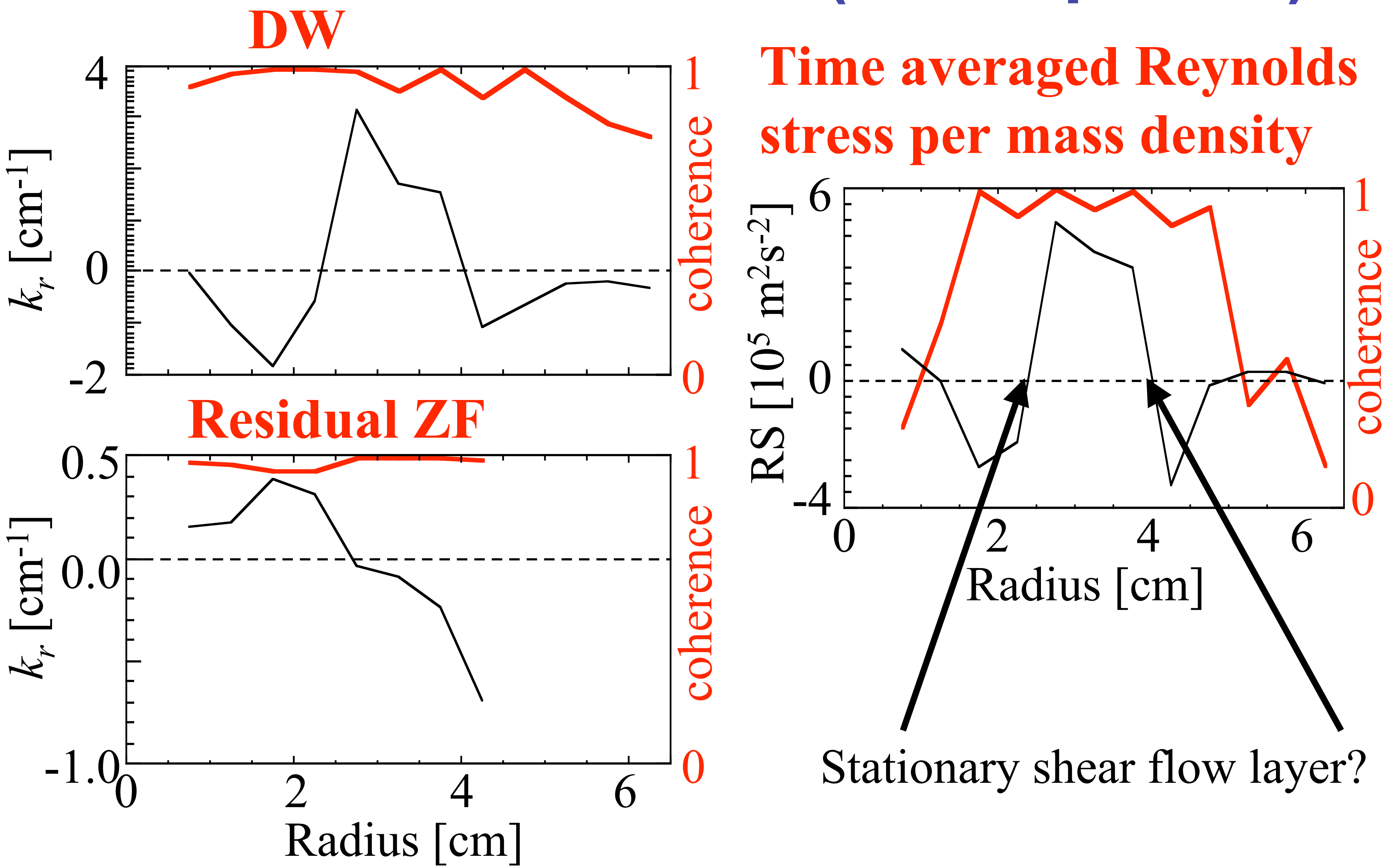
Residual ZF exists at r<~4.5cm (n > ϕ edge oscillations r>~4.5cm).

Poloidal and axial wave numbers



DW has *m*=3-5 and *n*=2-3, while residual ZF potential has *m*,*n*~0.

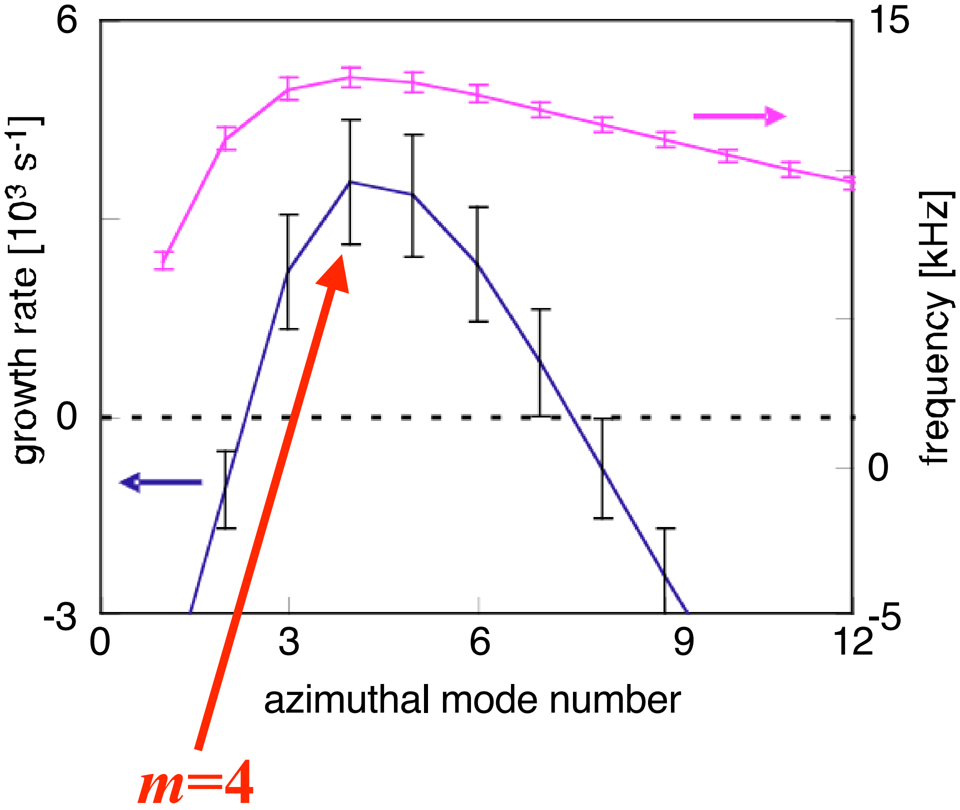
Radial wave numbers (radial profile)



Residual ZF has finite radial wave numbers, and propagates inward and outward.

Linear dispersion relation

Growth rate and frequency from `Numerical Linear Device` code [2].



Frequency calculation based on Hasegawa-Mima equation

$$\omega_{de,th} = \frac{\omega_{*,e}}{1 + k^2_{\perp}\rho^2_s}$$

(ExB velocity is not considered.)

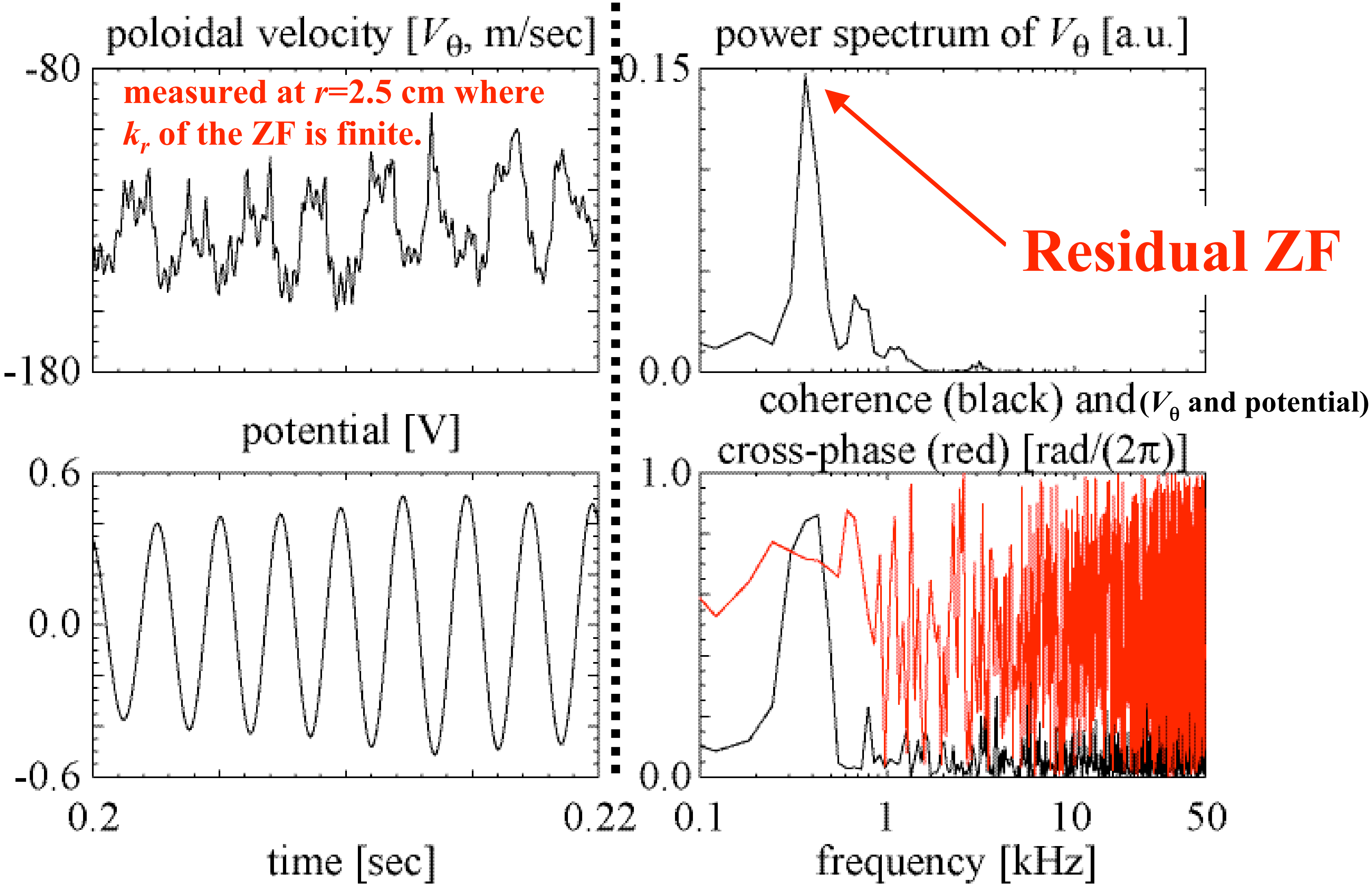
$\omega_{de,th}$ = 6.22-8.26 kHz at minimum RS gradient

$\omega_{de,exp}$ = 7-8 kHz

[2] N. Kasuya, et al., J. Phys. Soc. Jpn. **76** (2007) 044501

NLD calculation shows that *m*=4 mode is most unstable.
DW frequency base on HM eq. is consistent with observation.

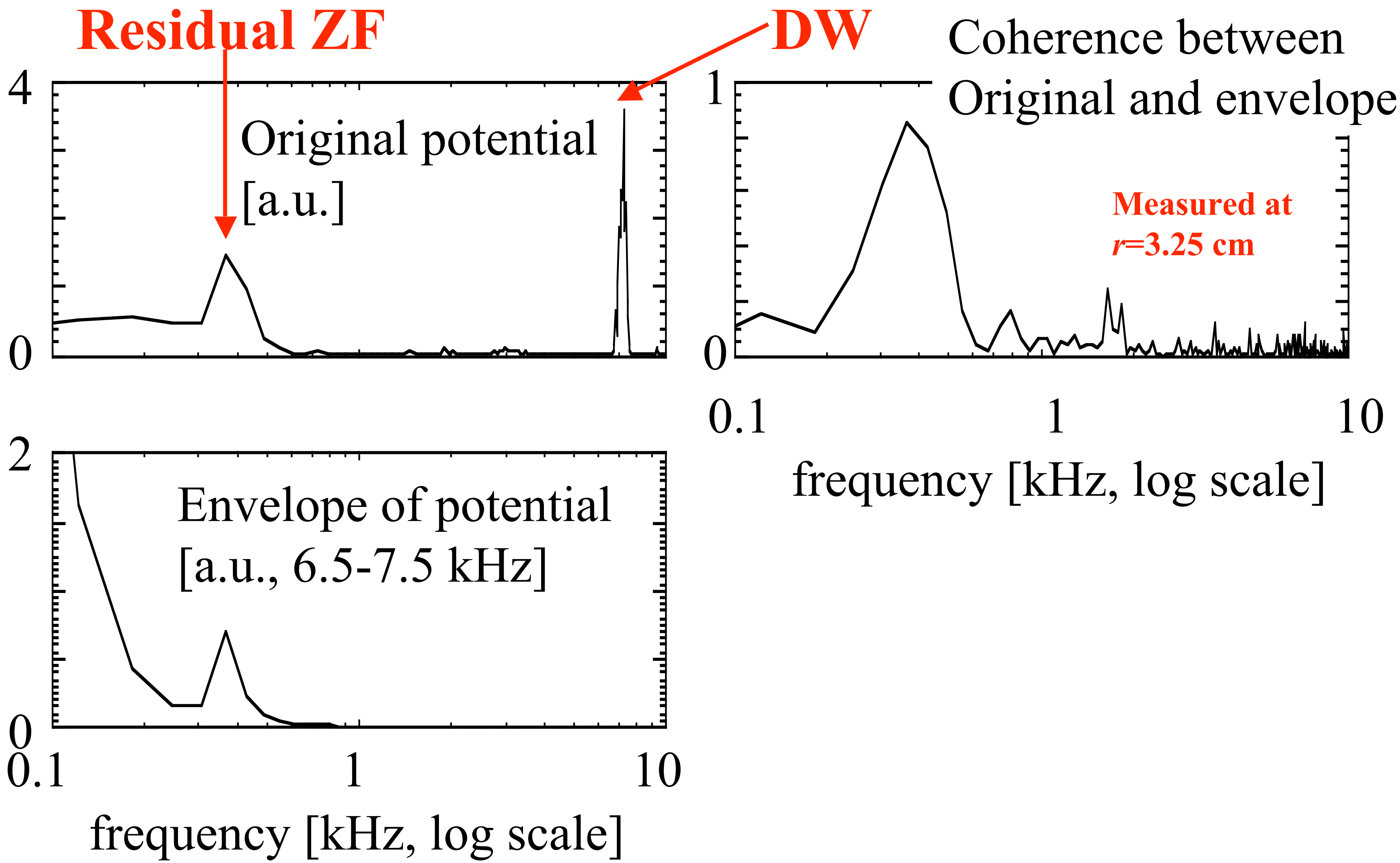
Poloidal velocity fluctuation



Residual ZF is associated with the poloidal velocity fluctuation derived from the Time Delay Estimation[3].

[3] C. Holland, et al., Phys. Rev. Lett. **96** (2006) 195002

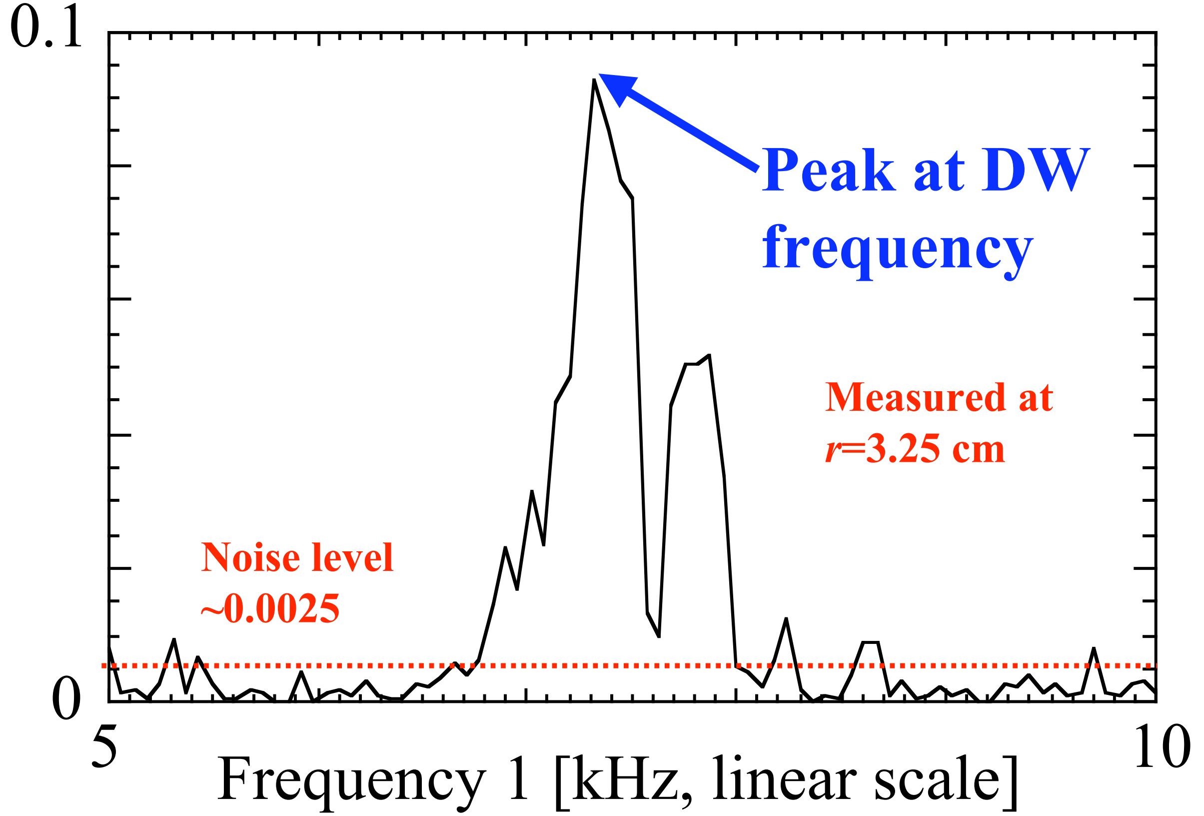
Modulational interaction



Amplitude of the DW is significantly modulated by the ZF.

Bispectral analysis

Squared cross-bicoherence of $\left\langle \tilde{E}_\theta(f_1)\tilde{E}_r(f_1 - f_3)\tilde{\Phi}_Z^*(f_3)\right\rangle$
(f_3=366 Hz, ZF frequency)



Nonlinear energy transfer between the DW and the ZF is significant.

Summary

1. **In this presentation, we have shown "the drift wave–zonal flow turbulence" in a cylindrical laboratory plasma.**

2. **Linear dispersion relations of observed fluctuations are consistent with the zonal flow (potential and poloidal velocity fluctuation) or the drift-wave.**

3. **Modulation of the drift wave amplitude by the zonal flow was confirmed.**

4. **The bispectral analysis of $<E_{\theta}E_{r}\Phi_{f}>$ shows significant nonlinear energy transfers between the zonal flow and the drift wave spectrum.**