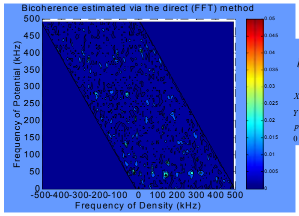
Nonlinear coupling – The zonal flow Er is nonlinearly coupled to the driftwave density fluctuations.



$$b^2(f_1,f_2)=\left(\frac{\left|X(f_1)Y(f_2)Y^*(f_1+f_2)\right|^2}{\left|X(f_1)\right|^2\left|Y(f_2)\right|^2\left|Y(f_1+f_2)\right|^2}\right)$$

$X(f)$ = Fourier Transform of potential signal at $\rho=0.69$

$Y(f)$ = Fourier Transform of density signal at $\rho=0.69$

plotted for:

$0<f_1<500\,kHz \qquad -f_1<f_2<(500-f_1)kHz$

$$b^2(f_1,f_2)=\left(\frac{\left|X(f_1)Y(f_2)Y^*(f_1+f_2)\right|^2}{\left|X(f_1)\right|^2\left|Y(f_2)\right|^2\left|Y(f_1+f_2)\right|^2}\right)$$

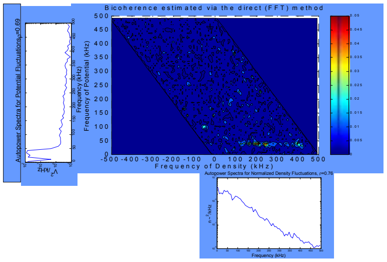
$X(f)$ = Fourier Transform of potential signal at $\rho=0.69$

$Y(f)$ = Fourier Transform of density signal at $\rho=0.75$

plotted for:

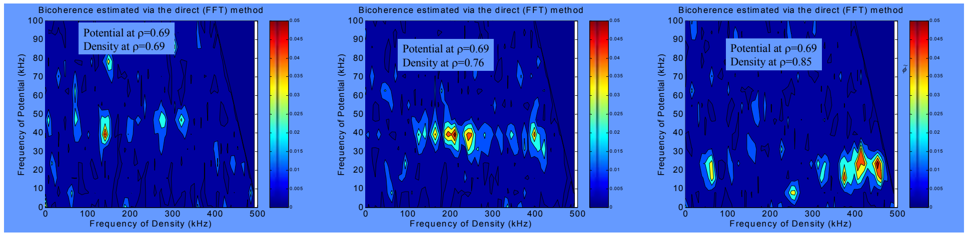
$0<f_1<500\,kHz \qquad -f_1<f_2<(500-f_1)kHz$

Potential fluctuations at ρ=0.69

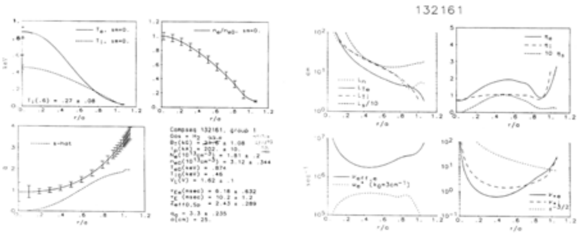


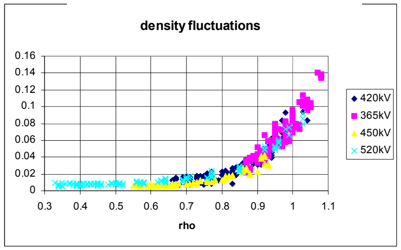
Density fluctuations at ρ=0.76

- Potential fluctuations are the integral of all zonal flow E_r at radii larger than the sample location.
- Density fluctuations couple with zonal flows only at the radius of the sample volume.
- Therefore: Interior potential fluctuations have nonlinear coupling with density fluctuations at larger radii.



Profiles for similar discharge
(B_T=2.2T vs. 2.5T)





For the discharge studied, **zonal flows are only found for 0.65<ρ<0.95** This is the region with:

- Strongest gradients
- Strongest driftwave fluctuations

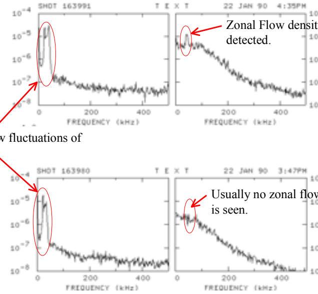
?? Conclusions ??

Linear coupling
Linear analysis shows only a weak zonal flow density fluctuations compared to the zonal flow fluctuations of potential.

- Usually no linearly correlated density fluctuation is found.
- Preliminary analysis suggests that a linearly correlated density fluctuation is detected only when the radial extent of the sample volume is small, ~ 2mm.
- This indicates that the density fluctuations have a short radial correlation length and/or have a radial mode structure that is anti-symmetric across the flux surface. The net density signal averages to zero for finite sample volume size.
- The relatively weak signal strength and the complicated radial mode structure of the zonal flow density fluctuation makes it unlikely that a poloidal mode structure can be determined. Initial studies don't find an m=0 mode as expected.
- Additional analysis of data with various sample volume alignments might allow estimates of the radial correlation length of the zonal flow.

ρ=0.80
θ=12º

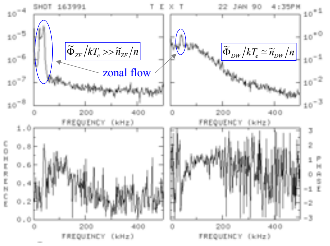
ρ=0.81
θ=44º



Zonal Flow density fluctuation is detected.

Zonal Flow fluctuations of potential

Usually no zonal flow density fluctuation is seen.



Estimate of E_r

Assume:Interior $\tilde{\phi}$ measurements are the result of many uncorrelated zonal flow layers. The signals from each layer add in an rms sense.

Given: $\tilde{\phi}_{total}$ = the measured fluctuations of potential

N = the number of uncorrelated zonal flow layers

$\tilde{\phi}_k$ = the potential fluctuations from one ZF layer

l_{ZF} = correlation length of zonal flow

$\tilde{E}_{ZF}$ = Zonal Flow radial electric field

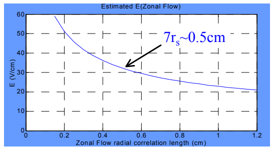
Δr = radial extent of zonal flow

Then:

$$\tilde{\phi}_{total}^2=\sum_{k=1}^{N}\tilde{\phi}_k^2\approx N\tilde{\phi}_1^2 \qquad N=\frac{\Delta r}{l_{ZF}}$$

$$\tilde{\phi}_1=\tilde{E}_{ZF}l_{ZF} \qquad \tilde{E}_{ZF}=\frac{\tilde{\phi}_{total}}{\sqrt{\Delta r\cdot l_{ZF}}}$$

Result: v_{ZF}~1.5x10³m/s
~ <E>/B ~ v_{de}



Interesting observations

- Strong GAM but no evidence of a ω=0 mode.
  - Reynolds stress vs. magnetic curvature
    ??(Hallatschek refers to the Stringer-Wilson term.)
- GAM is found only over a limited radial extent, 0.65<ρ<0.95 for this discharge.
  - Region with strong gradients and fluctuations??
- Density fluctuations data may provide information about the radial mode structure.

Conclusion:
Zonal Flows were Detector in TEXT

- Radial electric field fluctuations were measure with
  - m=0 poloidal mode structure (zonal flow).
  - Short radial correlation lengths, (poloidal correlation is long – machine size.)
  - Weak or non-existent density fluctuations at the same frequency.
  - Non-linear coupling with drift wave density fluctuations.
- Fluctuations are found at the GAM frequency, there is no experimental evidence of an ω=0 signal.