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Measurement and Analysis of the Fluctuations and Poloidal Flow on JFT-2M Tokamak

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Contents

1． Introduction （Fluctuation and zonal flow）
2． Fluctuation in OH plasma (GAM,LFMs)
3． Fluctuation during the L-mode (GAM,LFMs)
4． Fluctuation during the H-mode and E_rxB poloidal flow
5. Summary

Introduction

● Fluctuations and Zonal Flow

-------Candidate of the transport barrier mechanisms

Zonal Flow (ZF)

1. Stationary ZF,
   potential m/n=0/0, f=0
2. Oscillating ZF,
   GAM (Geodesic Acoustic Mode)
   potential m/n=0/0,
   $\omega_{GAM} \sim c_s/R$, c_s: sound velocity

Nonlinear Interaction
(bicoherence analysis)

Generation

Suppression

Turbulent potential fluctuations (Drift waves)

●ExB poloidal flow

By the radial electric field E_r
in the edge transport barrier (ETB)
during the H-mode

Fluctuations in JFT-2M

- It is important to measure electrostatic fluctuations $\tilde{\phi}, \tilde{n}_e$

Plasma	fluctuations	measurements
OH	GAM LFM, Background turbulence ○ significant bicoherence	Reciprocate Langmuir Probe (RLP) 1m/s Micowave Reflectometer (MRM)28GHz,38GHz
L-mode	GAM LFM, Background turbulence ○ significant bicoherence	Heavy Ion Beam Probe (HIBP) Tl_{81}^{+} MRM
H-mode ELM-free	LFM Multi Mode (drift ballooning like), Weak Background turbulence x bicoherence	HIBP MRM
enhanced D_α (H', EDA,HRS)	QCM, HFO Background turbulence x bicoherence	HIBP MRM

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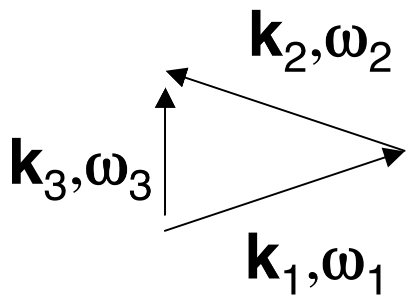
Statistical measure of three wave interaction

- The strength of the interaction is measured by bicoherence.
  If the waves f_1, f_2, $f_3=f_1+f_2$ are independent waves, $b(f_1,f_2)=0$.

Summed Squared Bicoherence

$$\sum_{f_2} b^2(f_1,f_2) = \sum_{f_2} \frac{|\hat{B}(f_1,f_2)|^2}{<|\Phi(f_1,f_2)|^2><|\Phi(f_3)|^2>}$$



Bispectrum Function

$$\hat{B}(f_1,f_2) = < \Phi(f_1)\Phi(f_2)\Phi^*(f_3 = f_1 \pm f_2) >$$

$\Phi(f)$: Fourier transform of $\phi(t)$

Biphase

$$\theta = tan^{-1} \frac{\mathrm{Im}\,\hat{B}(f_1,f_2)}{\mathrm{Re}\,\hat{B}(f_1,f_2)}$$

(Ref.) Kim et al., IEEE Trans. on Plasma Sci. **PS-7**,120 (1979)

2. Fluctuation in OH plasma (GAM,LFMs)

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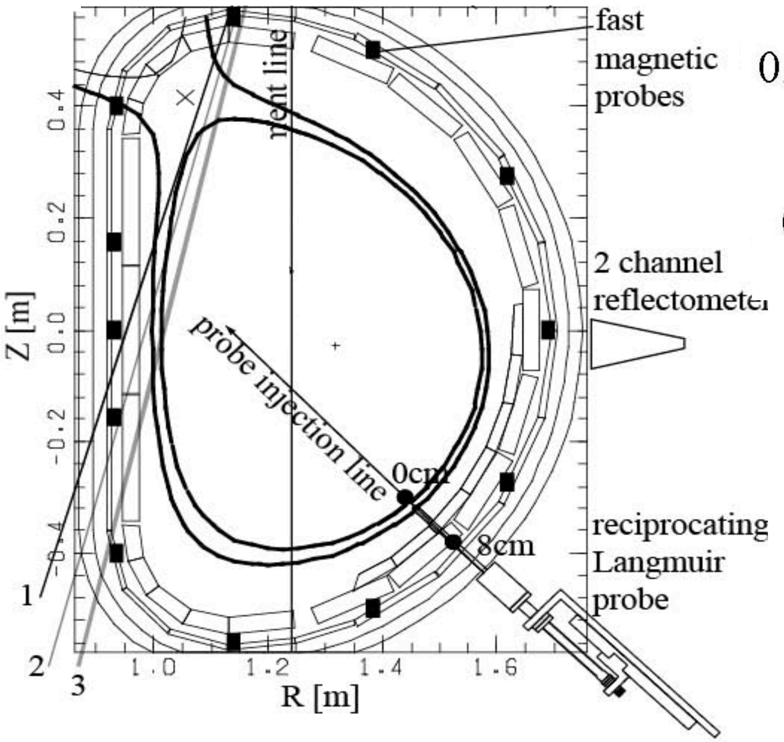
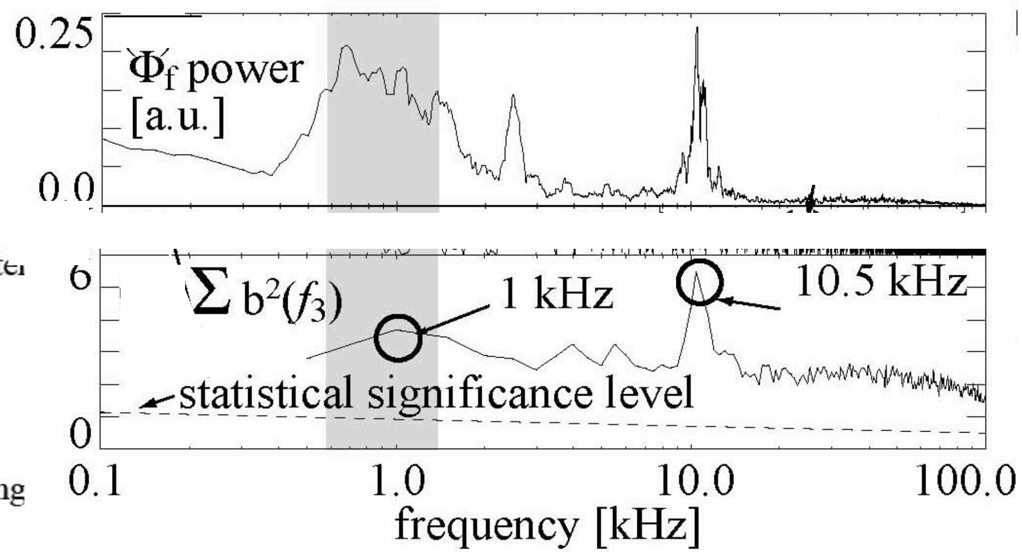
- Potential fluctuation measured by RLP



LFMs **GAM**



$$f_{LFM} << f_{GAM} = \sqrt{2}\frac{c_s}{2\pi R}$$

Bicoherence and biphase of the $\tilde{\phi}$ of OH plasma(r~0.9a) obtained（RLP）

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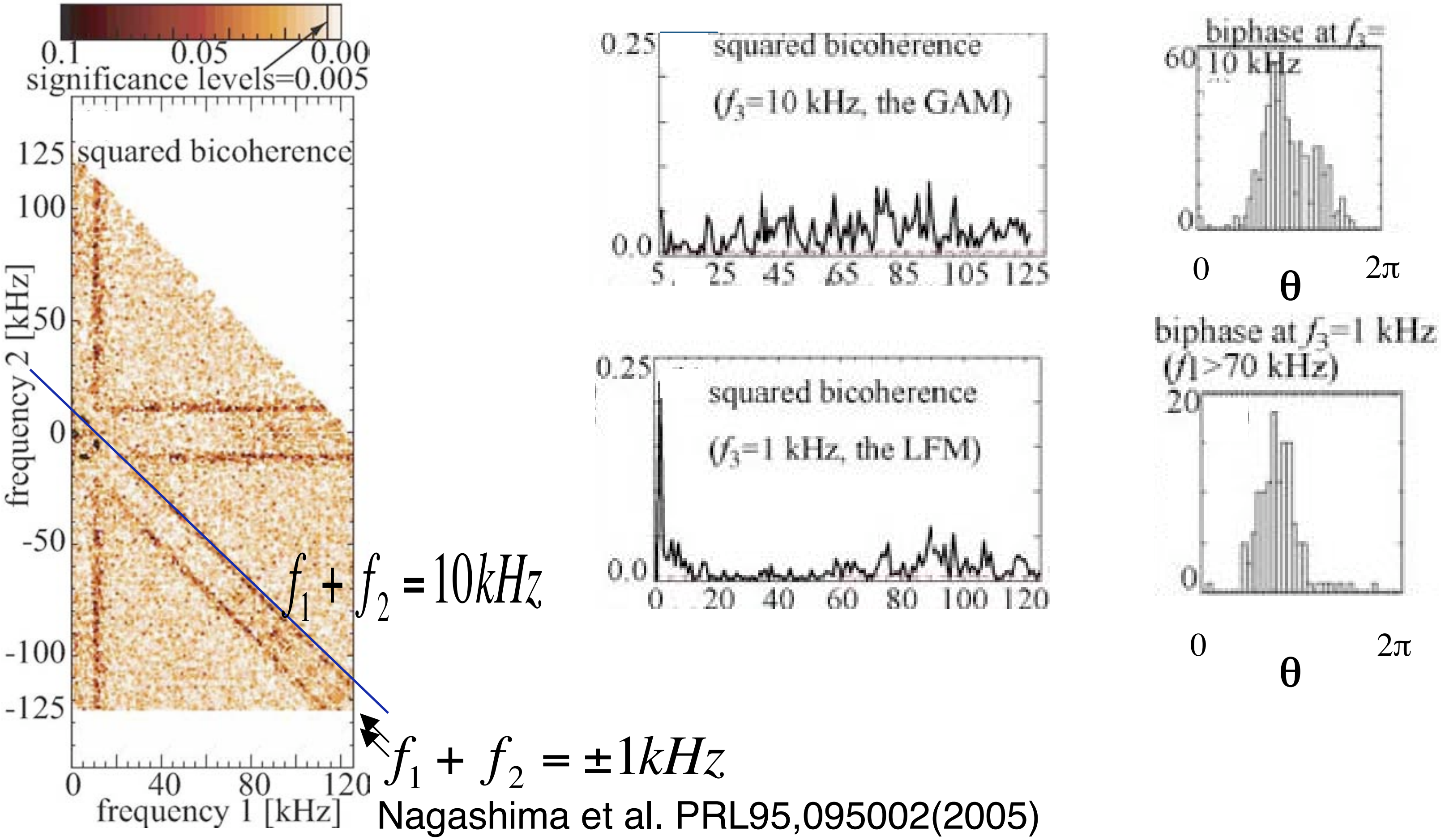
- Three wave nonlinear interaction was confirmed (for LFM as GAM)



Nagashima et al. PRL95,095002(2005)

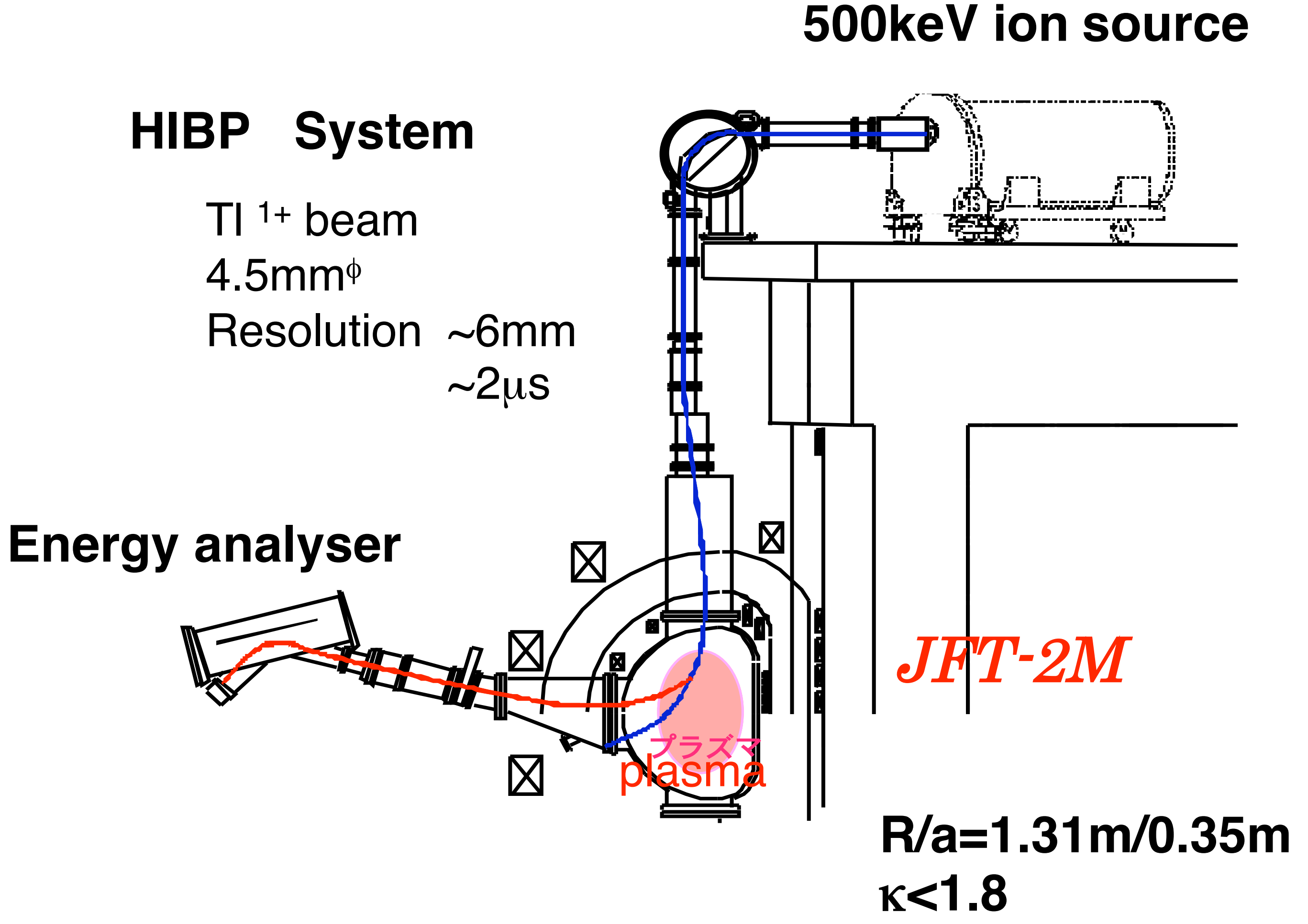
10kHz（GAM）,1kHz（LFM) interacts nonlinearly

○ with the back ground turbulence of the wide frequency range

○ with biphase peaked at ~ 0.8π

3. Fluctuation during NB-heated L-mode plasma

- **Potential / density fluctuation $\tilde{\phi}, \tilde{n}_e$ of the plasma interior is measured directly by HIBP**



Significant bicoherence obtained during the L-mode by the HIBP (r~0.9a) (NBH)

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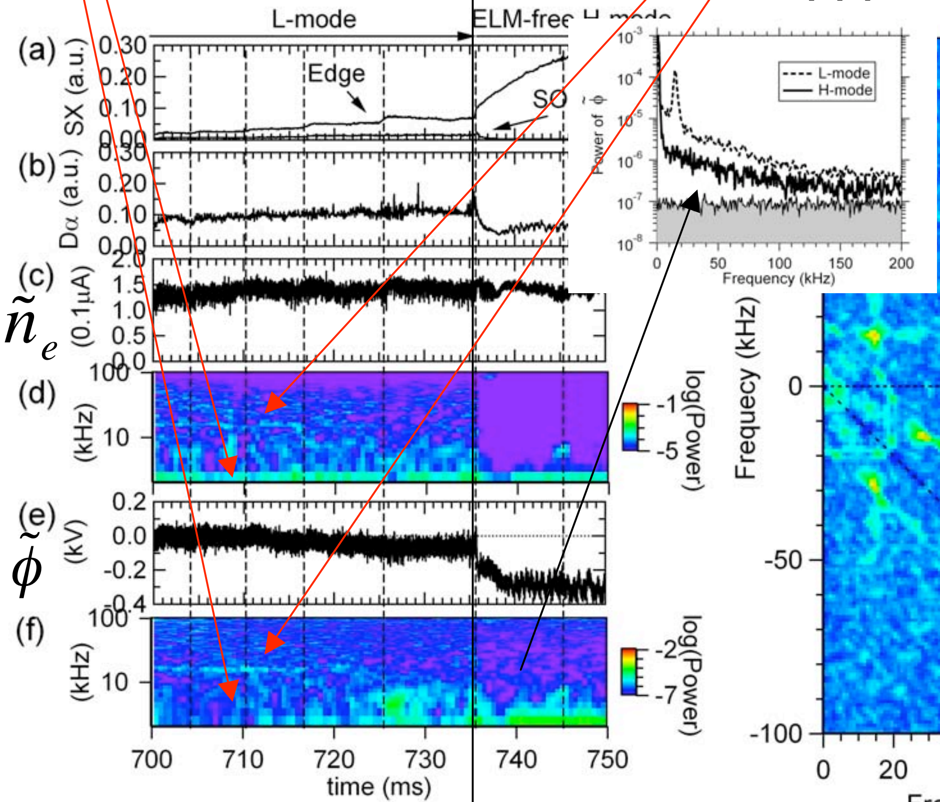
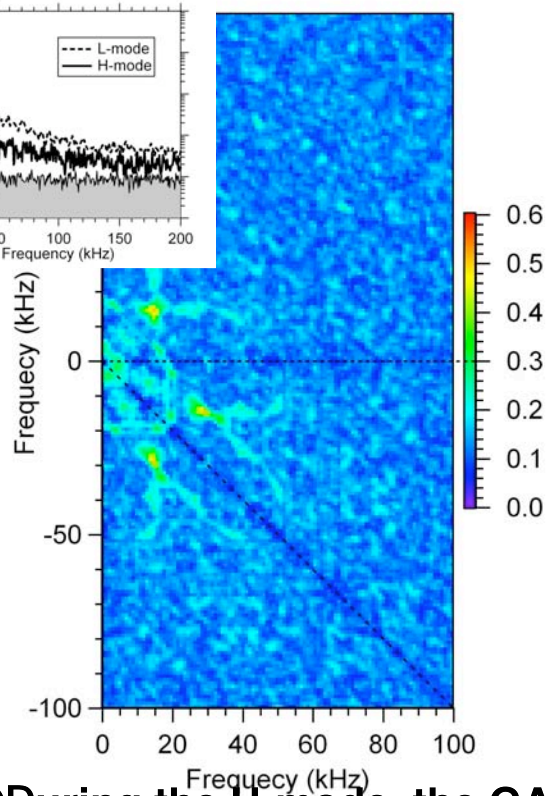
- Nonlinear coupling between GAM(~15kHz) and turbulence, LFM and turbulence, observed also during the L-mode (as in the OH plasma)

L-mode → H-mode

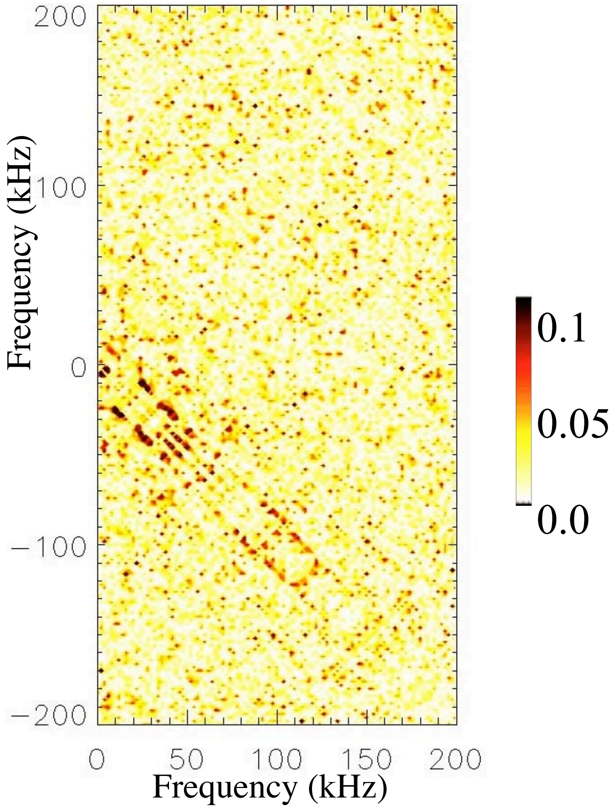


Ido et al. NF **46**,512(2006)

Auto-bicoherence (φφφ)[1]

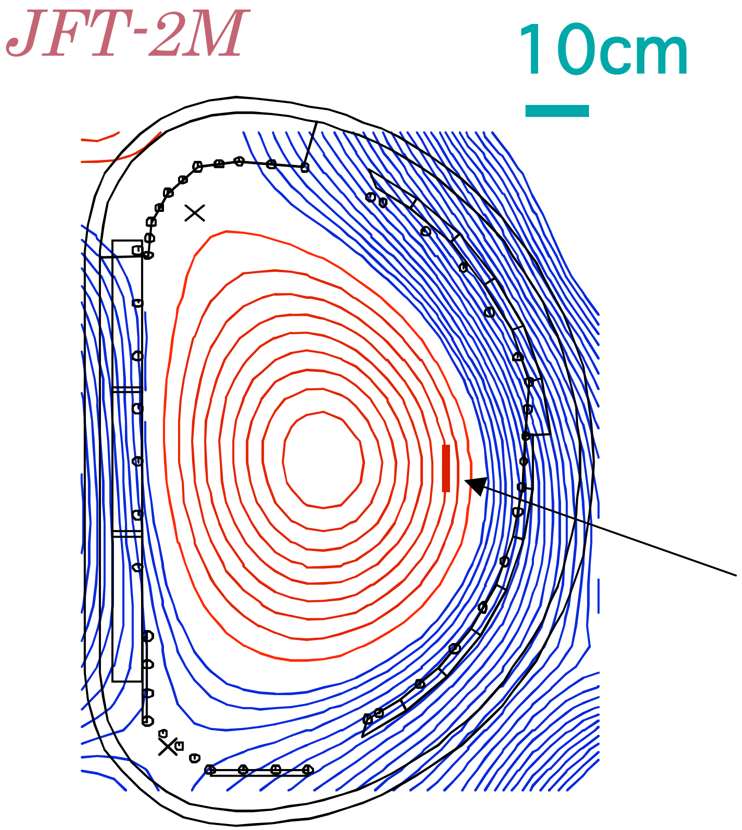


Cross-bicoherence (nnφ)[2]



○During the H-mode, the GAM disappears , presumably due to the decrease of the turbulence power by 1~2 order.

- **Edge potential fluctuation ϕ(t) and E_r measured by HIBP**



○ **NBH H-mode** --- $E_r \approx -200V/cm$

○ **ECH H-mode** --- $E_r, \tilde{\phi}, \tilde{n}$

Edge ECH position

f_{EC}~ 60GHz, P_{EC}~0.4MW

Potential fluctuation (HIBP) at L/H transition by NBH+ECH

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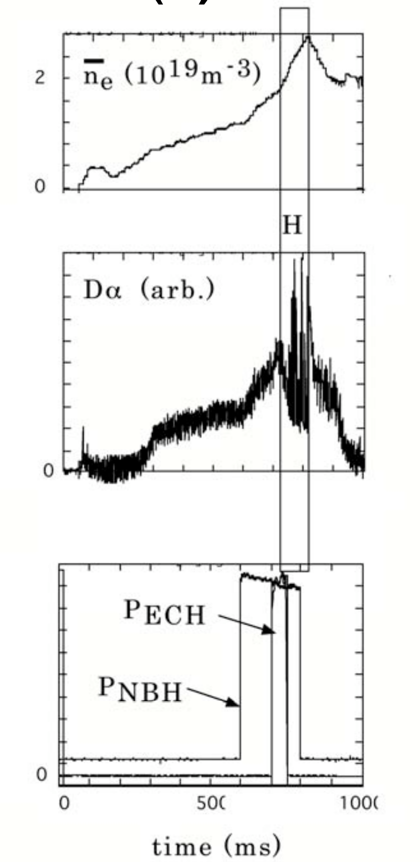
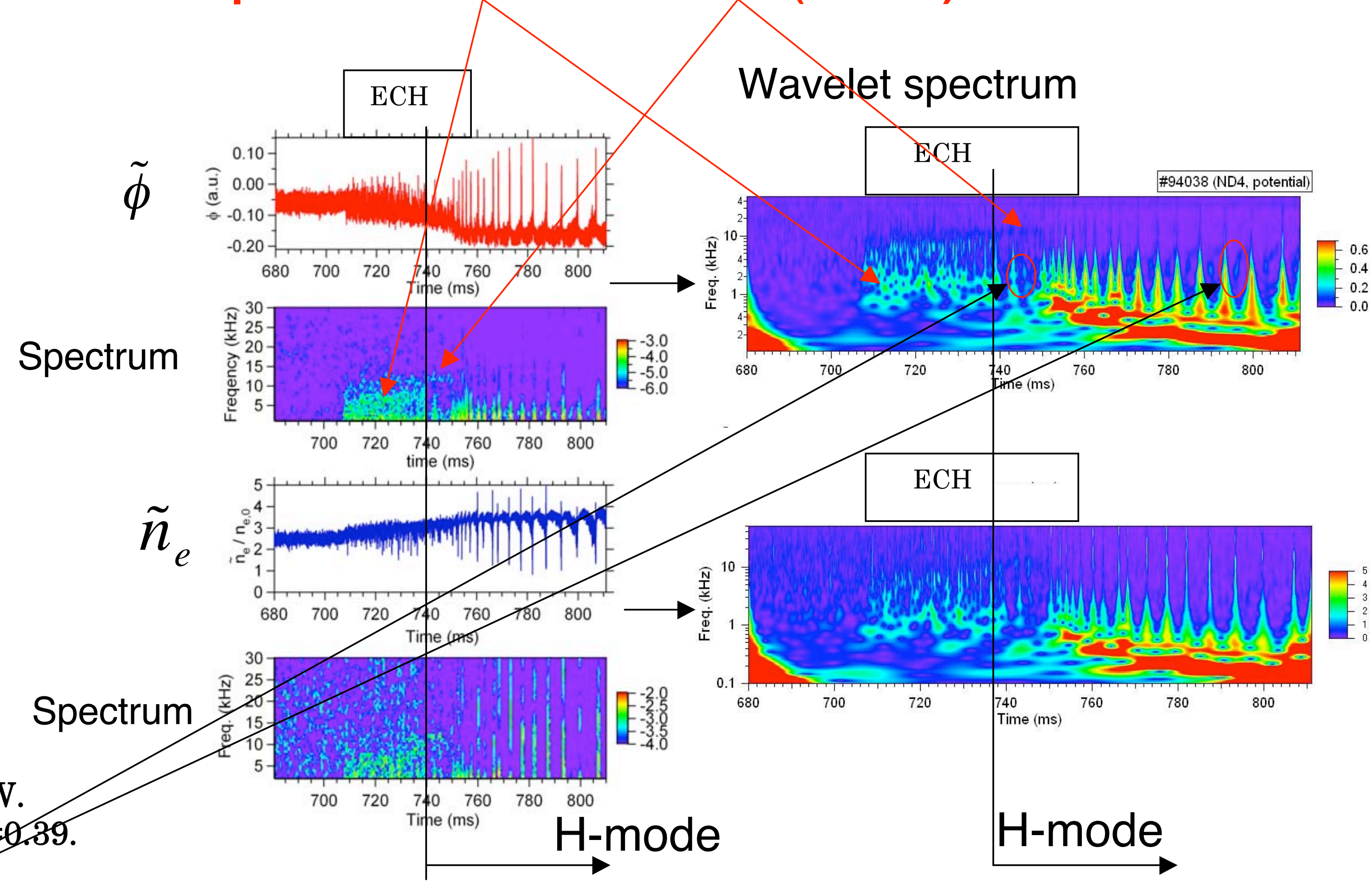
NBH(L) + ECH



• **ECH produced LFM and GAM (10kHz).**



P_{NB}=0.30MW, P_{EC}=0.20MW.
Ip=0.21MA. B_{to}=1.20T. β_p=0.39.
κ=1.46. δ=0.46.

○GAM coexists with L/H-transition.

○LFM (~1kHz < f < 5 kHz) exists during the H-mode, and between ELMs

Comparison between the ExB flow velocity by GAM and by Er at the ETB

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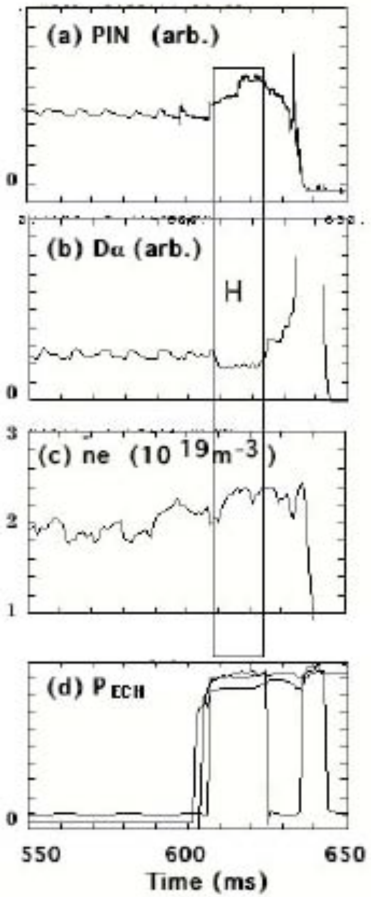
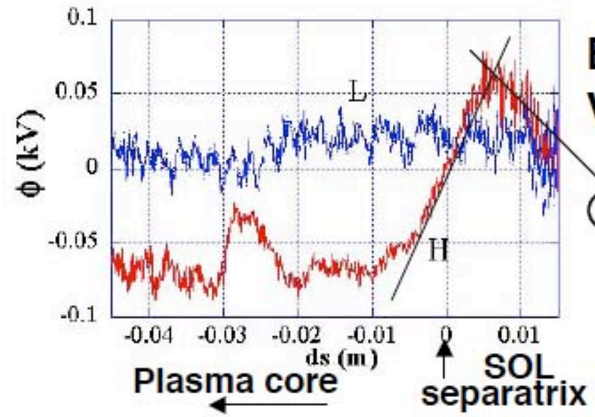
H-mode

ECH only



I_p=0.23MA, B_{to}=1.23T,κ=1.37, δ=0.32,
q_{95}=2.32, r_o/a=0.86, P_{EC}=0.39MW

● **Potential profile by HIBP (ECH H-mode, 0.85a-1.15a)**



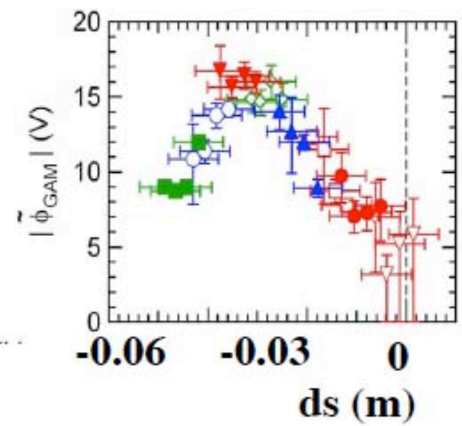
E_r = -130 *V/cm*--○negative as NB H-mode,
V_{ExB}=-12 *km/s* (ETB)--- (el.diamag)
+4 *km/s* (SOL)---(ion diamag)
○ Large flow velo. shear at separatrix
$\nabla V_{E\times B}$=1.6E6 s^{-1}

● **L-mode --- Oscillating ExB poloidal flow by GAM (HIBP)** ⟶

$|E_r|$ = 5-10 *V/cm* , 10-15 *kHz* *AC*
$V_{ExB,GAM}$ = 0.5 - 1 *km/s*

● **DC flow velocity ~ (10~20) x $V_{EXB,GAM}$**
(H-mode) (L-mode)

L-mode GAM potential



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Summary

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Fluctuation and poloidal flow was investigated.

1) Nonlinear coupling between the background turbulence and GAM, and between background turbulence and LFM were clarified in L-mode plasma as well as OH plasma. Therefore LFM seems to be generated by the turbulence as the zonal flow does.Significant bicoherence and nearly constant biphase were obtained.

2) Usually the GAM disappears during the H-mode. But Edge ECH of NBH L-mode enhances a low frequency (~ 1 kHz) potential fluctuation and the GAM is generated. The GAM survives at the beginning of the H-mode by ECH.

3) During the ECH H-mode (as by NBH), negative electric field and resultant DC poloidal flow velocity (el. diamag direction) develops. The flow velocity is typically 10~20 times larger compared with the typical AC poloidal flow by the GAM E_r in the L-mode.