Electric Fields, Turbulence and Self-Organisation in Magnetised Plasmas Workshop , Lisbon, June 29 ~ 30, 2015

Dynamics of Nonlinear Interactions between Electron Temperature Gradient Mode and Ion-scale Fluctuations in Linear Magnetized Plasmas

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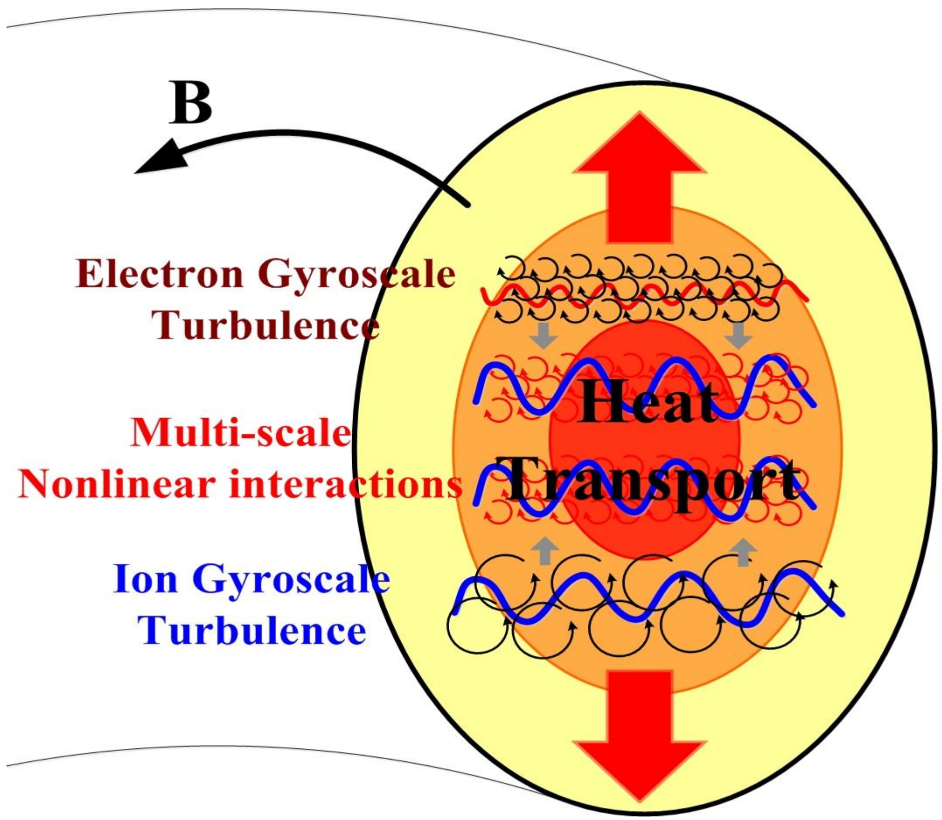
Outline

1. Background and Purpose
2. Experimental Apparatus
3. Experimental Results
4. Summary

Background and Purpose



Anomalous heat transport
－ion scale－

<u>Gradient Driven Instability</u>

- Drift wave (DW) mode[1)]
- Flute mode[2)]
- Ion temperature gradient (ITG) mode[3)]

Anomalous electron heat transport

<u>Electron Temperature Gradient (ETG) Mode[4)]</u>

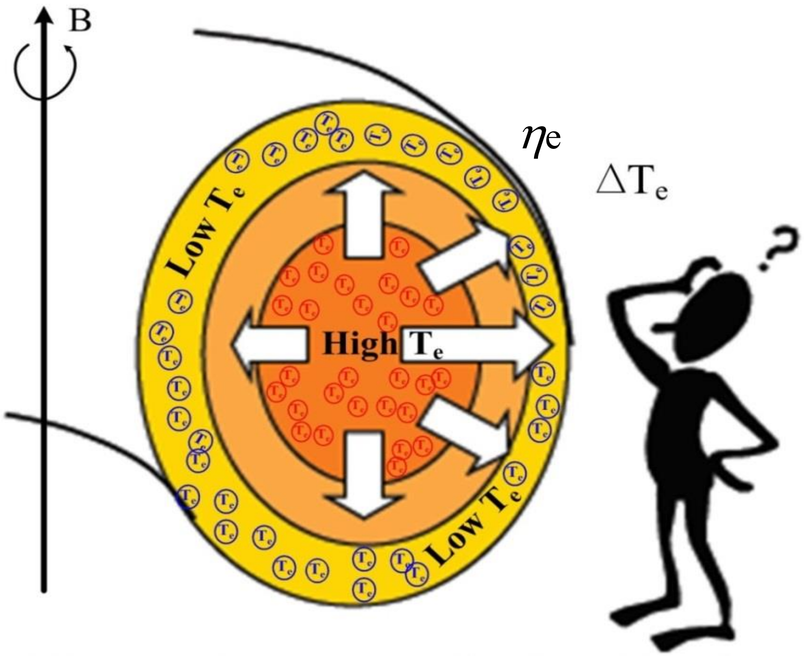
electron heat transport ～ ion heat transport
$(\chi_e \sim \chi_i)$

- **Open problems on ETG mode**
- **Excitation mechanism**
- **Suppression mechanism**

Produce and control the ETG to understand the mechanism of <u>excitation</u> and <u>multi-scale interaction</u> of the ETG mode

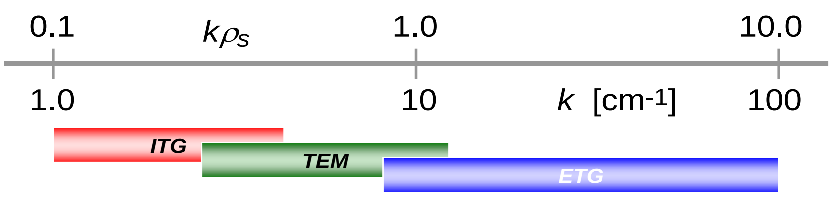
1) W. Horton, Rev. Mod. Phys. **71** (1999) 735.
2) F. Brochard et al., Phys. Plasmas **12** (2005) 062104.
3) V. Sokolov et al., Phys. Rev. Lett. **89** (2002) 095001.
4) S. K. Mattoo et al., Phys. Rev. Lett. **108** (2012) 255007.

Research of ETG mode



ETG mode:

- **Electrostatic mode (low β)**
- **Electron diamagnetic direction**
- $k_\perp \rho_e \leq 1 < k_\perp \rho_i$, $\Omega_i < \omega << \Omega_e$



Wavelength scales of Fluctuations

Theory

✓ **Excitation**

- Y. C. Lee et al., Phys. Fluids **30**, 1331 (1987).
- W. Horton and B. G. Hong, Phys. Fluids **31**, 2971 (1988).
- Y. Idomura et al., Phys. Plasmas **7**, 2456 (2000).
- W. Dorland et al., Phys. Rev. Lett. **85**, 5579 (2000).
- S. -I. Itoh and K. Itoh, Plasma Phys. Control. Fusion **43**, 1055 (2001).
- F. Jenko, J. Plasma Fusion Res. Ser. **6**, 11 (2004).

Multi-Scale Interactions

✓ **Suppression**

- Z. Gao et al., Phys. Plasmas **11**, 3053 (2004).
- M. Romanelli et al., Phys. Plasmas **11**, 3845 (2004).

Experiment

✓ **Excitation**

- E. Mazzucato et al., Phys. Rev. Lett. **101**, 075001 (2008).
  → **Observation**
- X. Wei et al., Phys. Plasmas **17**, 042108 (2010).
  → **Identification**
- X. R. Fu et al., Phys. Rev. Lett. **19**, 032303 (2012).
  → **High β**

✓ **Suppression**

- D. R. Smith et al., Phys. Rev. Lett. **102**, 225005 (2009).
  → **Large E×B Shear**
- H. Y. Yuh et al., Phys. Rev. Lett. **106**, 055003 (2011).
  → **Magnetic Shear**

∇-Driven Instability / Turbulence

		Excitation 'Bare' Instability	Multi-Scale Interaction	Suppression
Ion-scale ~ρ_i		• Drift wave ~ 1960 • Geometrical ~ 1980 (∇$\boldsymbol{B}$, …) • Trapped particle • ITG mode ~ 1990	• Geodesic acoustic mode (Conway, Nagashima) • Zonal flow (Fujisawa, …) • Streamer (Yamada, …) ※Causal relations "Multi-scale Renormalized Turbulence"	• E×B flow shear • linear or nonlinear
Electron-scale ~ρ_e	※ Experi.	✓ <u>ETG mode</u> • Observation (E. Mazzucato) ~ 2008 • Identification (X. Wei) ~ 2010 • High β (X. R. Fu) ~ 2012	?	• Large E×B shear (D. R. Smith) • Magnetic Shear (H. Y. Yuh) • Density Gradient (Y. Ren)
	※Theories	✓ <u>ETG mode</u> (Horton, Dorland, Jenko, ….) ~ 1990	• Elongated toroidal (cascade, Jenko) • Nonlinear ion-scale DW (radially elongated, Itoh, Jenko) • Streamer (Idomura) • Zonal flow (?) feeble (Diamond)	• E×B shear (Z. Gao)

Experimental Apparatus for ETG Mode

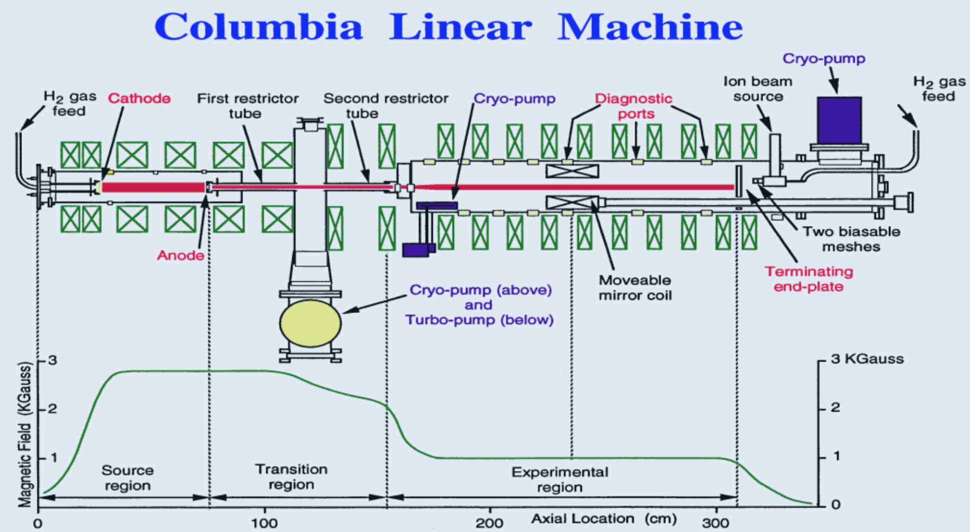
National Spherical Torus Experiment (NSTX)

Fluctuations : $\omega/2\pi$ ~1 MHz
T_e = ~2 keV, n_e = ~4 × 10^{19} m^{-3}

- **Troidal Device**
- **Difficult to Control ETG**
- **Changing Plasma Parameters**

E. Mazzucato et al., Phys. Rev. Lett. **101**, 075001 (2008).

Columbia Linear Machine (CLM)



Fluctuations : $\omega/2\pi$ ~2 MHz
T_e = 5-15 eV, n_e = ~2 × 10^{15} m^{-3}

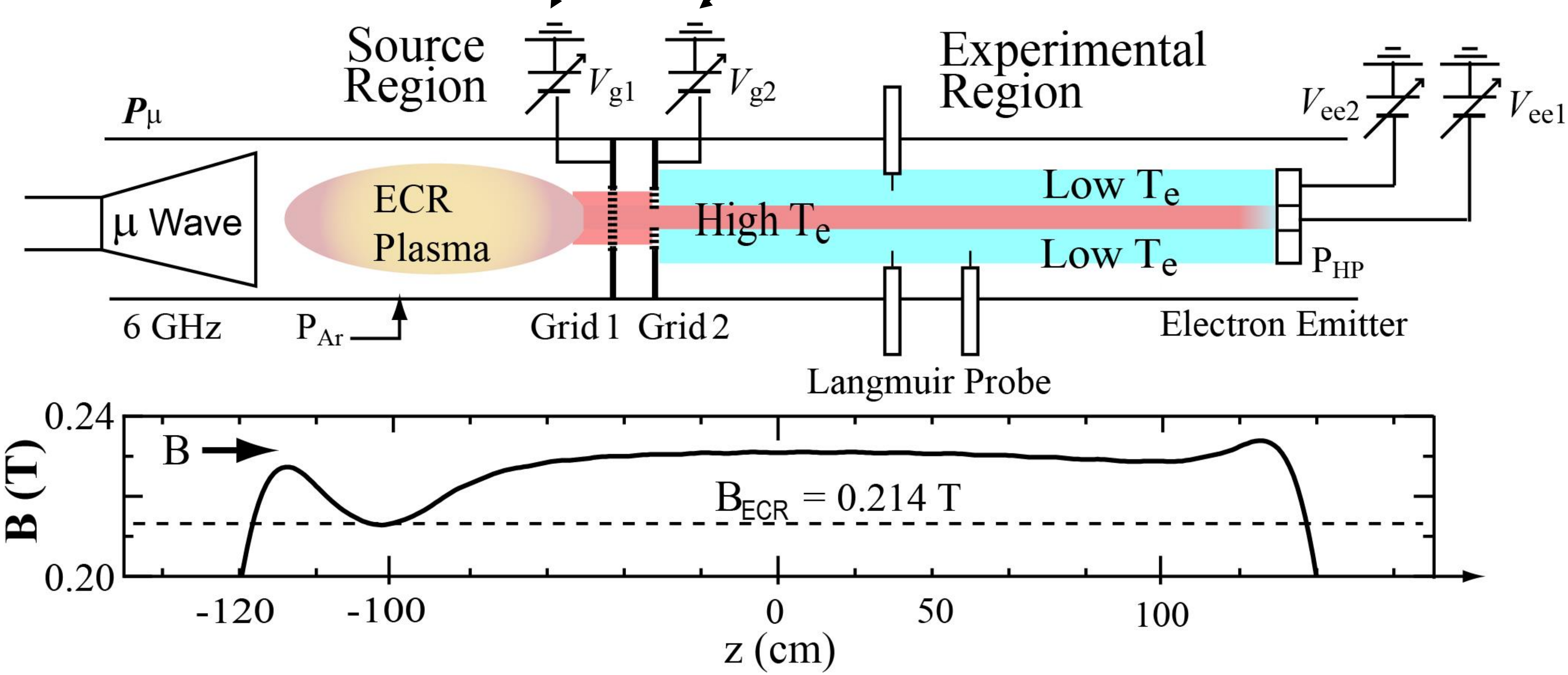
- **Linear Device**
- **Using the Electron Beam**
- **Forming the Density Gradient**

X.Wei et al., Phys. Plasmas **17**, 042108 (2010).

Experimental Apparatus

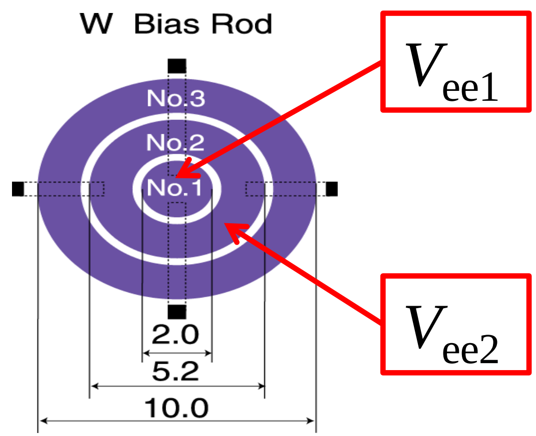
P_{μ} = 20 W
P_{HP} = 3 kW
P_{Ar} = 1 × 10^{-4} Torr

***B*: 0.214～0.23 T**
ρ_e = ~0.04 mm, ρ_i = ~2.5 mm

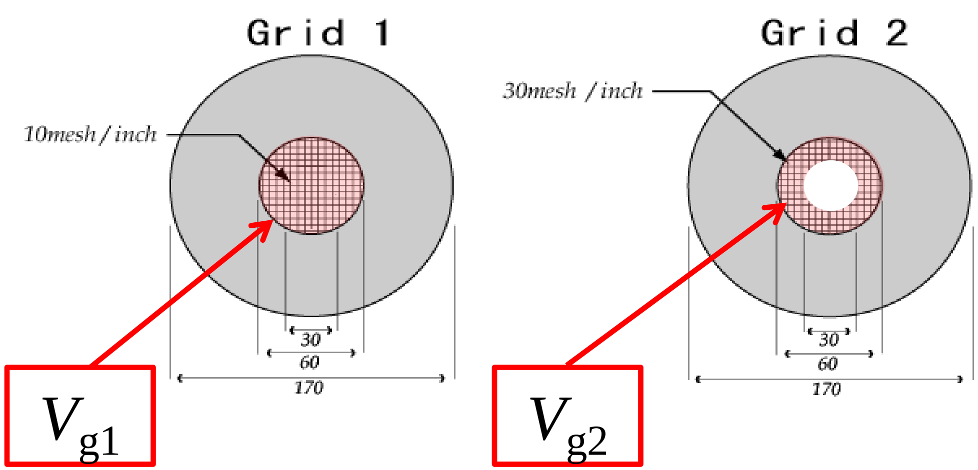


Q_T Upgrade Machine at Tohoku University

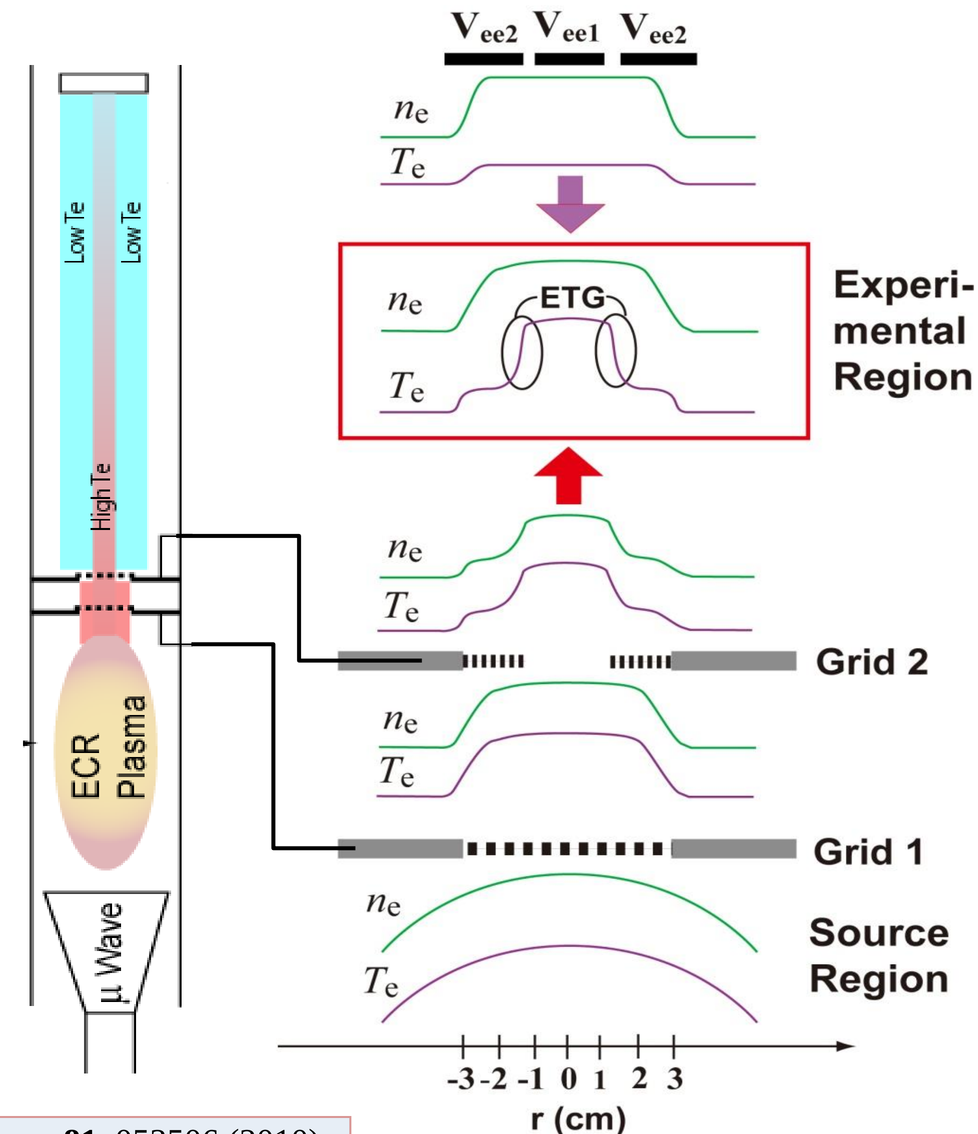
Electron emitter (W hot plate)



Configuration of mesh grids



Electron emitter

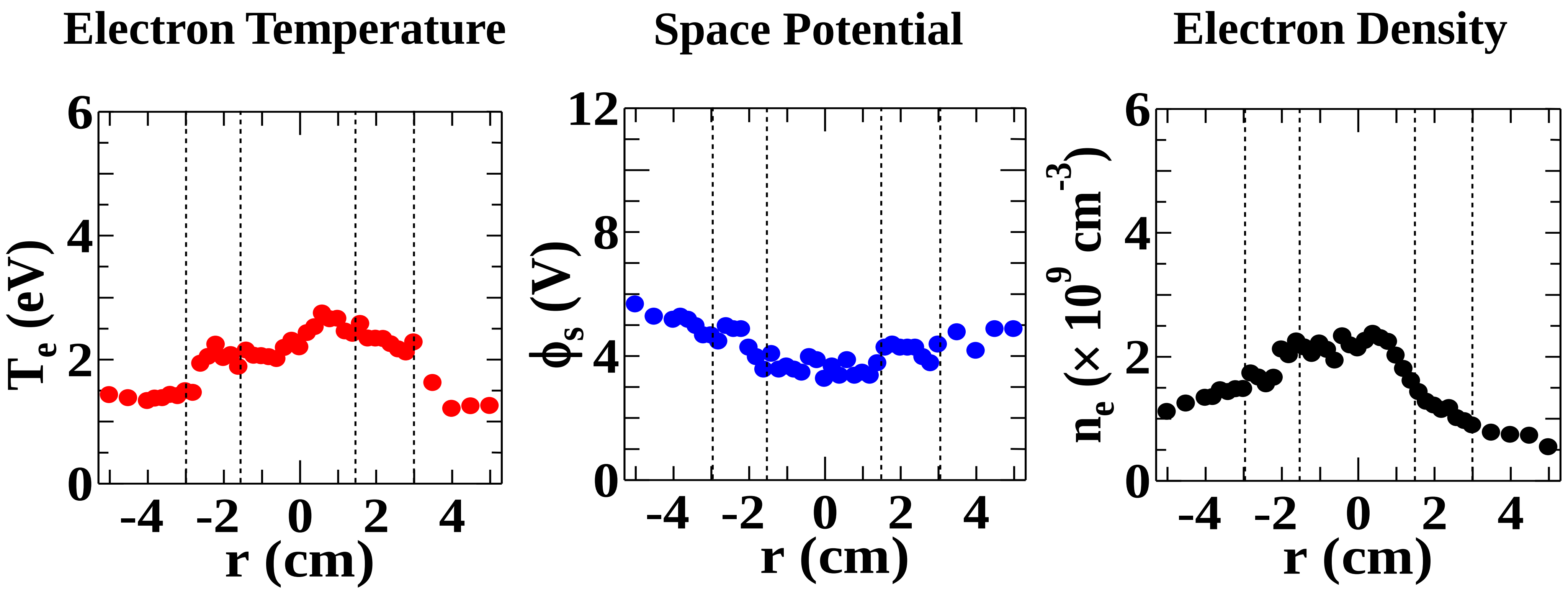


C. Moon, T. Kaneko, S. Tamura, and R. Hatakeyama, Rev. Sci. Instrum. **81**, 053506 (2010).

Control of the electron density and temperature profiles from the source to experimental regions by using the mesh grids.

Plasma Parameters

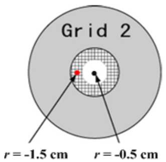
P_{μ}= 60 W, P_{HP}= 3 kW, P_{Ar}=1 × 10^{-4} Torr
V_{g1} = 0V, V_{g2} = 0V, V_{ee1} = 0 V, V_{ee2} = 0 V

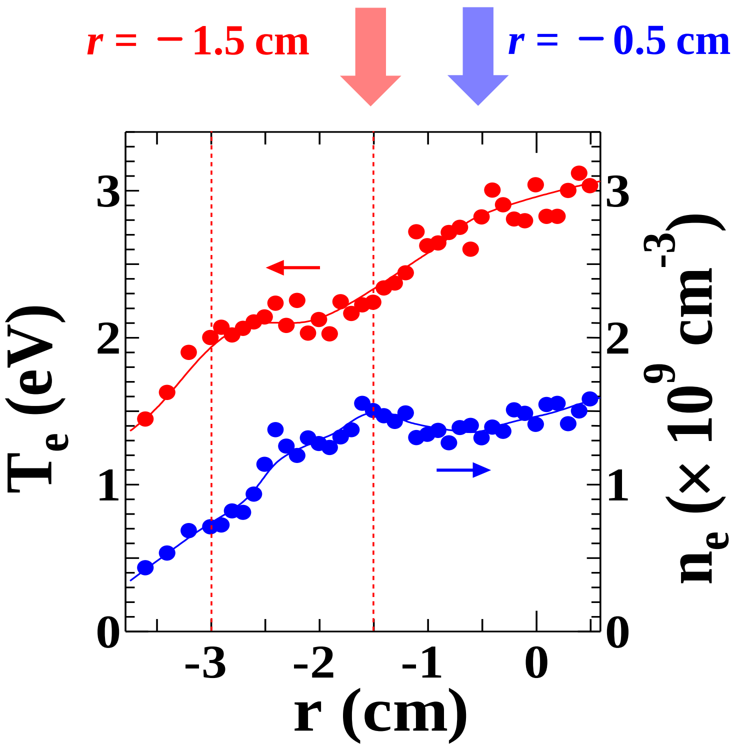


Radial Profiles of a Typical Plasma Parameters

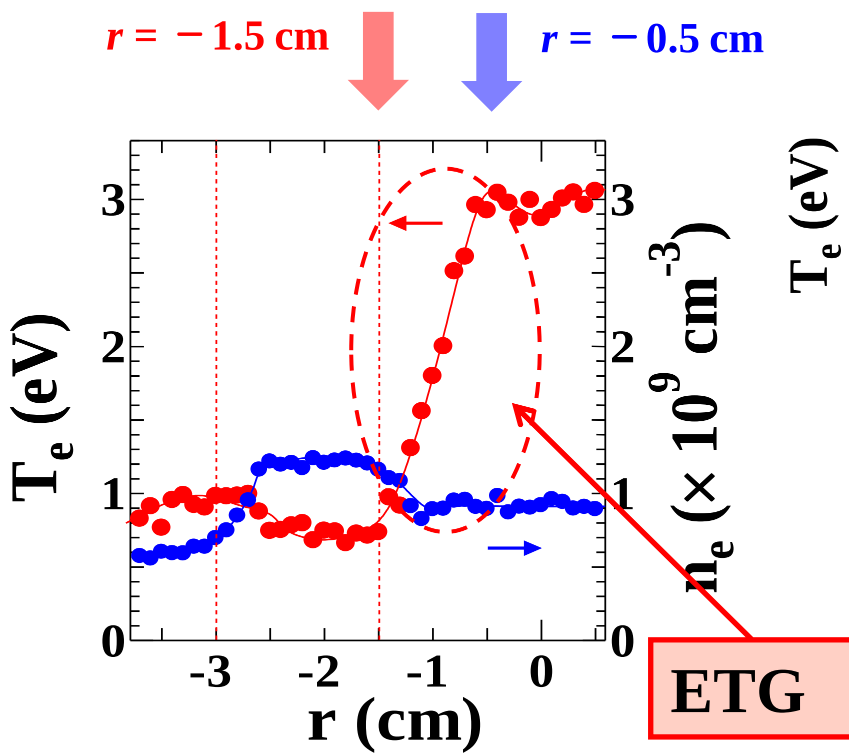
Formation and Control of ETG

P_{μ} = 20 W, V_{ee1} = −4 V, V_{ee2} = −1.5 V, V_{g1} = −10 V

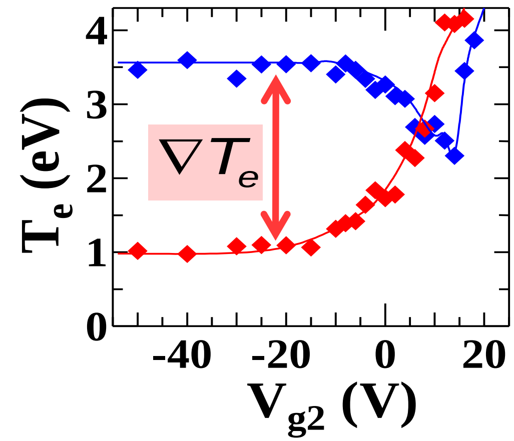


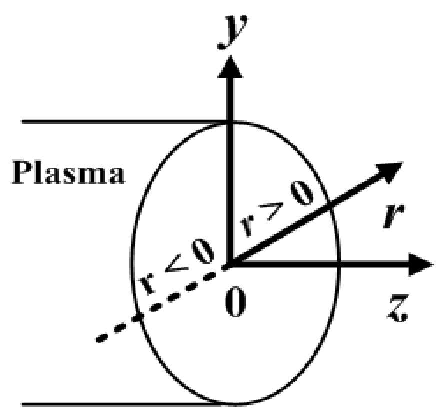


V_{g2} = 3 V



V_{g2} = −30 V

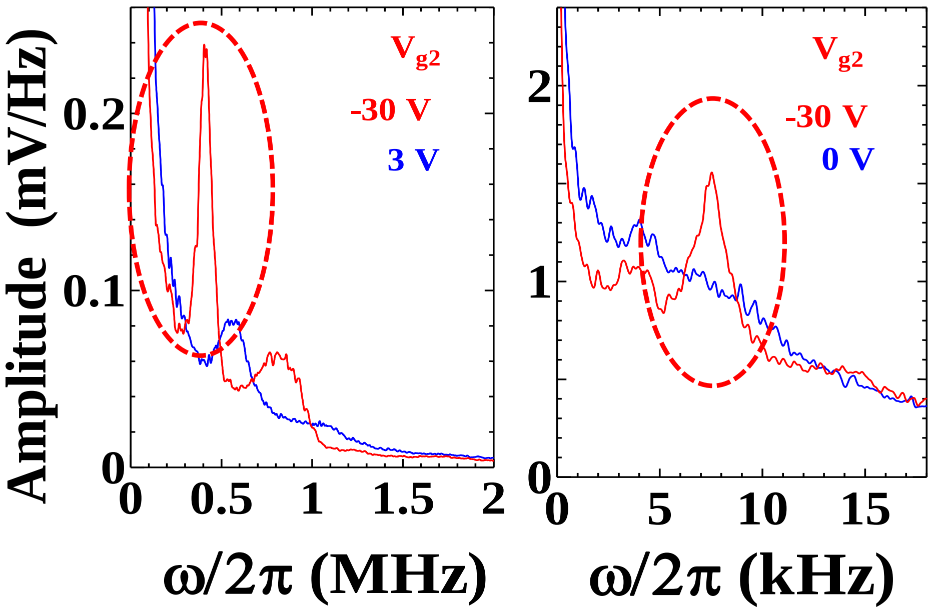




ETG can be generated easily by controlling the grid bias voltages V_{g2} .

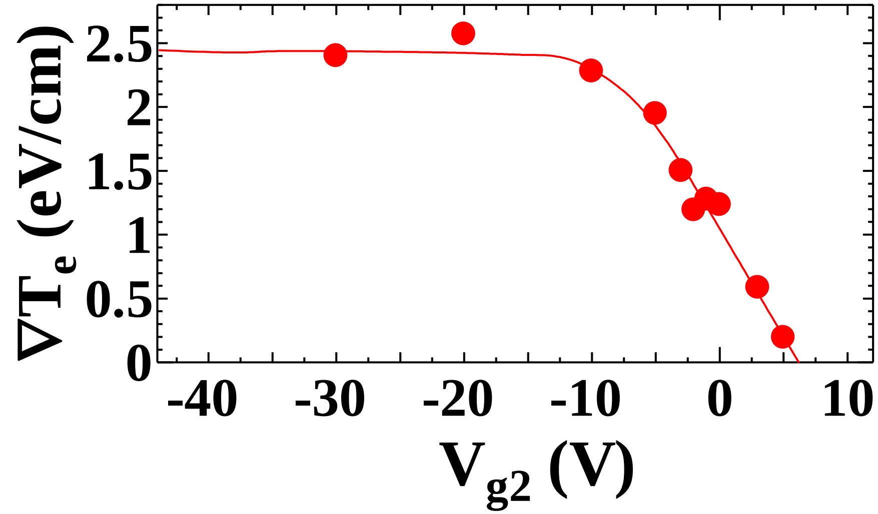
Effect of ETG on Fluctuations

P_μ = 20 W, V_{ee1} = − 4 V
V_{ee2} = − 1.5 V, V_{g1} = − 10 V
r = − 1.5 cm

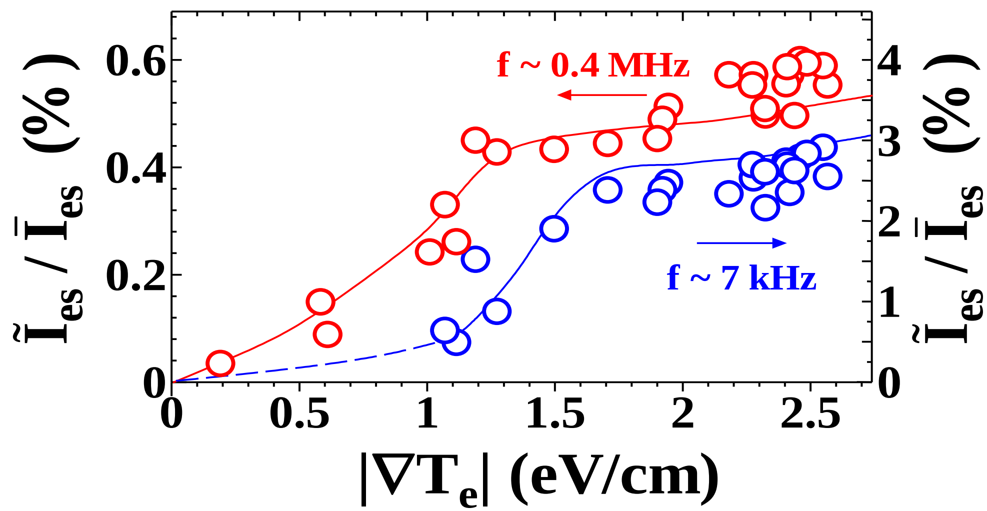


high and low frequency

ETG (∇Te)



Normalized Amp.



A high-frequency fluctuation (~ 0.4 MHz) is excited in situations where large ETG is formed (ETG mode).

Linear Dispersion Relations

The perturbed electron density of the linearized Vlasov equation:

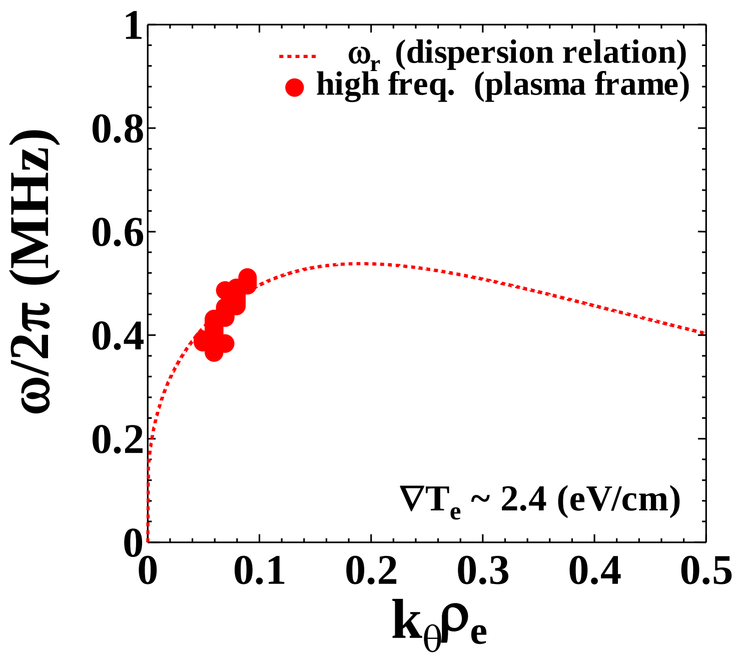
$$\tau + (k_\perp \lambda_{De})^2 + b\left(1 + \frac{1}{2\lambda_e{}^2}\right) - \frac{1}{2\lambda_e{}^2} + b\frac{\omega^*_{T_e}}{\omega} + \frac{\omega^*_{T_e}}{4\lambda_e{}^2\omega}(1+b) = 0,$$

where $\tau = \frac{T_e}{T_i}$, $k_\perp = k_y$, $\lambda_e = \frac{\omega}{k_\parallel v_e}$, $b = \frac{(k_\perp \rho_e)^2}{2}$, $\omega^*_{T_e} = \frac{k_\perp T_e}{eBL_{Te}}$.

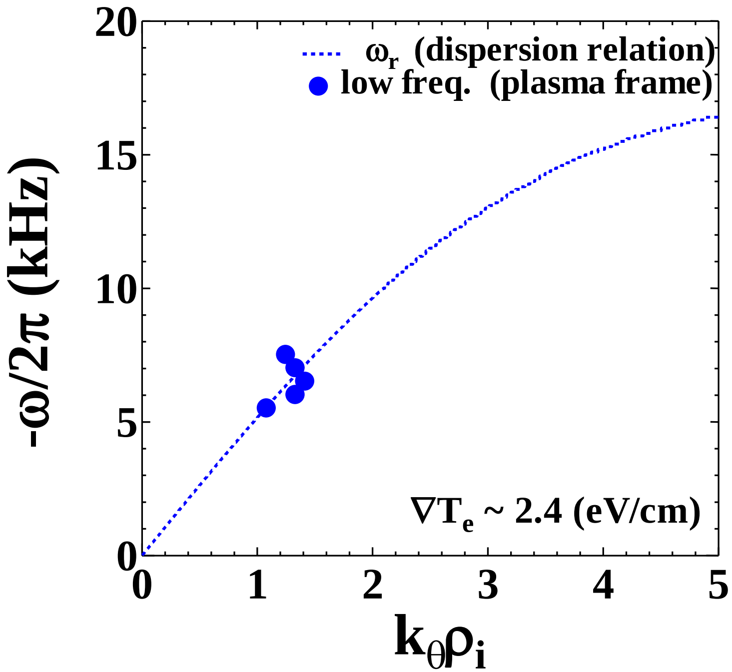
[Phys. Fluids **30**, 1331 (1987), Phys. Plasmas **17**, 042108 (2010)]

The typical experimental plasma parameters

$T_{e0} = 3$ eV, $T_i = 0.3$ eV, $n_e = 1\times10^9$ cm^{-3},
$\lambda_{De} = 0.039$ cm, $B = 2300$ G, $L_{T_e} = 1.2$ cm,
$k_\parallel = 0.06$ cm^{-1}, $\rho_e = 0.004$ cm, $\rho_i = 0.25$ cm.



ETG mode (~ 0.4MHz)



DW mode (~7 kHz)

The high and low frequency of fluctuations are consistent with the theoretical estimation from the linear dispersion relation of ETG and DW

Bispectral Analysis (Nonlinear Coupling)

Bicoherence: **the degree of <u>nonlinear coupling between the three waves</u> (the value in the range from 0 to 1)**

The bicoherence is defined as

$$b_{xyz}^{2}(f_1, f_2) = \frac{\left|\left\langle B_{xyz}(f_1, f_2)\right\rangle\right|^2}{\left\langle\left|X(f_1+f_2)\right|^2\right\rangle\left\langle\left|Y(f_1)Z(f_2)\right|^2\right\rangle}$$

< > : Averaged ensembles

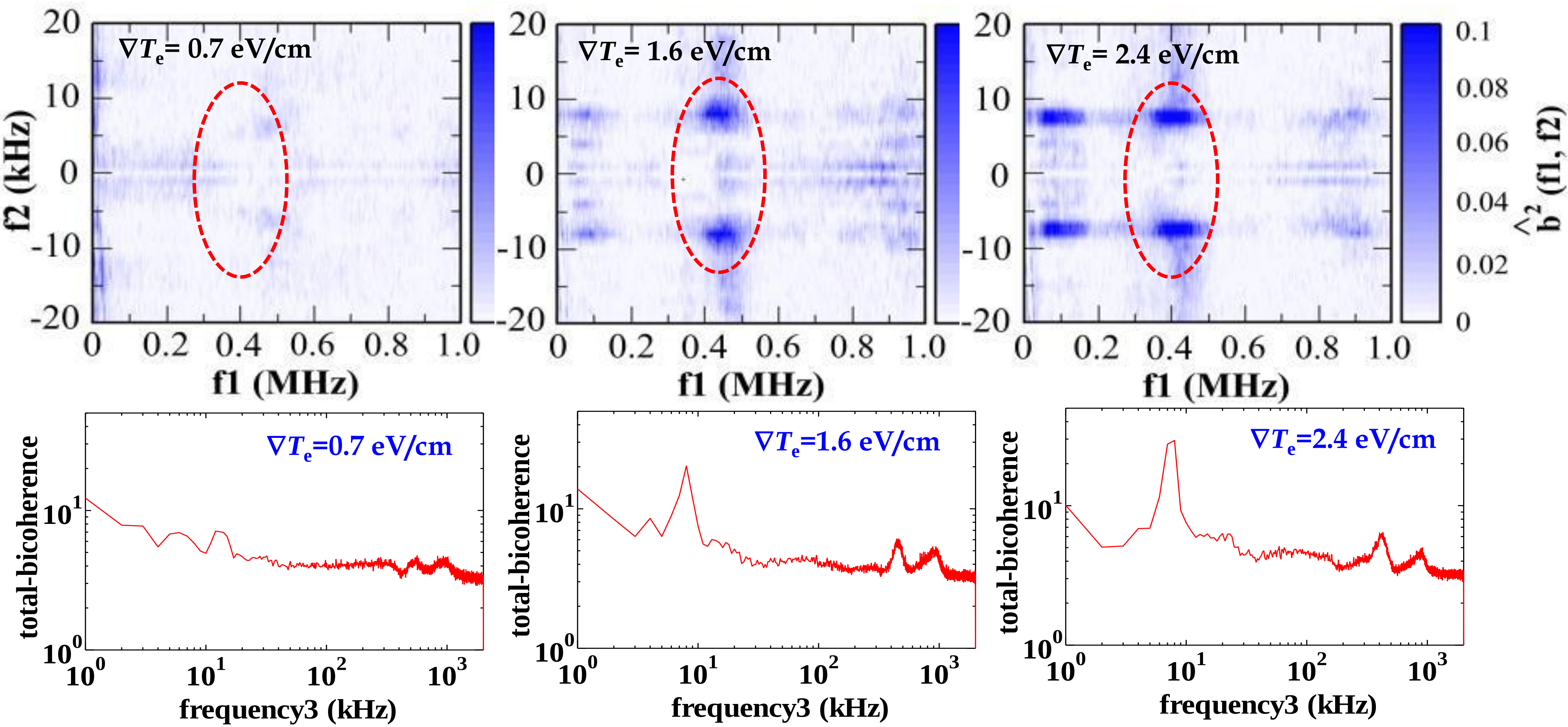
- **The variance of the bicoherence is $d\,b^2(f_1+f_2) \leq 1/N \sim 0.0014$.**

The bispectral analysis can clarify the three-wave nonlinear interactions quantitatively.

Bicoherence of the High & Low Frequency Fluctuations

Squared Bicoherence

P_μ = 20 W, V_{g1} = −10 V, V_{ee1} = −4.0 V, V_{ee2} = −1.5 V, r = −1.5 cm

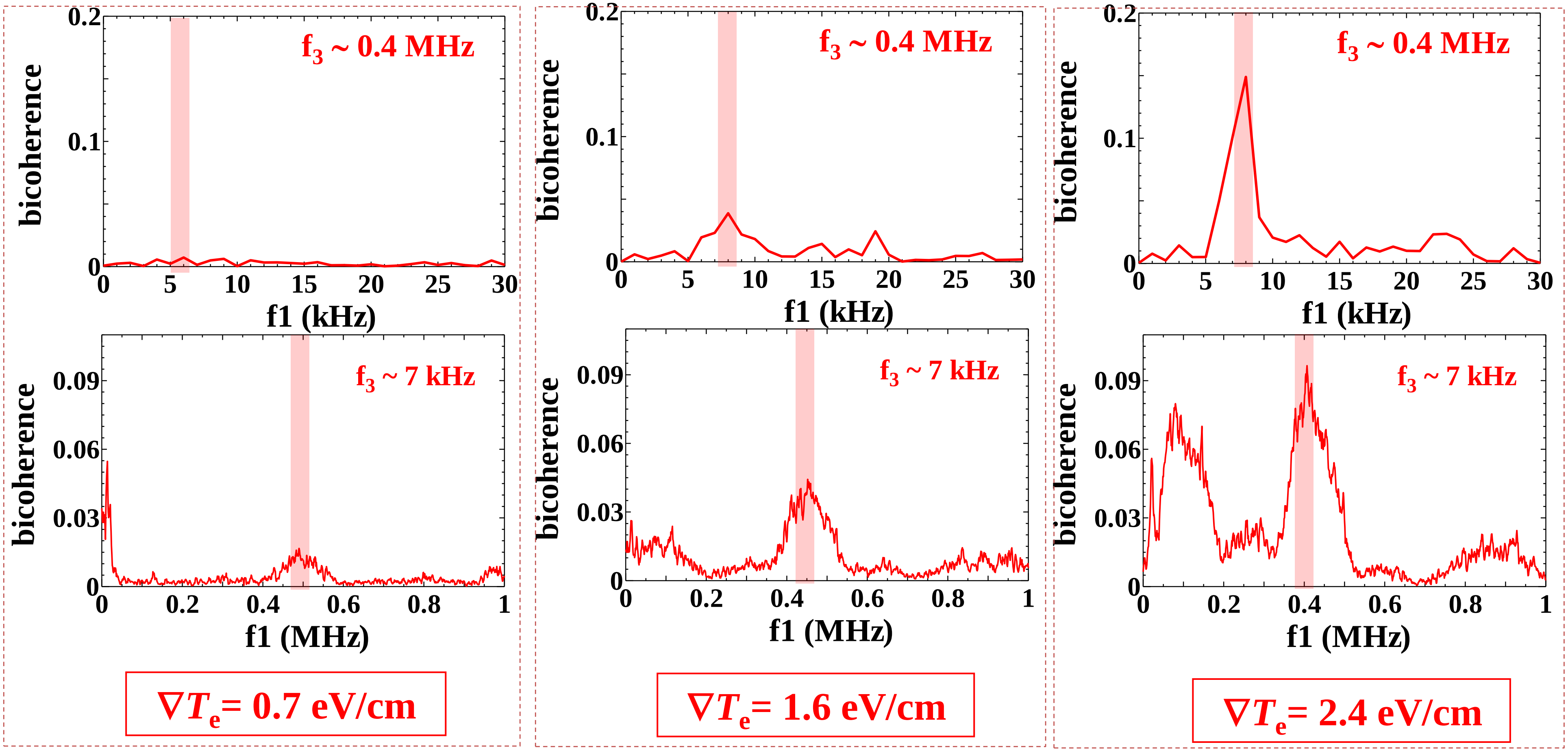


The nonlinear coupling between the ETG mode and drift wave (DW) mode become stronger as the magnitude of ETG is increased.

Bicoherence of the High & Low Frequency Fluctuations

ETG (~0.4 MHz) & DW (~7 kHz) modes

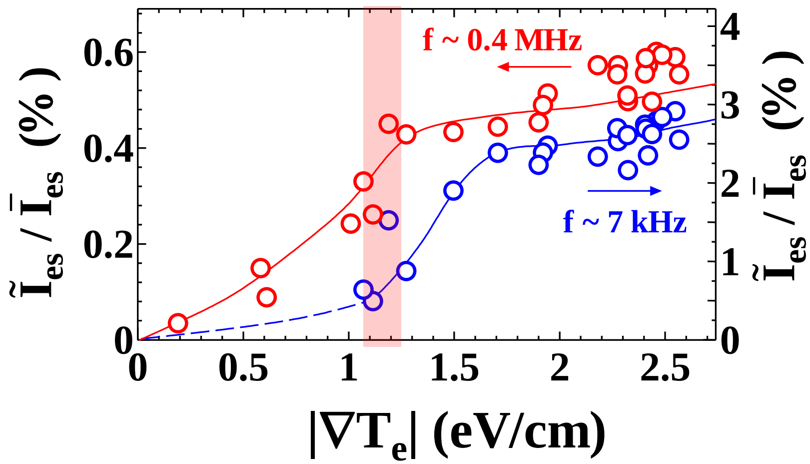
P_μ = 20 W, V_{g1} = −10 V, V_{ee1} = −4.0 V, V_{ee2} = −1.5 V, r = −1.5 cm

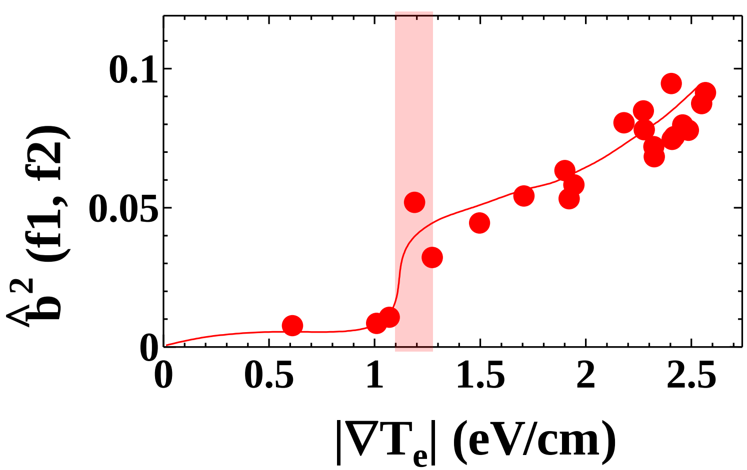


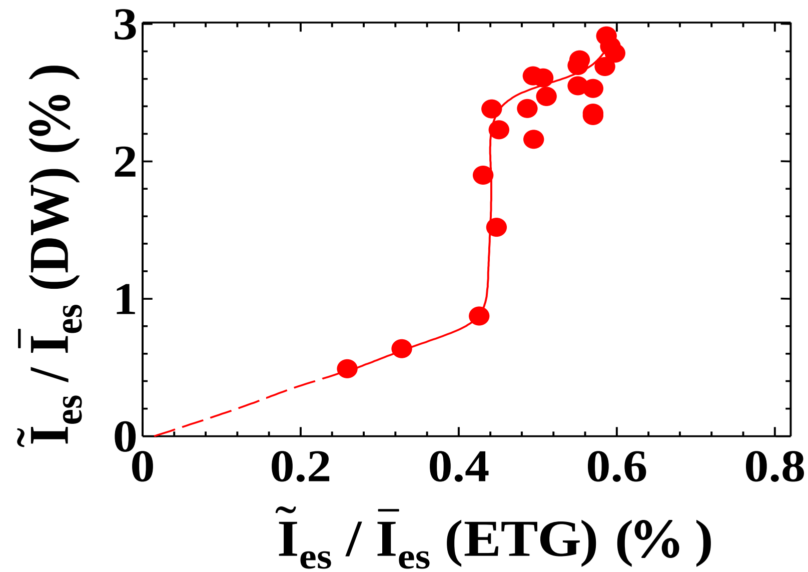
When the magnitude of ETG is increased, the slice of bicoherence between ETG mode and drift wave mode has a noticeable peak.

Nonlinear Energy Transfer (drift wave mode)

P_{μ} = 20 W, V_{g1} = −10 V, V_{ee1} = −4 V, V_{ee2} = −1.5 V, r = −1.5 cm







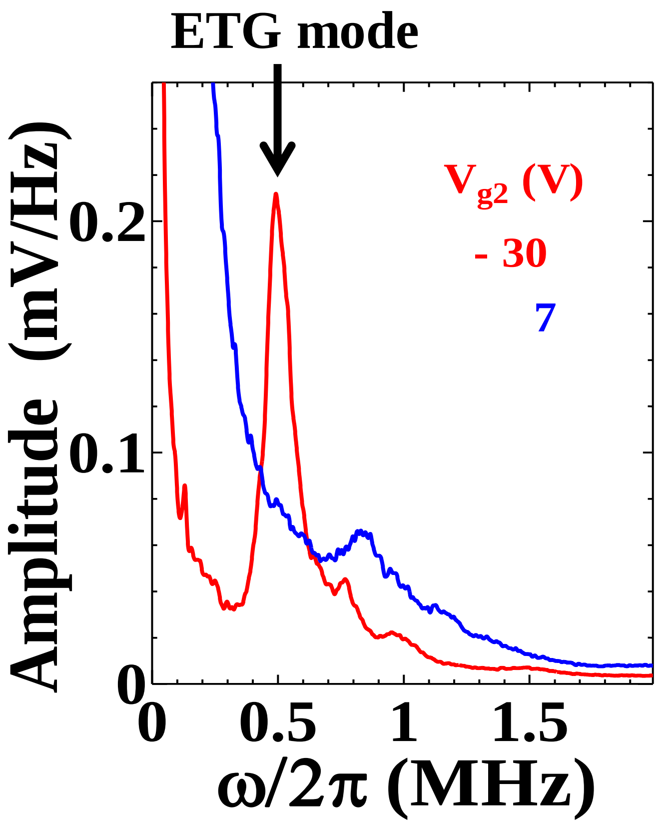
※ High-frequency fluctuations (ETG mode) versus low-frequency fluctuations (Drift wave mode).

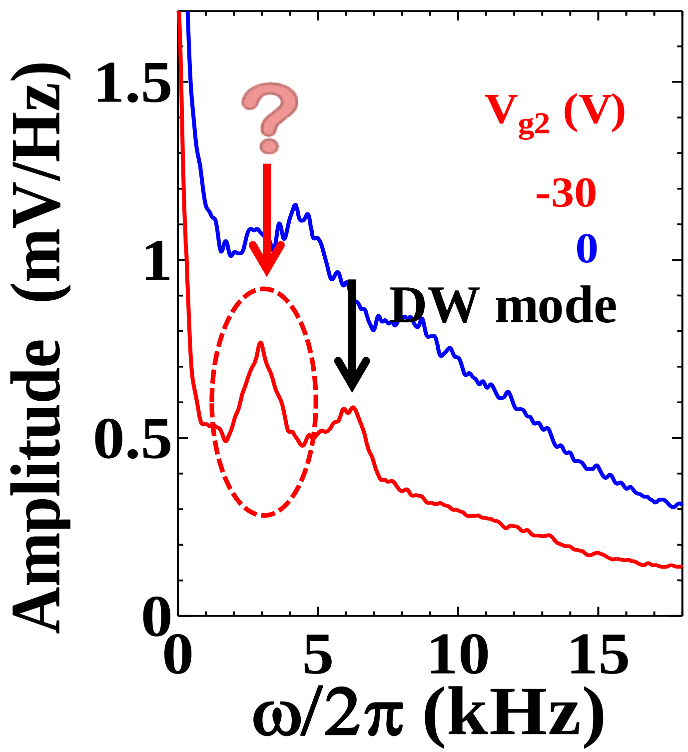
C. Moon, T. Kaneko, and R. Hatakeyama, *Phys. Rev. Lett.* **111**, 115001 (2013).

The energy of the ETG mode is transferred to the drift wave mode through the nonlinear interaction for $\nabla T_e \geq 1.2$ eV/cm.

Effect of ETG on Fluctuations

P_{μ} = 20 W, V_{ee1} = −4 V, V_{ee2} = −1.5 V, V_{g1} = −10 V, r = −0.9 cm





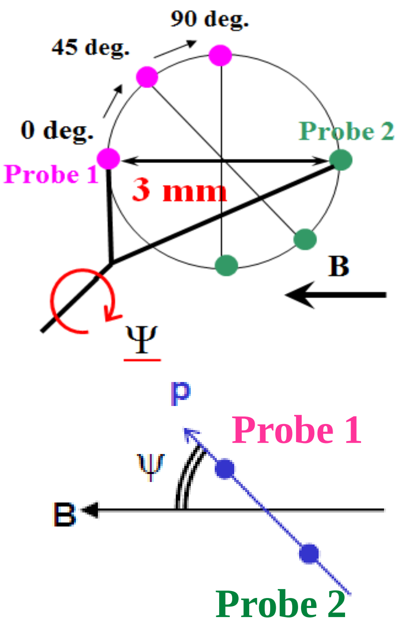
High-Frequency

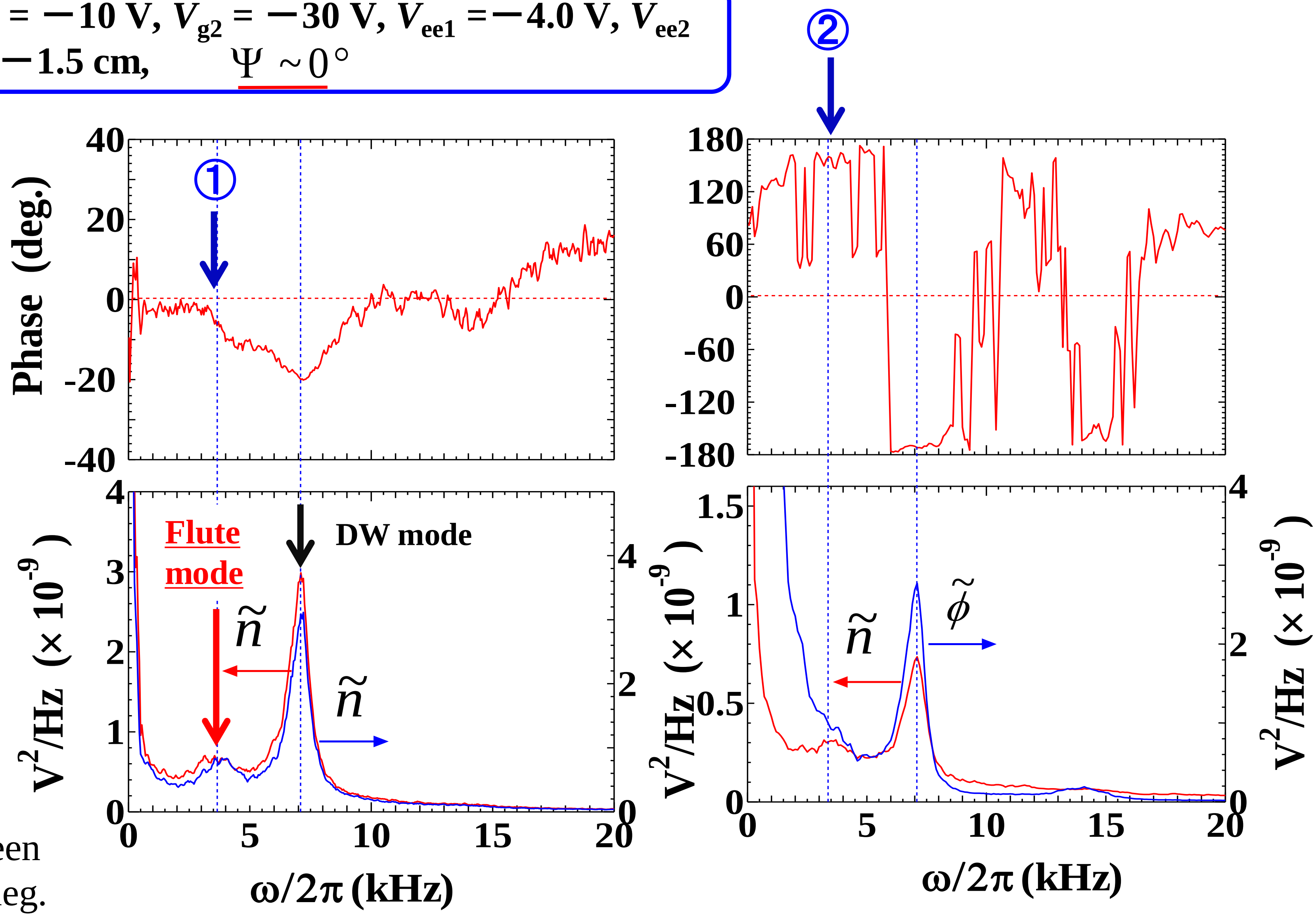
Low-Frequency

It is observed another low-frequency (~3.6 kHz) mode when the large ETG is formed.

Identification of a low-frequency fluctuation

P_μ = 20 W, V_{g1} = −10 V, V_{g2} = −30 V, V_{ee1} = −4.0 V, V_{ee2} = −1.5 V, r = −1.5 cm, $\Psi \sim 0°$





※ Flute mode

① $k_{\|} \sim 0$

② phase shift between $\tilde{n}$ and $\tilde{\phi}$ is 180 deg.

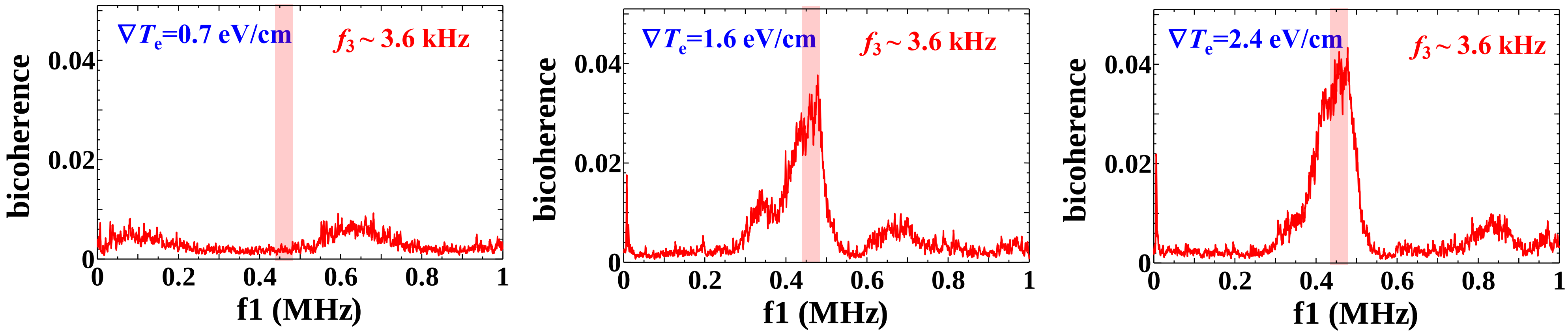
Phase shift between $\tilde{n}$ and $\tilde{n}$

Phase shift between $\tilde{n}$ and $\tilde{\phi}$

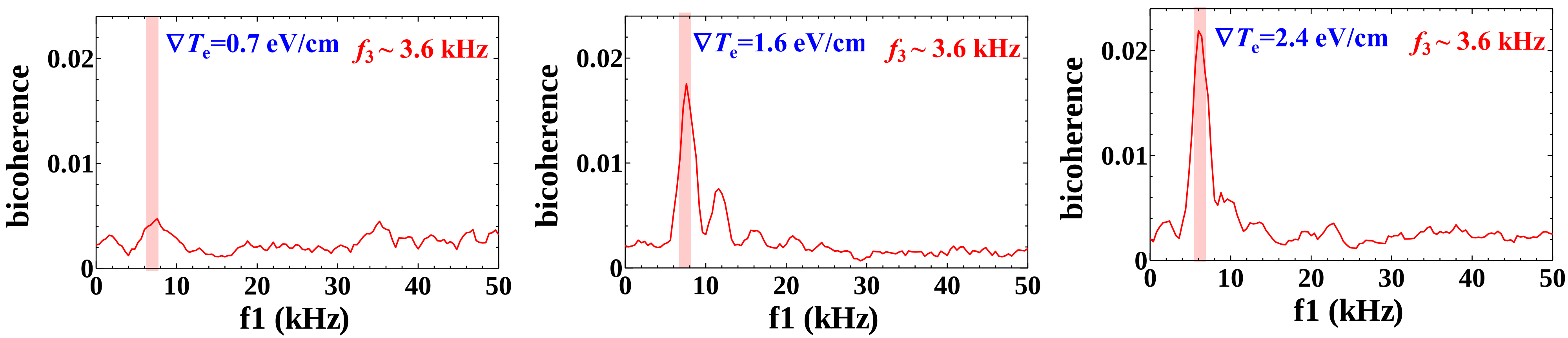
Bicoherence of the High & Low Frequency Fluctuations

P_μ = 20 W, V_{g1} = −10 V, V_{ee1} = −4.0 V, V_{ee2} = −1.5 V, r = −0.9 cm

ETG mode (f_2 = ~0.4 MHz)



DW mode (f_2 = ~7 kHz)

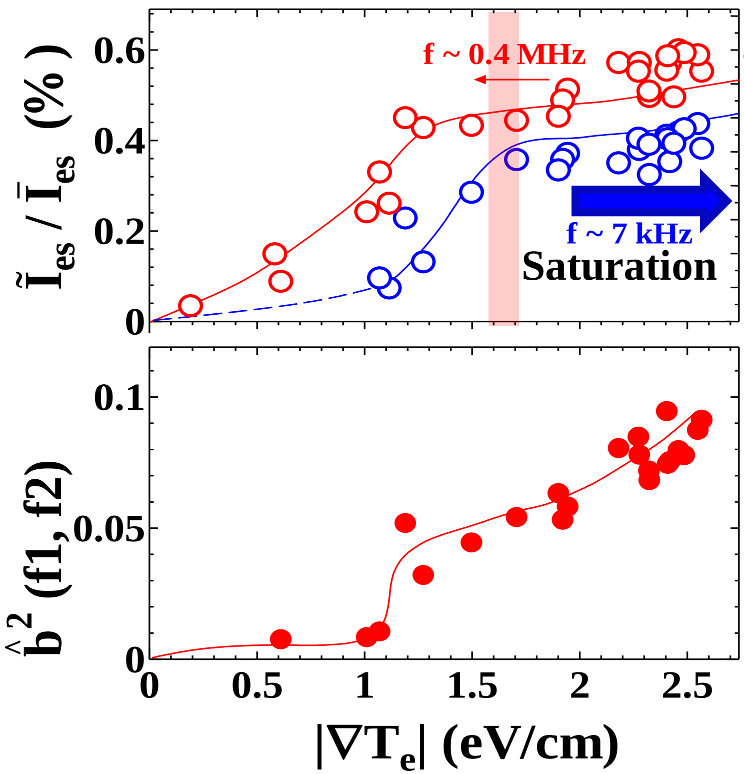


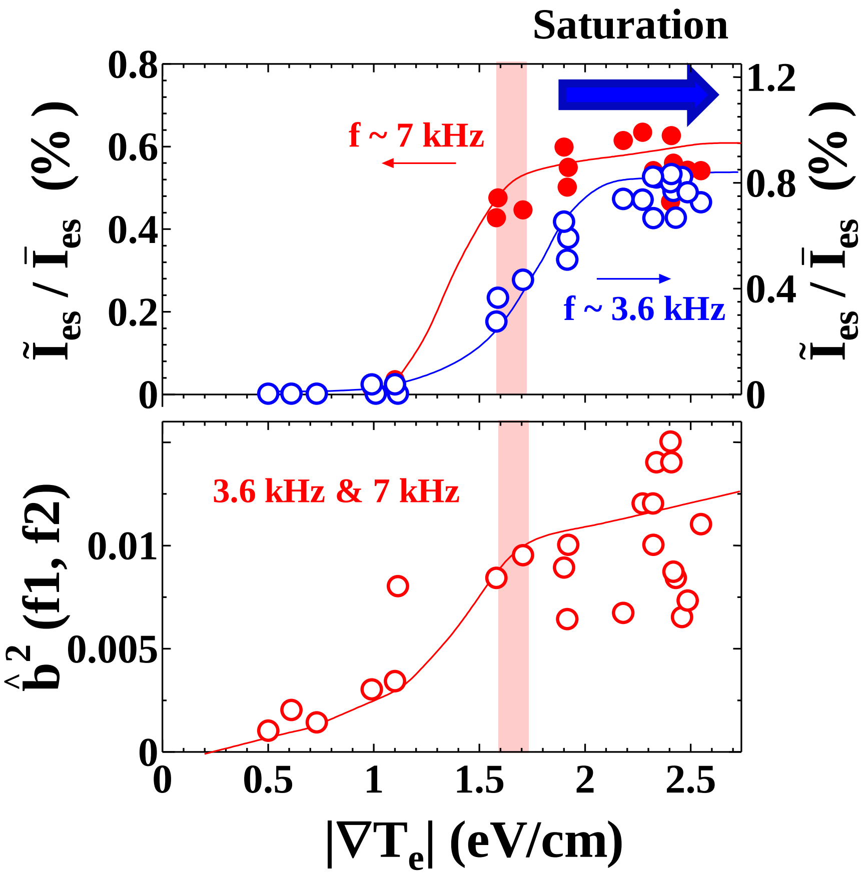
The slice of bicoherence between the DW mode and the flute mode has a noticeable peak when the magnitude of ETG is increased.

Nonlinear Energy Transfer (flute mode)

P_μ = 20 W, V_{g1} = −10 V, V_{ee1} = −4 V, V_{ee2} = −1.5 V, r = −0.9 cm

Nonlinear interaction between ETG mode and DW mode





C. Moon, et al., Phys. Plasmas **22**, 052301 (2013).

It is considered that the energy of the DW mode is transferred to the flute mode through the nonlinear interaction.

Effect of ETG on the Nonlinear Interplay

Free Energy Source (∇T)

ETG

Saturation (Sat.)
Increase (Inc.)

Electron-scale fluctuation $\sim\rho_e$

Sat. (∇T_e> ~1.2 eV/cm)
Inc. (∇T_e> ~0.1 eV/cm)

ETG mode (~0.4 MHz)

Anomalous electron heat transport[1)]

Energy Transfer

Ion-scale fluctuation $\sim\rho_i$

Inc. (∇T_e> ~1.2 eV/cm)
Sat. (∇T_e> ~1.7 eV/cm)

Drift wave mode[2)] **(~7 kHz)**

Energy Transfer

Flute mode[3)] **(~3.6 kHz)**

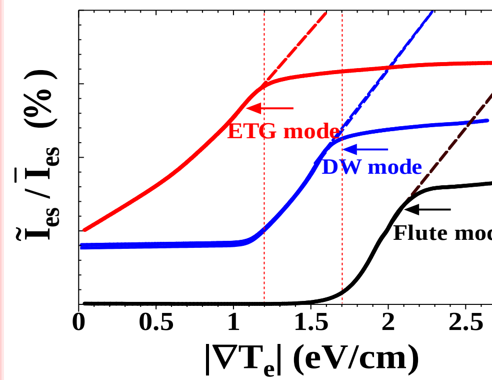
Inc. (∇T_e> ~1.7 eV/cm)
Sat. (∇T_e> ~2.2 eV/cm)

Anomalous heat transport[6)]

Device-scale fluctuation

? ~1 kHz

- **Streamers**[4)]
- **Zonal flow**[5)]



Fluctuations Level as a Function of the ETG

References

1) F. Ryter, et al., Phys. Rev. Lett. **86**, 5498 (2001).
2) C. Moon, et al., Phys. Rev. Lett. **111**, 115001 (2013).
3) C. Moon, et al., Phys. Plasmas **22**, 115001 (2015).
4) T. Yamada, et al., Phys. Rev. Lett. **105**, 225002 (2010).
5) Y. Nagashima, et al., Phys. Plasmas **16**, 020706 (2009).
6) S.–I. Itoh and K. Itoh, Plasma Phys. Control. Fusion **43**, 1055 (2001).

Summary

In order to understand the electron temperature gradient (ETG) mode driven anomalous heat transport, we investigate a multi-scale nonlinear coupling between the electron-scale ETG mode and the ion-scale fluctuations in linear magnetized plasmas.

- The formed ETG is found to excite a high-frequency fluctuation (~0.4 MHz), i.e., ETG mode, furthermore, the drift wave (DW) mode (~7 kHz), which is enhanced by the nonlinear coupling with the ETG mode.
- It is observed another low-frequency (~3.6 kHz) fluctuation associated with the flute mode is enhanced by the nonlinear coupling with the DW mode.
- The ETG mode energy was transferred to the DW mode, and then the energy was ultimately transferred to the flute mode, which was triggered by the disparate scale nonlinear interactions between the ETG and ion-scale low-frequency modes.

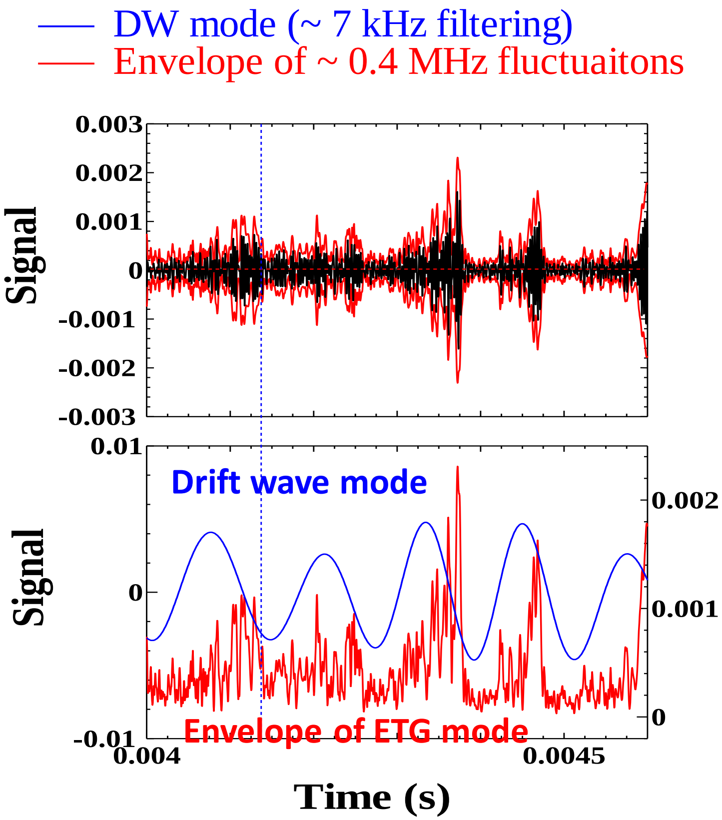
Acknowledgements

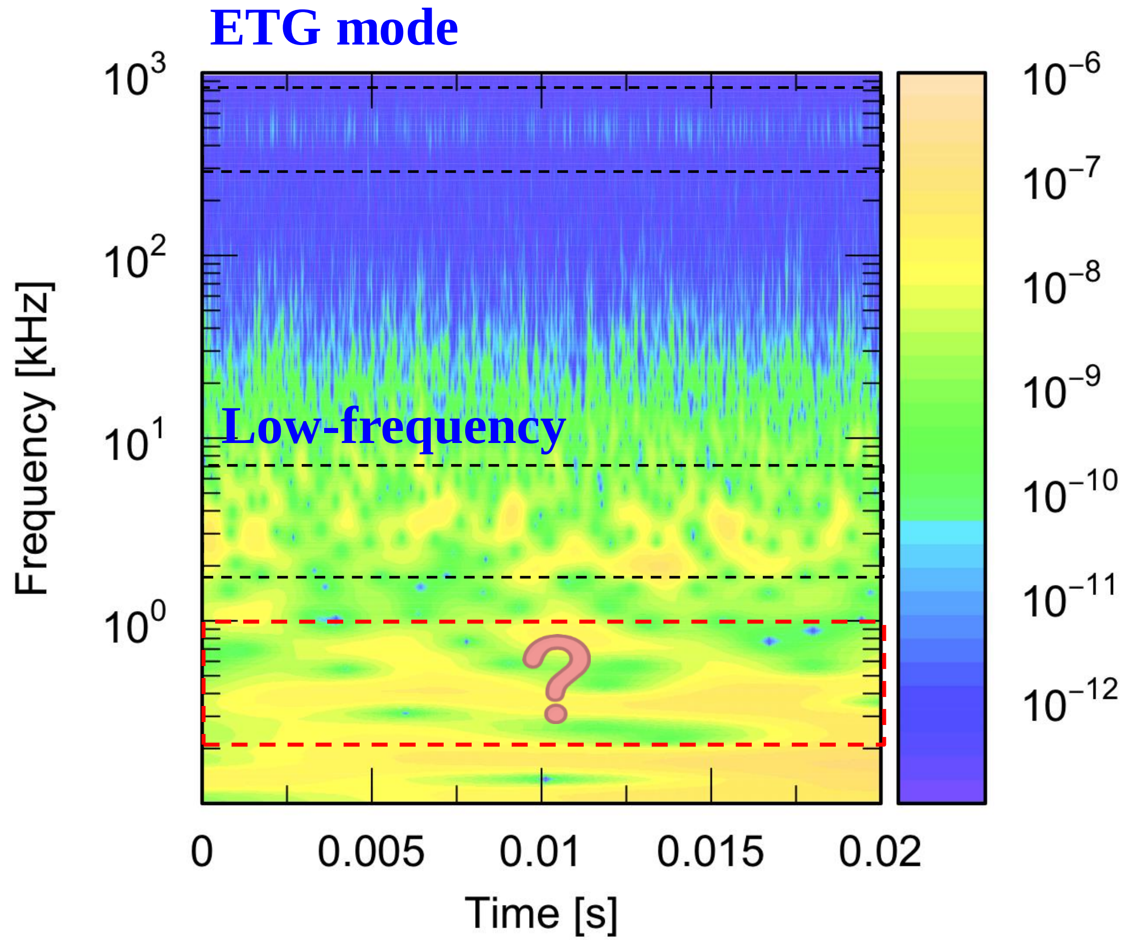
The authors acknowledge helpful discussions by Prof. S. Inagaki and Prof. S.-I. Itoh. This work was supported by the Grant-in-Aid for JSPS Fellows (23-1638), and a Grant-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology, Japan. This work was partly supported by the Grant-in-Aid for Scientific Research of JSPF, Japan (Nos. 15H02155 and 23244113), by the collaboration programs of the RIAM of Kyushu University and of NIFS (NIFS13KOCT001), and by the Asada Science Foundation.

The Temporal Evolution of Fluctuations

$P_{\mu} = 20$ W, $V_{ee1} = -4$ V
$V_{ee2} = -1.5$ V, $V_{g1} = -10$ V
$r = -1.5$ cm, $\nabla T_e = 2.4$ eV/cm

Envelope & Filter





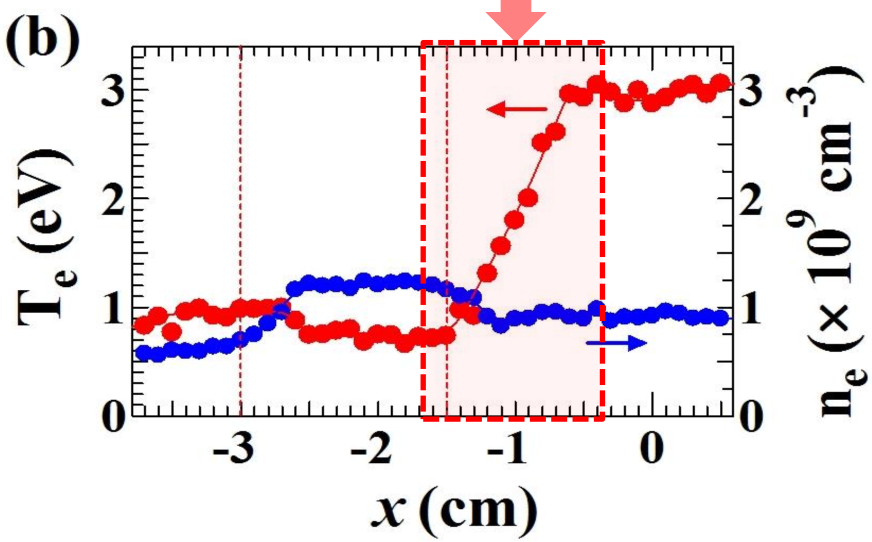
Wavelet spectrum

The modulation of ETG mode with low-frequency fluctuations is well observed when sufficient ETG is formed.

プラズマの半径方向分布

P_μ = 20 W, V_{g1} = −10 V, V_{g2} = −30V,
V_{ee1} = −4.0 V, V_{ee2} = −1.5 V, r = −1.5 cm

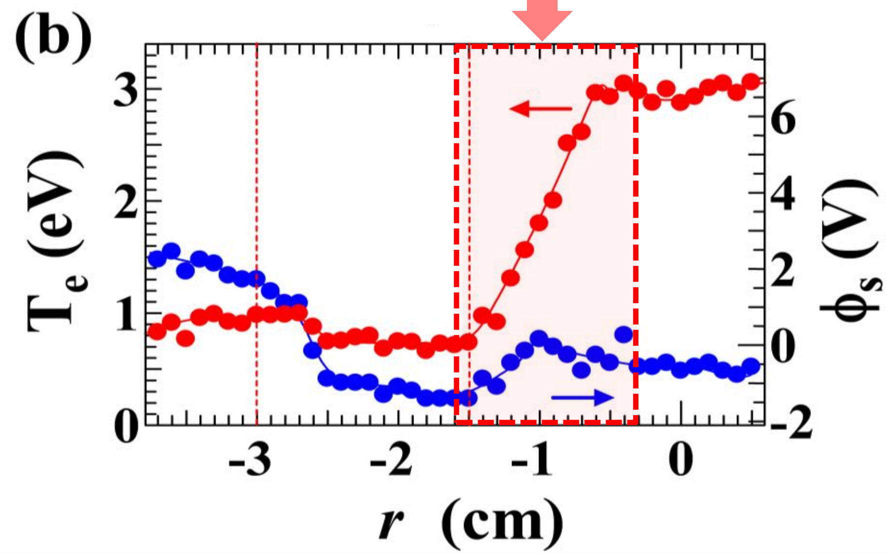
PRL2013の図1



電子密度勾配が谷のように形成

$$\left|\frac{n_e'}{n_e}\right| = 14.5\ m^{-1}$$

POP2015の図2

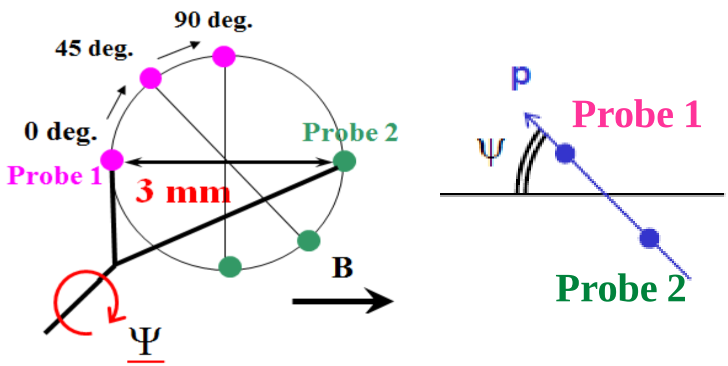


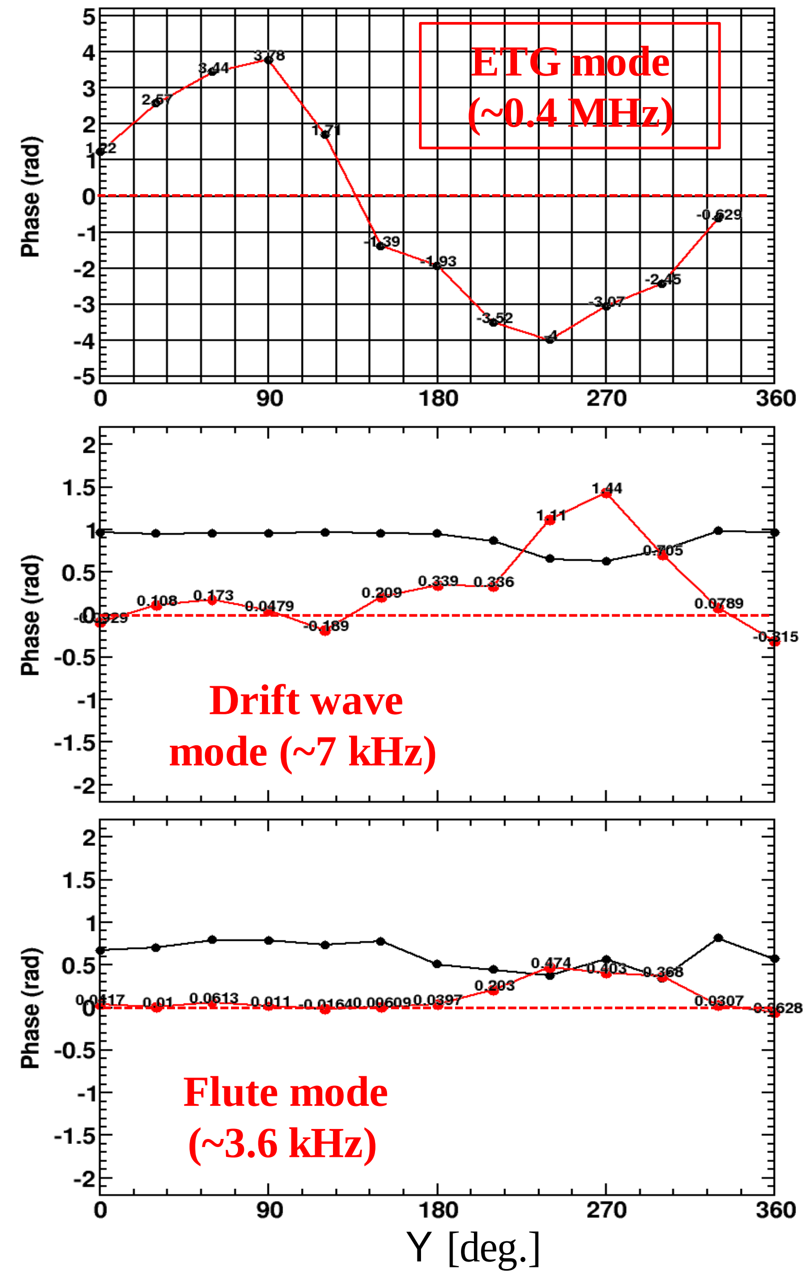
E_r ≃ +0.1 (V/cm)

E x ***B***方向はイオン反磁性方向

位相差測定によるモード数の同定（密度揺動のみ）

P_{μ} = 20 W,
V_{g1} = −10 V,
V_{g2} = −30V,
V_{ee1} = −4.0 V,
V_{ee2} = −1.5 V,
r = −1.5 cm



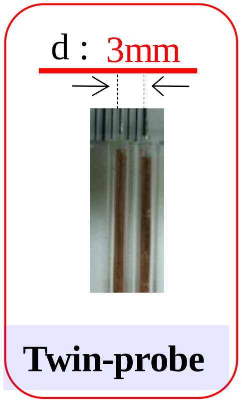


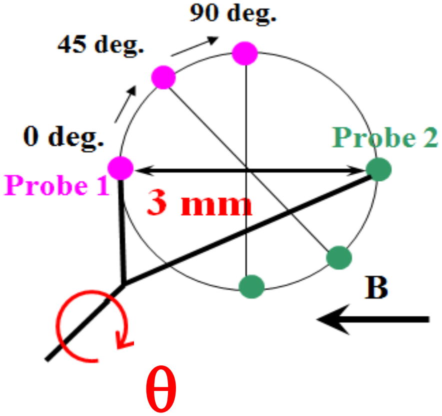
磁場に垂直（θ）方向への伝搬方向とそのモード数

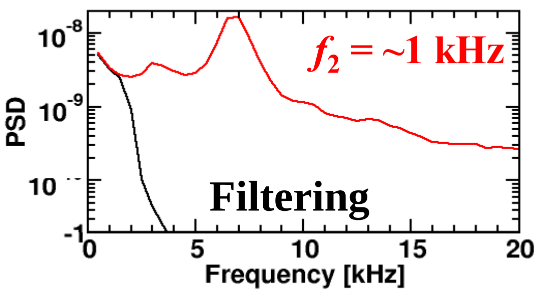
	ETG	DW	flute
mode number	~40	~8	~2
波長 λ(mm)	~2.4	*~11.5*	*~44.9*
周波数 *f* (kHz)	460	7	3.6
伝搬方向	電子反磁性	イオン反磁性（？）	イオン反磁性（？）

Spatial Structure of the Lower-frequency Fluctuations

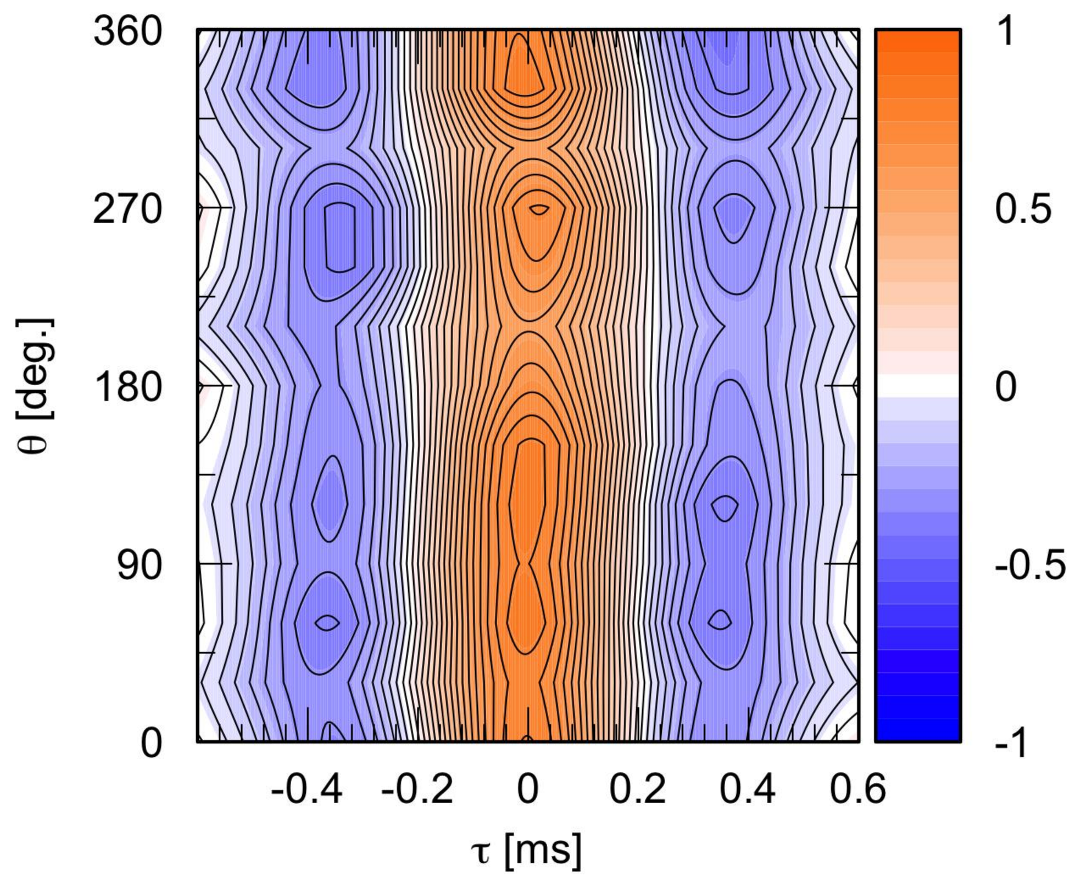
P_{μ} = 20 W, V_{g1} = −10 V, V_{ee1} = −4.0 V, V_{ee2} = −1.5 V, V_{g2} = −30 V (∇T_e = 2.4 eV/cm).







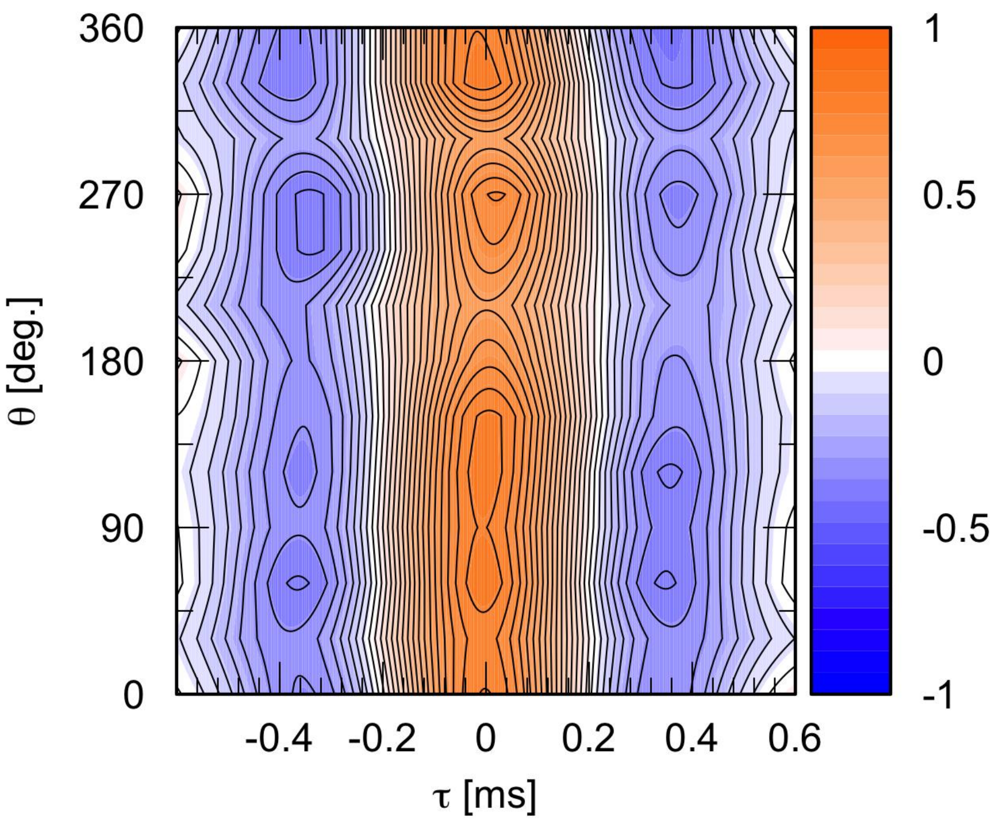
Cross-Correction with $\tilde{n}$ and $\tilde{n}$

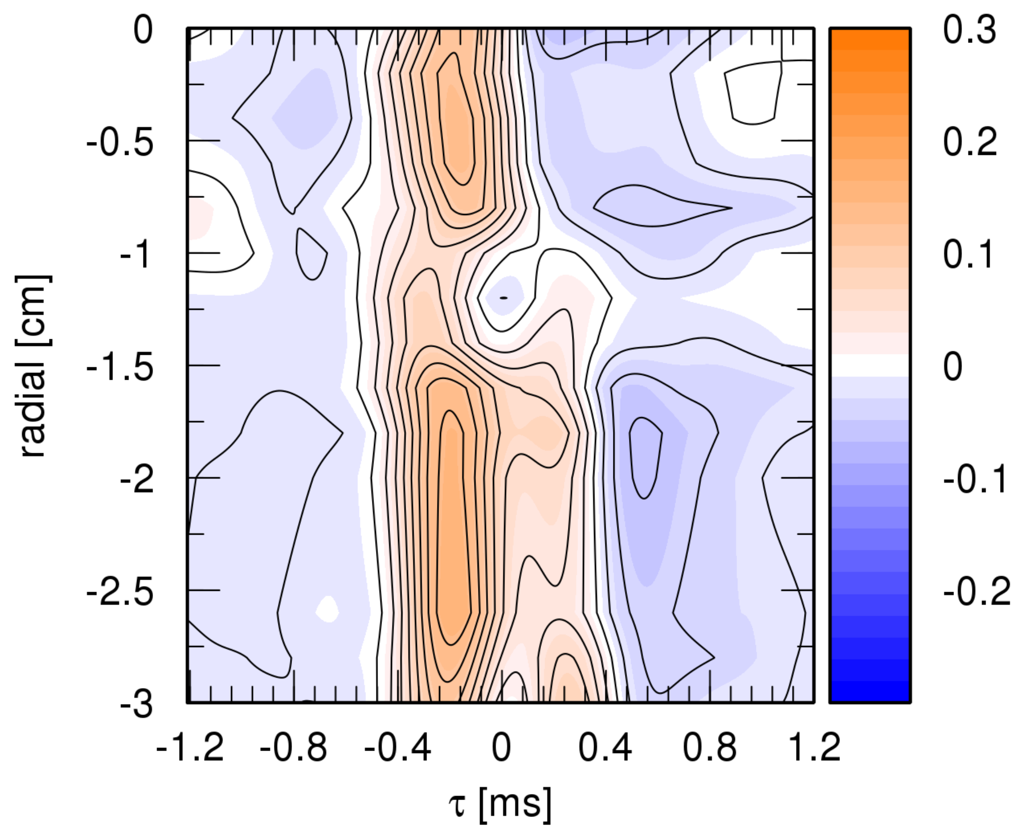


It is found that the fluctuations with $f \simeq 1$ kHz is the poloidal wave number k_{θ}= 0 (m ~ 0).

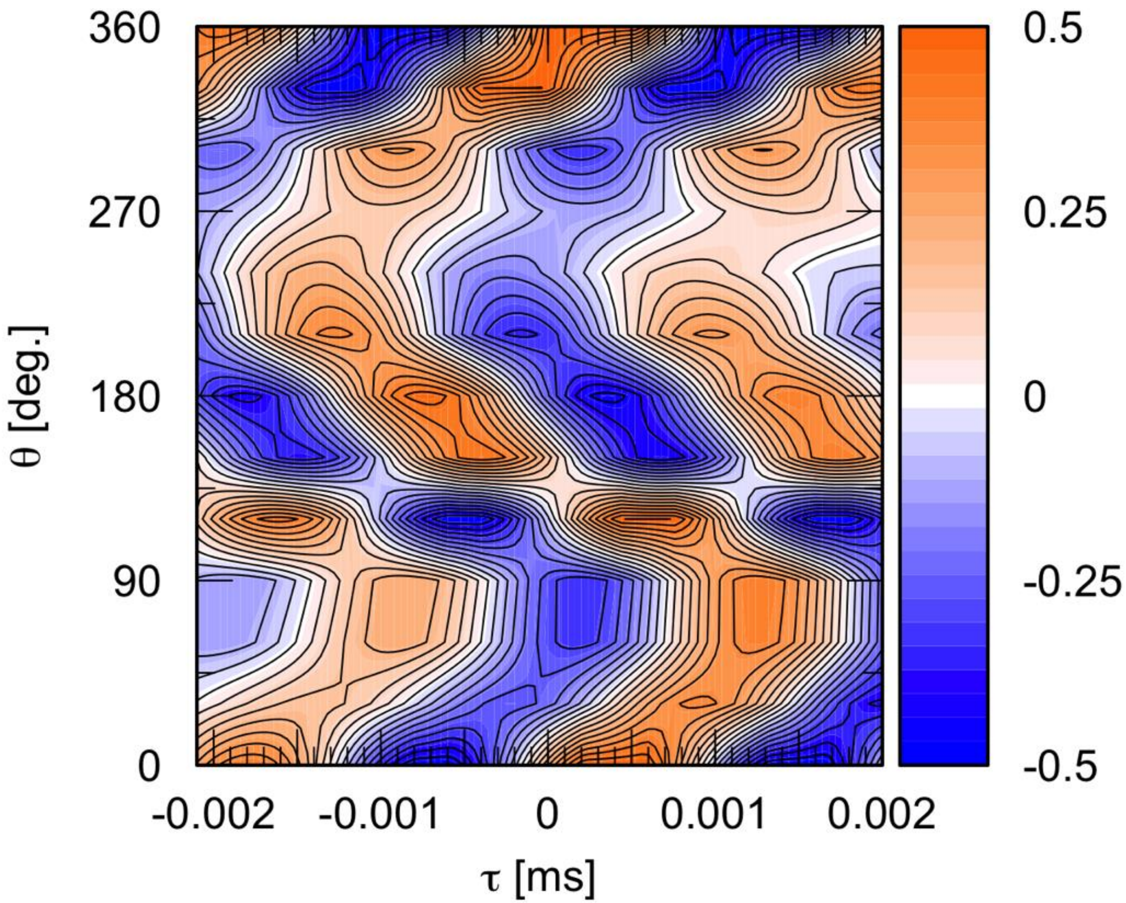
Spatial Structure of Low-frequency Fluctuations

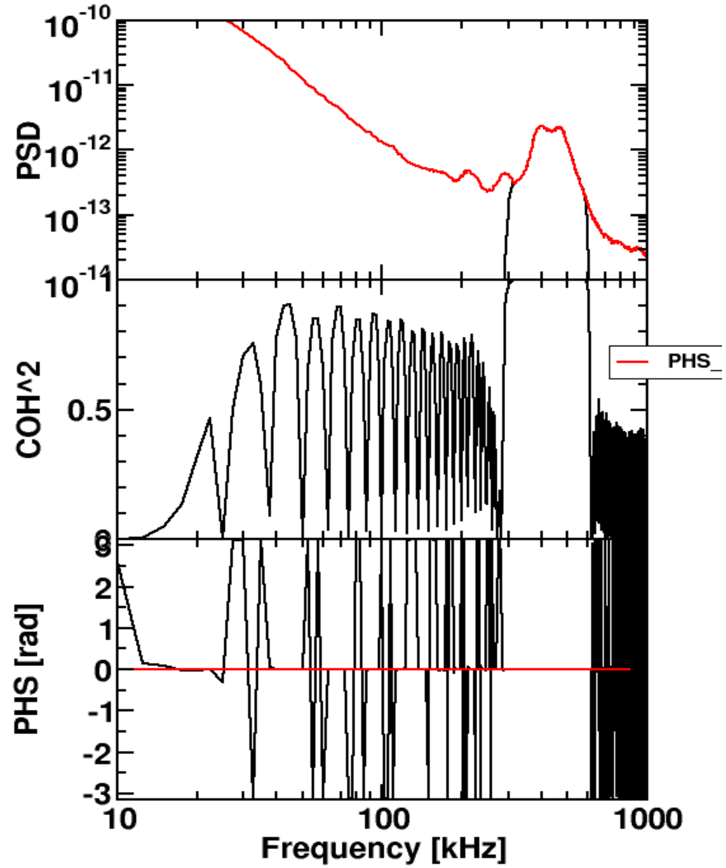
Cross-Correction with $\tilde{n}$ and $\tilde{n}$





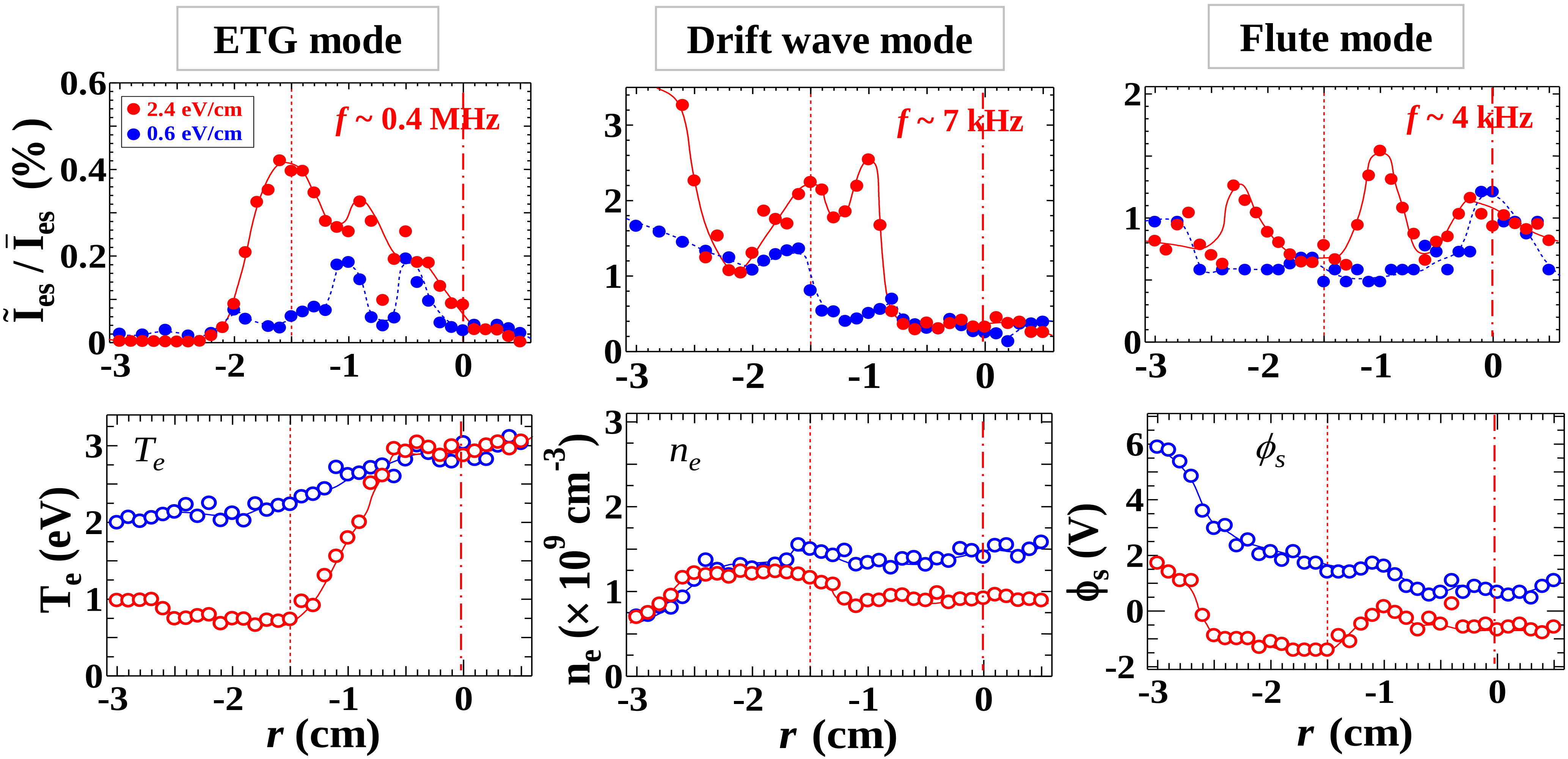
Spatial Structure of ETG mode





Radial Profiles of ETG driven Fluctuations

P_μ= 20 W, V_{g1} = − 10 V, V_{g2} = − 30 or 3 V, V_{ee1} = − 4 V, V_{ee2} = − 1.5 V

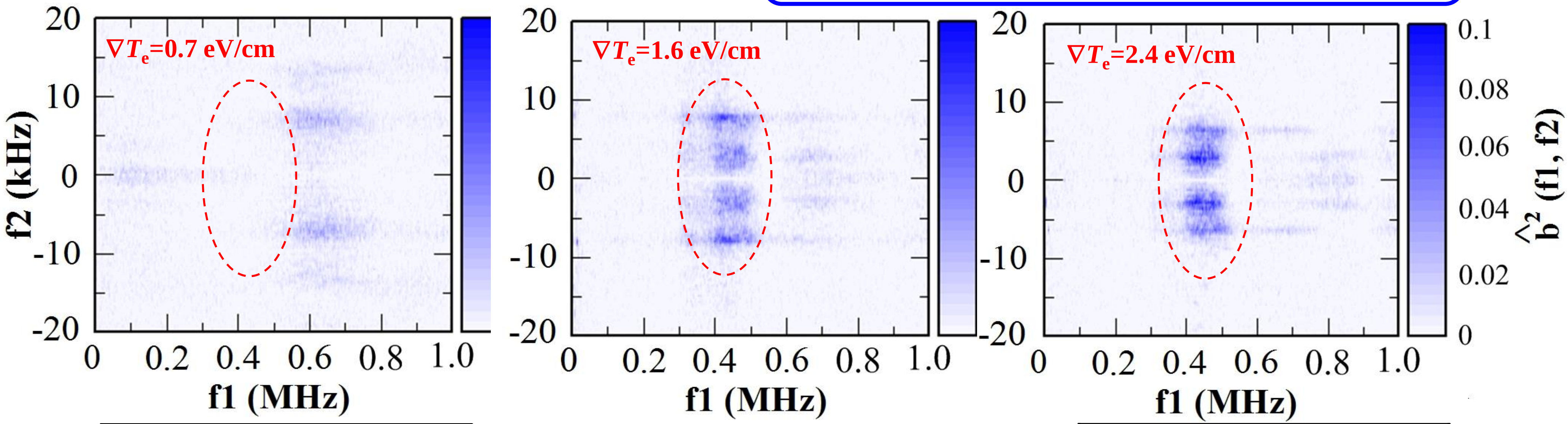


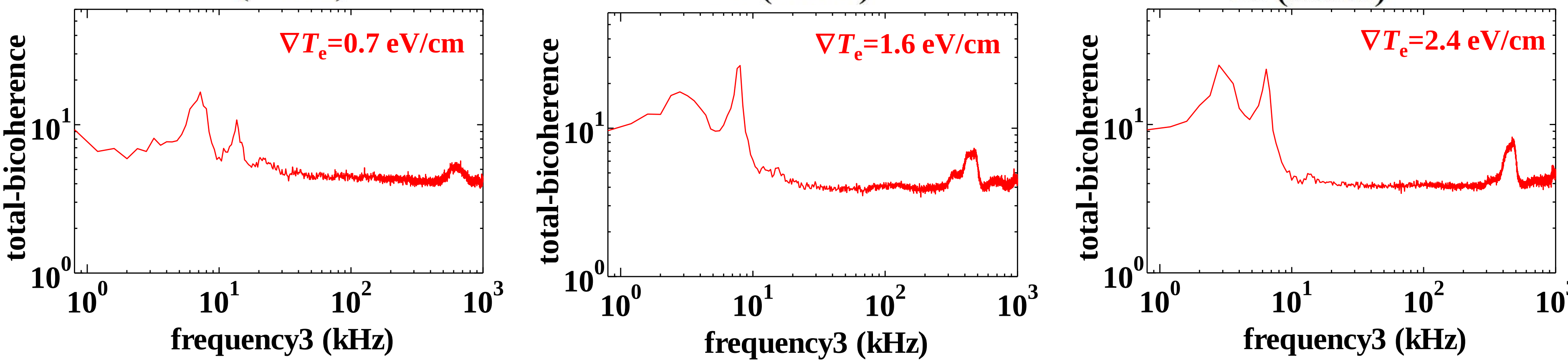
It is observed another low-frequency (~4 kHz) mode when the electron temperature gradient ∇T_e exceeds a certain threshold.

Bicoherence of the High & Low Frequency Fluctuations

Squared Bicoherence

P_{μ} = 20 W, V_{g1} = −10 V, V_{ee1} = −4.0 V, V_{ee2} = −1.5 V, r = −0.9 cm

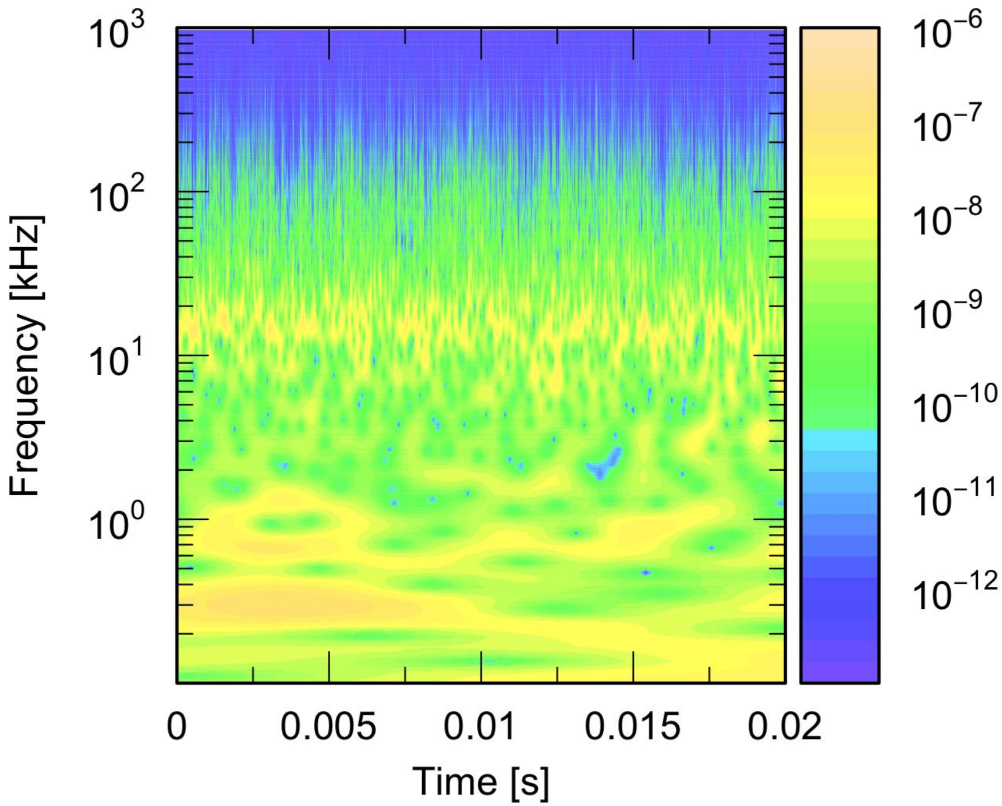




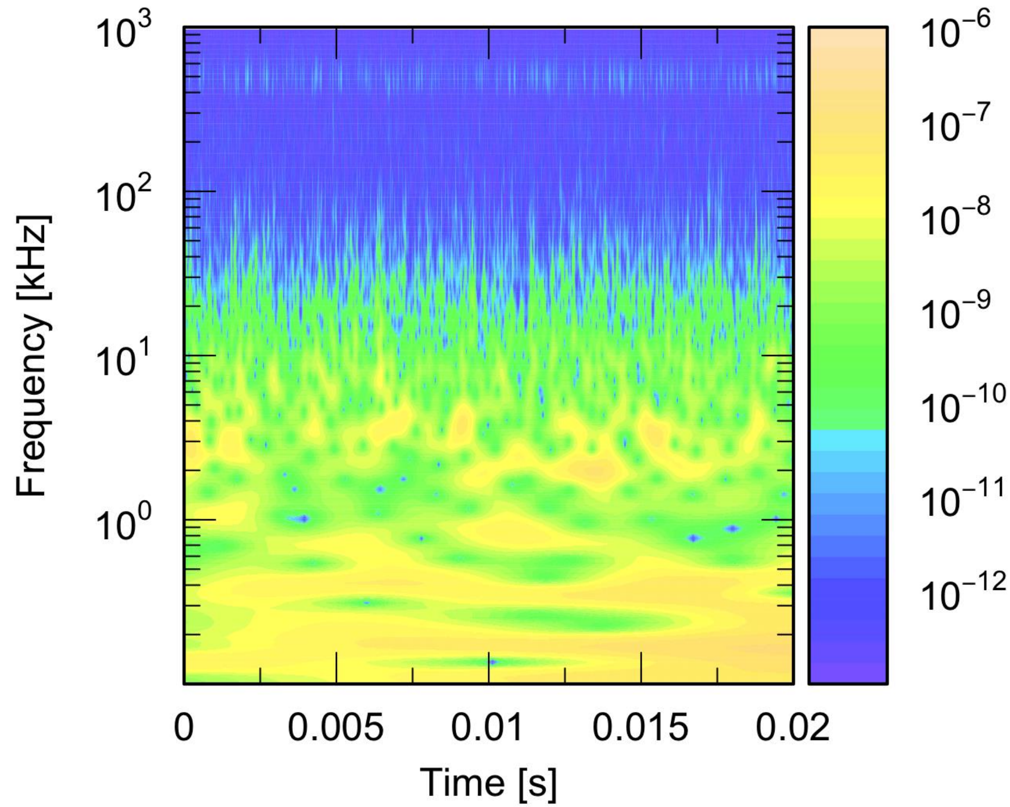
The nonlinear couplings between the ETG mode and the ion-scale Fluctuations become stronger as the magnitude of ETG is increased.

The Temporal Evolution of Fluctuations

P_μ = 20 W, V_{ee1} = −4 V, V_{ee2} = −1.5 V, V_{g1} = −10 V, r = −1.5 cm



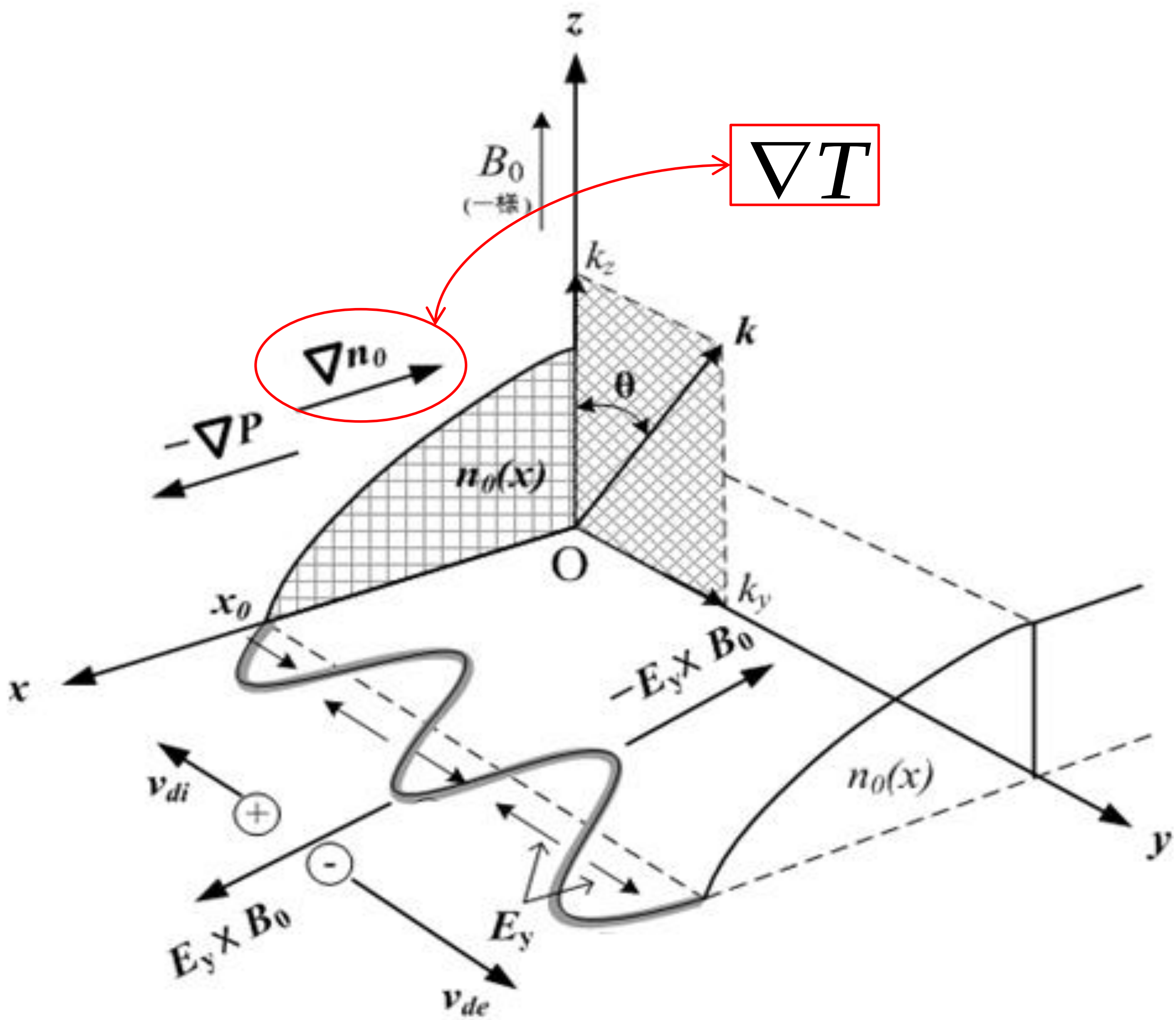
∇T_e = 0.7 eV/cm



∇T_e = 2.4 eV/cm

The modulation of ETG mode with low-frequency fluctuations is well observed when sufficient ETG is formed.

付録 1:ETGモードの機構



- 圧力勾配による力 F

$$F = -\nabla p_{e,i} / n_0 = -kT_{e,i} \nabla n_0 / n_0$$

$$p = nkT$$

ドリフト不安定性場合

$$\nabla p = Tk\nabla n$$

① わずがの波状の外乱.

② 正負電荷のドリフト運動が発生.

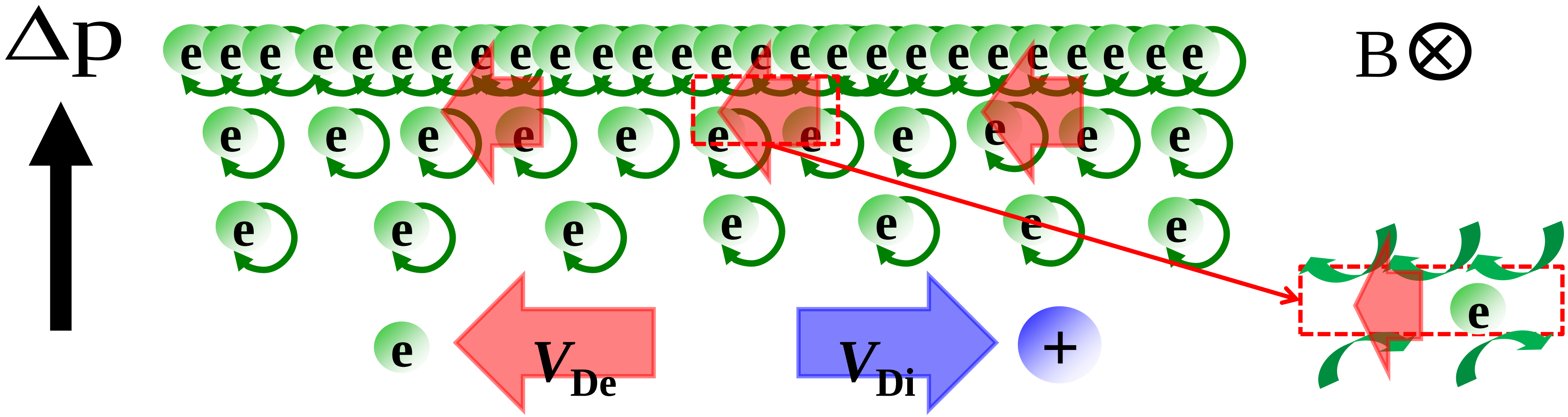
③ 荷電分離が生じて電界Eが誘起.

④ E×Bドリフトによってxの正負両方向に波状の変位が助長される.

ETG 不安定性場合

$$\nabla p = nk\nabla T$$

付録 2: 反磁性ドリフト



プラズマの圧力によって各粒子が受ける力は

$$\boldsymbol{F} = -\frac{1}{n}\nabla p$$

これは(仮想的な)反磁性ドリフトである。
これはイオンと電子に対してドリフトの方向が異なるため電流を生ずる。

$$V_{de} = -\frac{B\times\nabla p}{enB^2} = \frac{k_b T_e}{eB}\frac{n'}{n} = \frac{k_b T_e}{eB}\frac{T_e'}{T_e}$$

$$V_{di} = -\frac{B\times\nabla p}{enB^2} = \frac{k_b T_e}{eB}\frac{n'}{n} = \frac{k_b T_e}{eB}\frac{T_e'}{T_e}$$

これから反磁性電流は

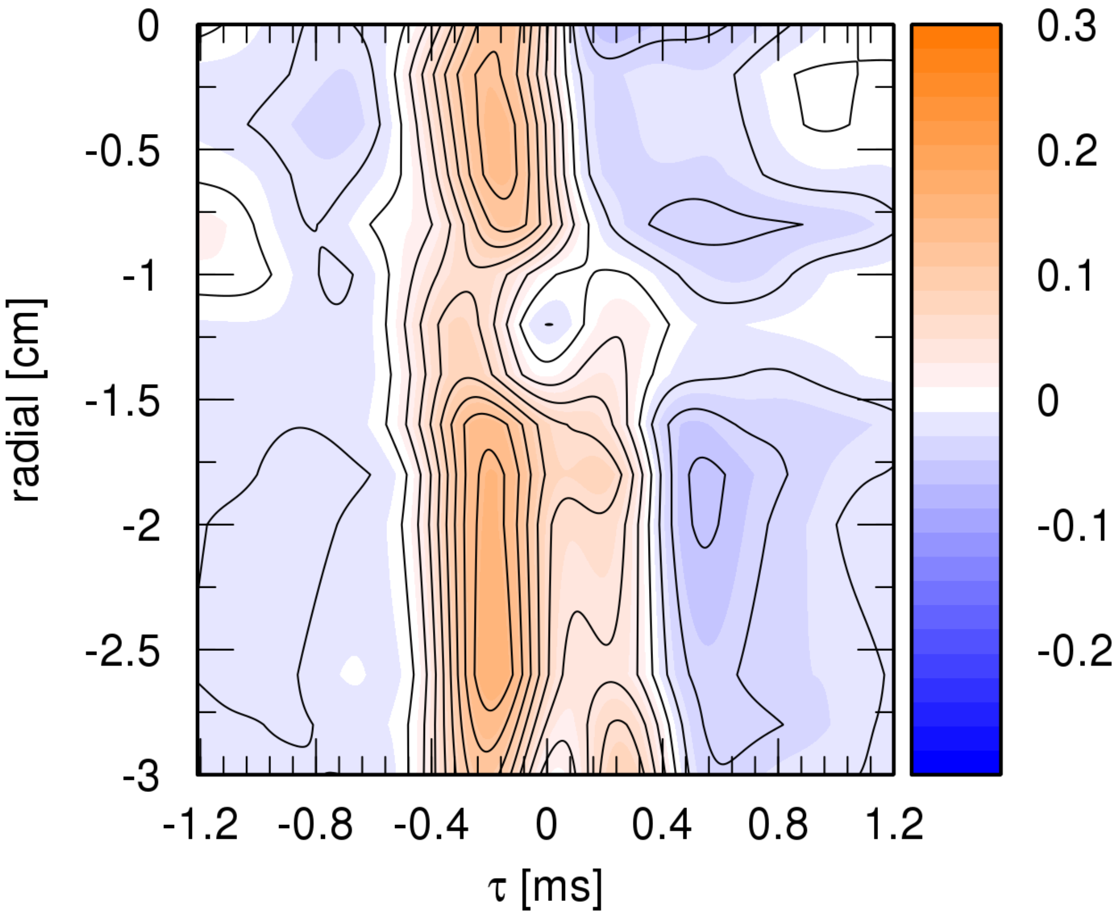
$$\boldsymbol{j}_D = ne(\boldsymbol{v}_{Di} - \boldsymbol{v}_{De}) = k_B(T_i + T_e)\frac{\boldsymbol{B}\times\nabla n}{B^2}$$

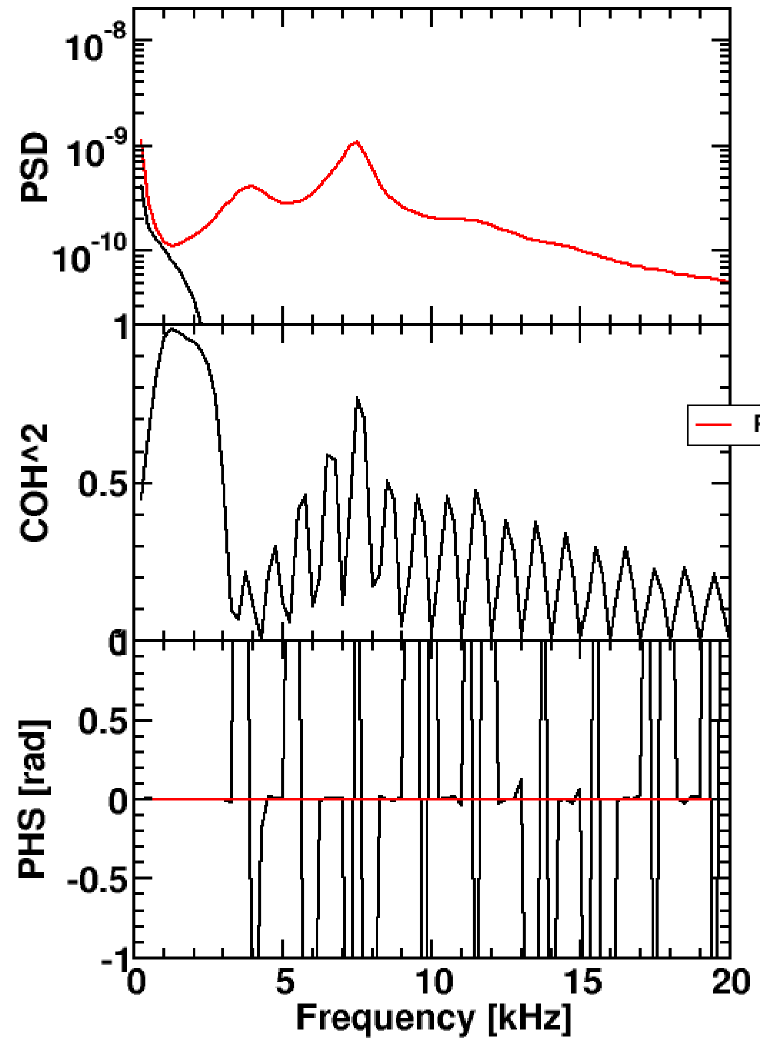
Summary

We investigate the effects of the radial electric field (E_r) on suppression of ETG mode through multiscale nonlinear interactions in linear magnetized plasmas.

- The formed ETG is found to excite a high-frequency fluctuation (~0.4 MHz), i.e., ETG mode, furthermore, the drift wave (DW) mode (~7 kHz), which is enhanced by the nonlinear coupling with the ETG mode.
- It is found that a sufficiently large E_r ($E \times B$ velocity shear) can suppress the ETG mode regardless of its signs.
- The ETG mode amplitude is decreased by the energy transfer of ETG mode to DW mode through the multi-scale non-linear coupling in the slightly negative E_r .

Nonlinear Energy Transfer





Summary

We investigate the effects of the radial electric field (E_r) on suppression of ETG mode through multiscale nonlinear interactions in linear magnetized plasmas.

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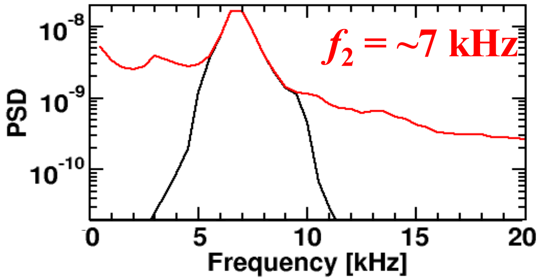
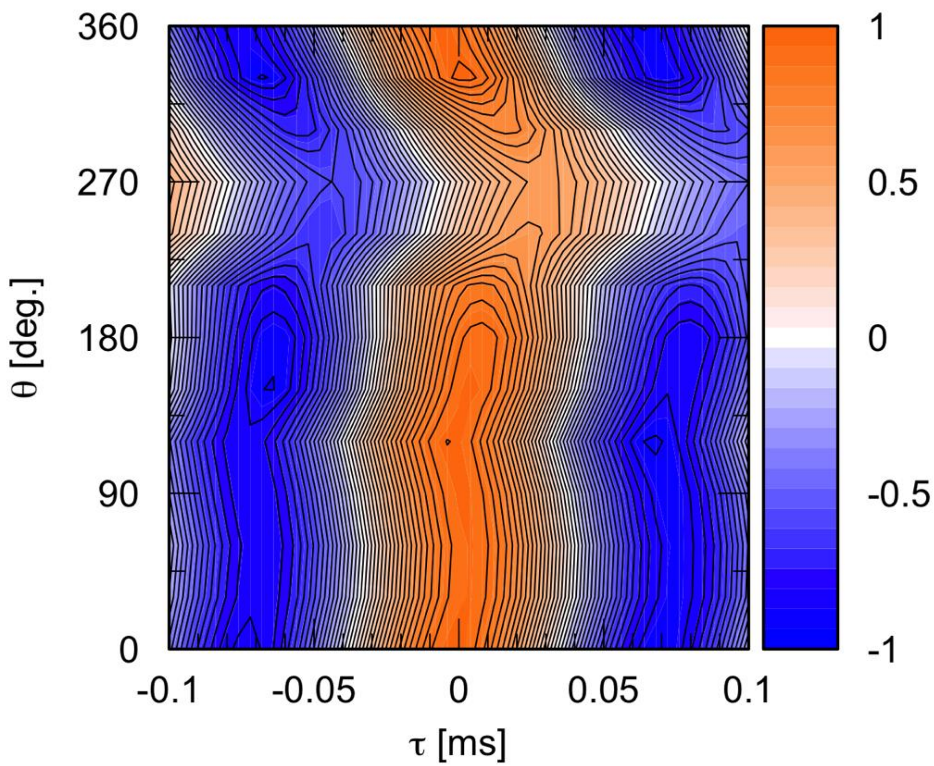
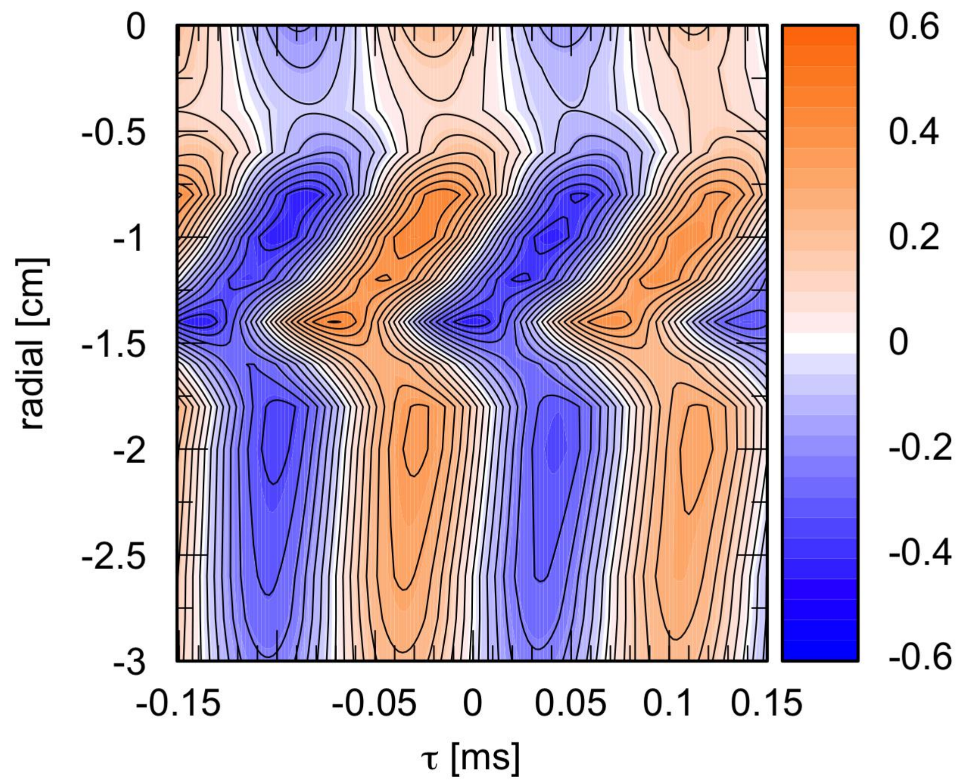
Spatial Structure of Low-frequency Fluctuations



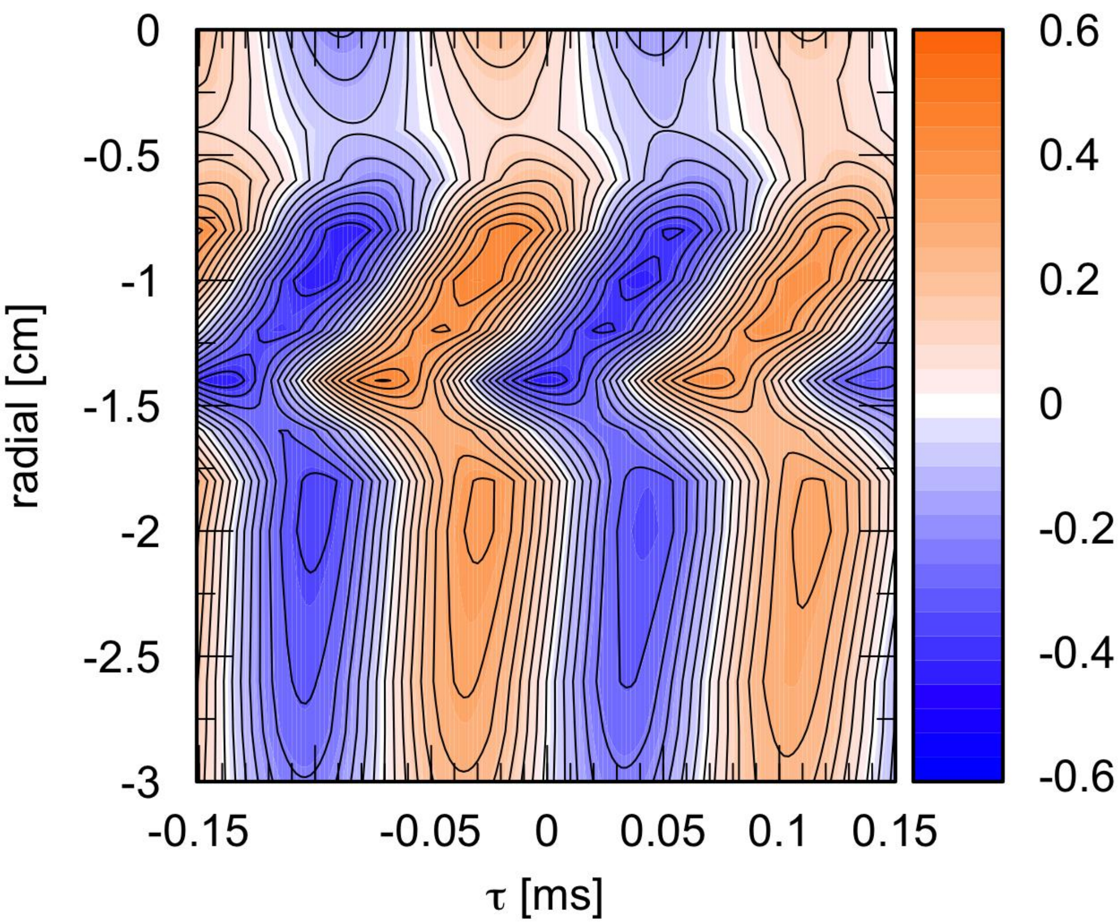
P_μ = 20 W, V_{g1} = −10 V, V_{ee1} = −4.0 V, V_{ee2} = −1.5 V, V_{g2} = −30 V (∇T_e = 2.4 eV/cm).

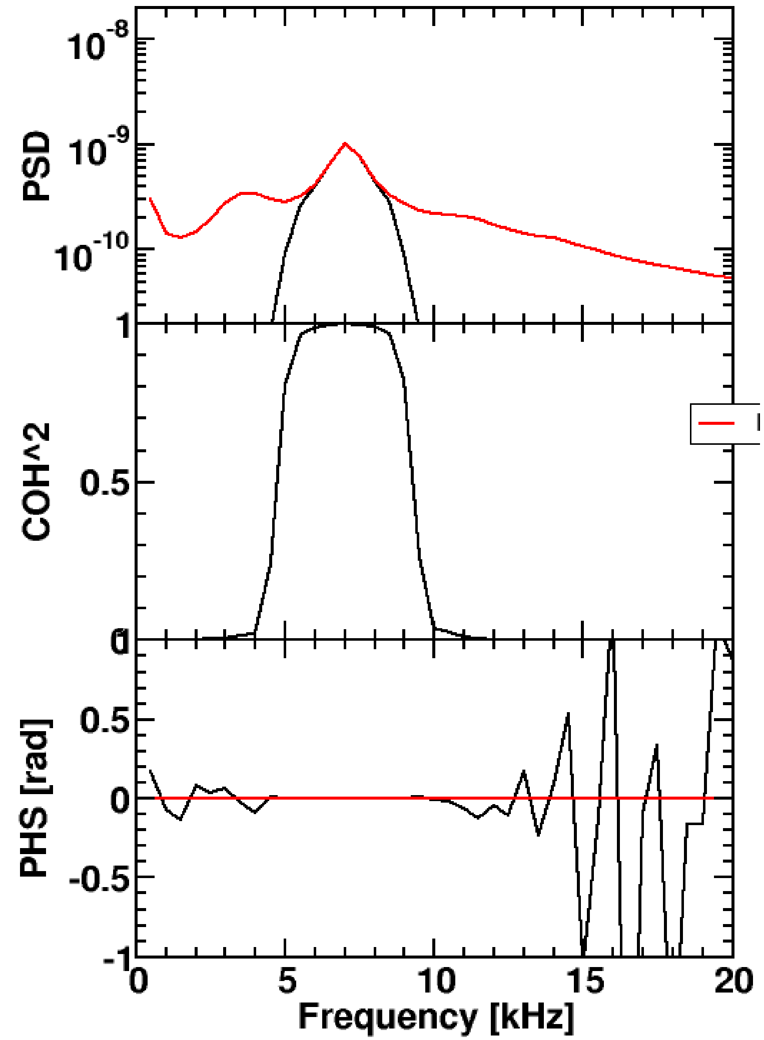




It is found that the fluctuations with $f \simeq 7$ kHz is parallel wave number $k_\parallel = 0$ that the energy of the DW mode is transferred to the flute mode through the nonlinear interaction.

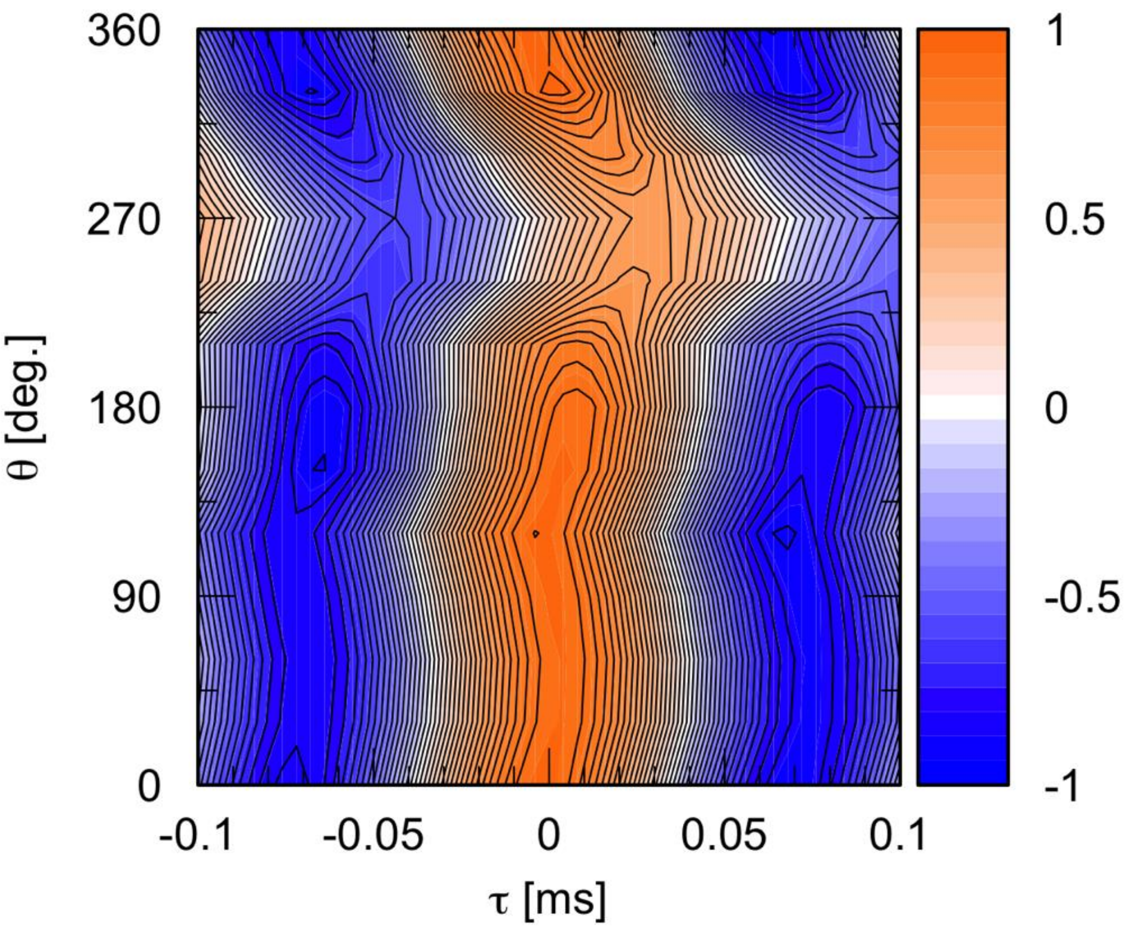
Nonlinear Energy Transfer

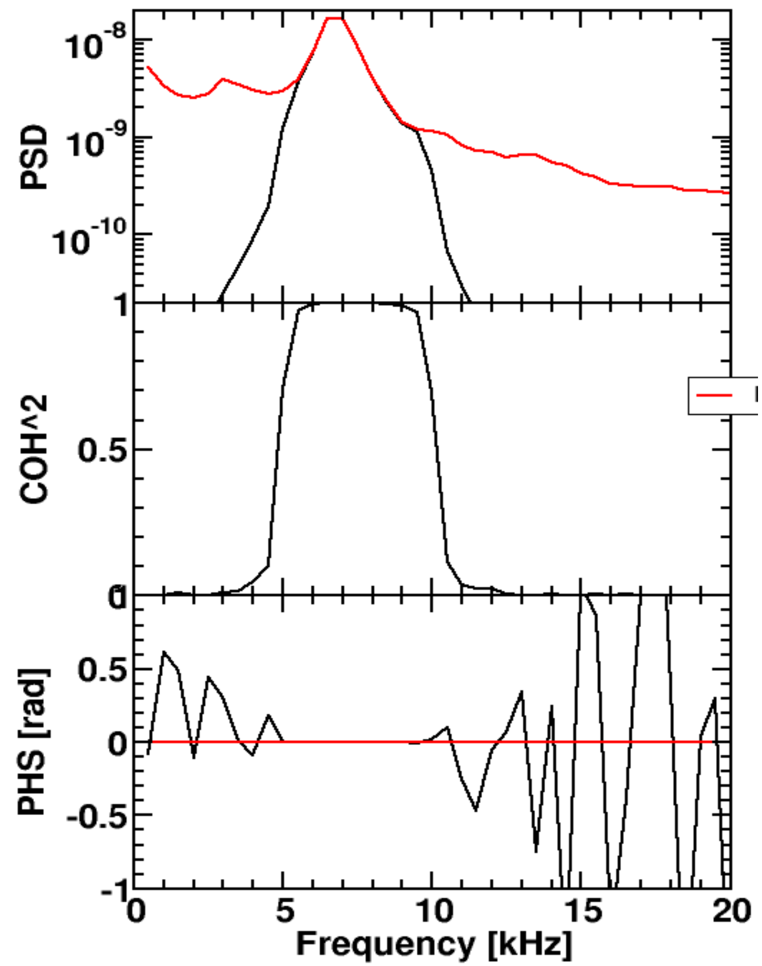




It is considered that the energy of the DW mode is transferred to the flute mode through the nonlinear interaction.

Nonlinear Energy Transfer





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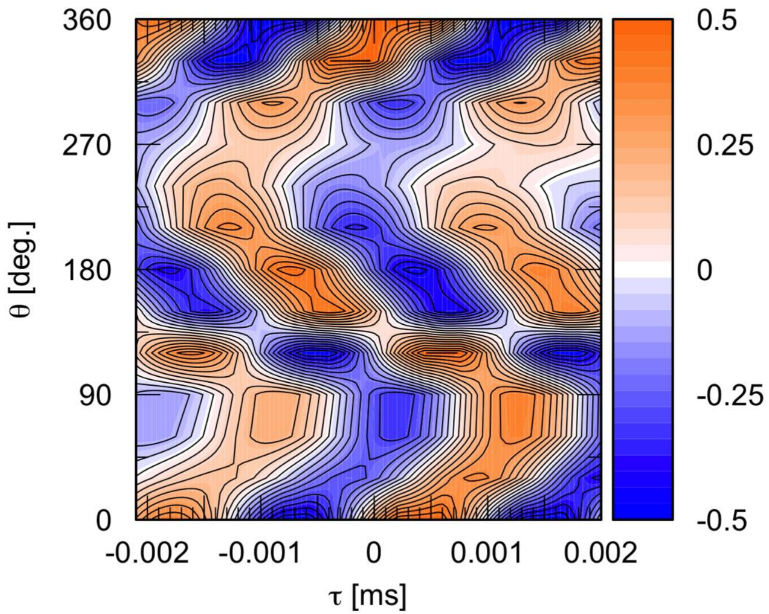
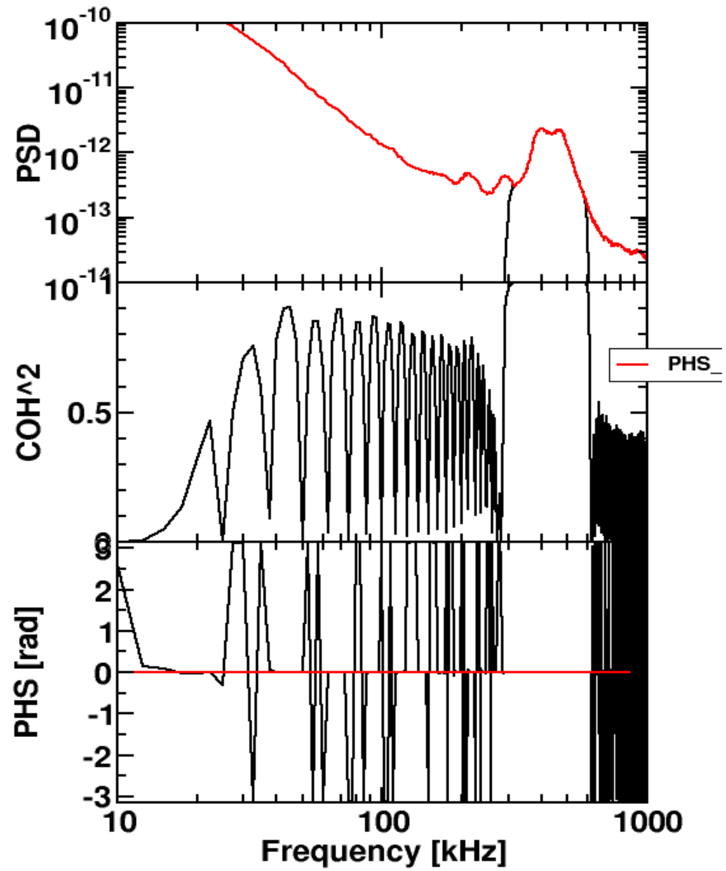
Nonlinear Energy Transfer





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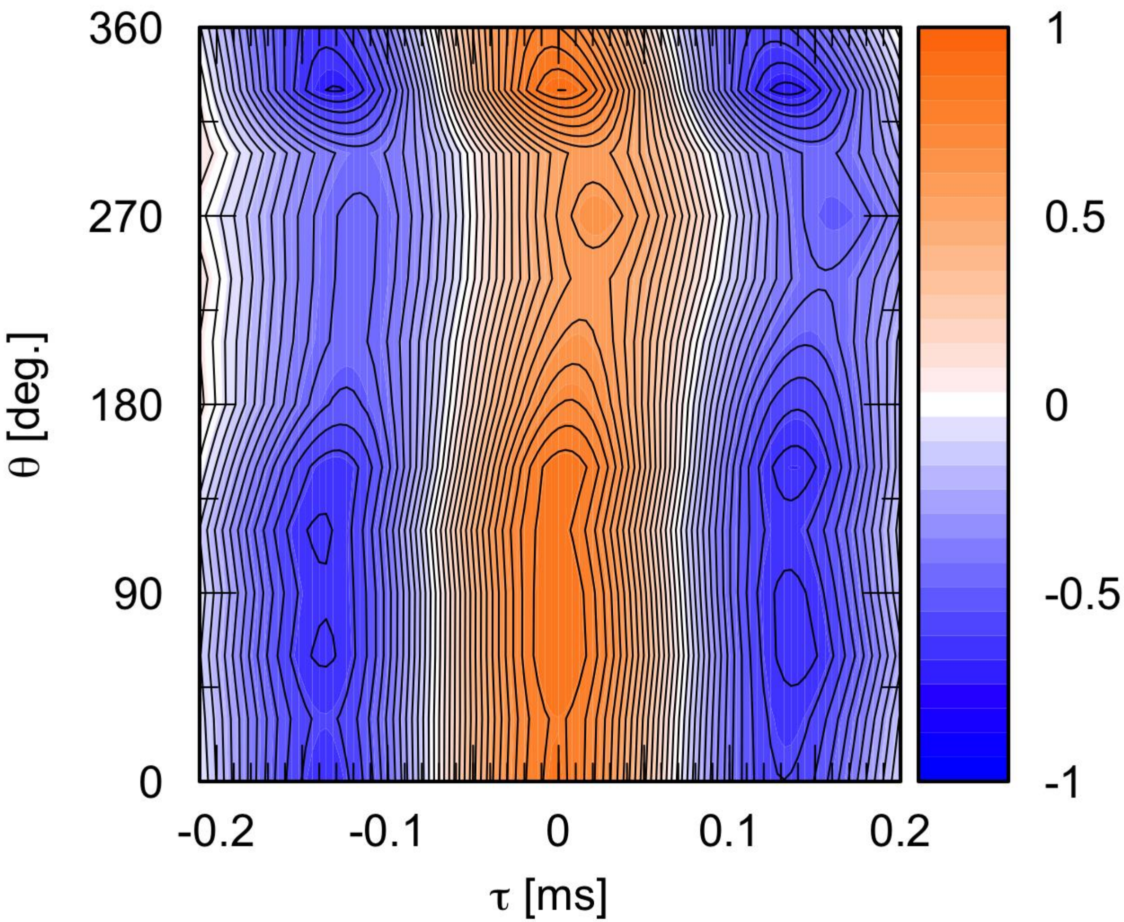
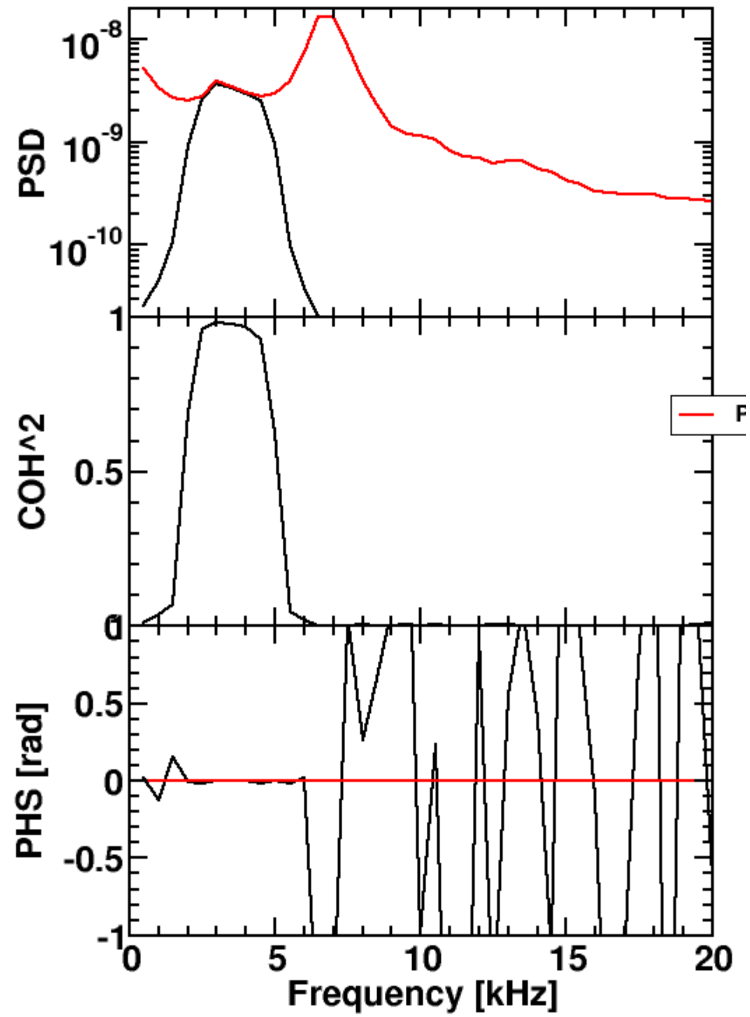
Nonlinear Energy Transfer





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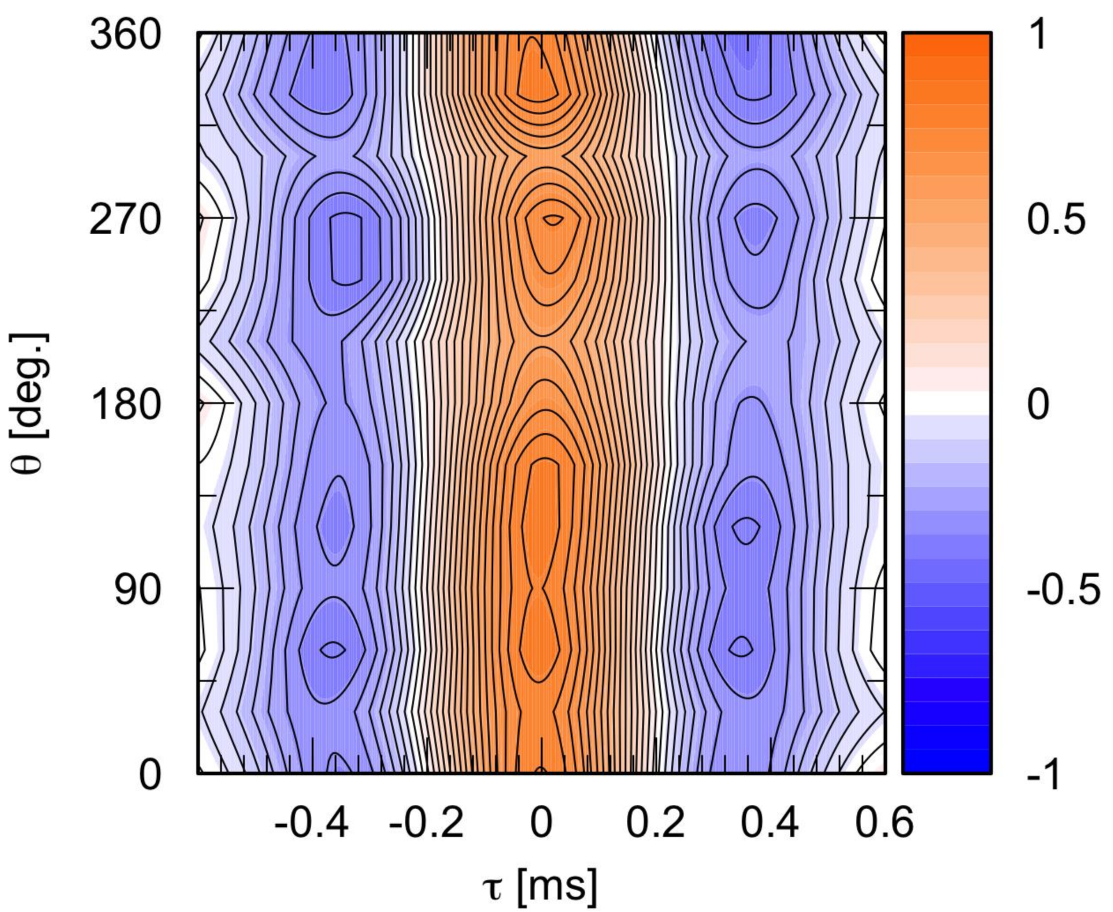
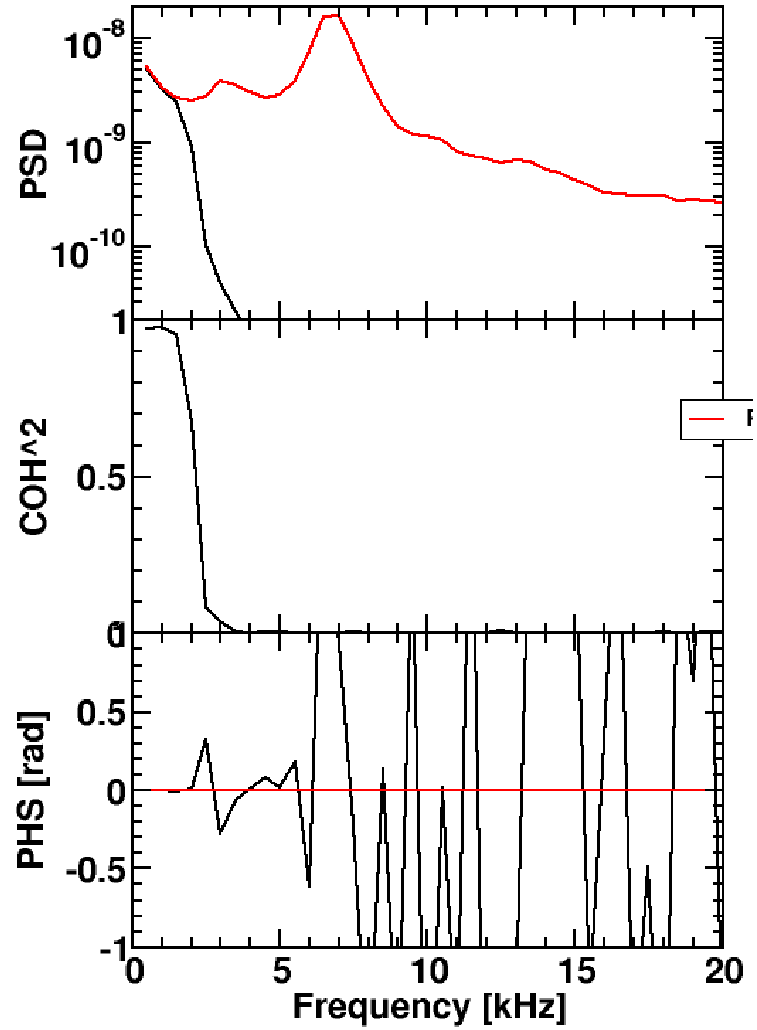
Nonlinear Energy Transfer





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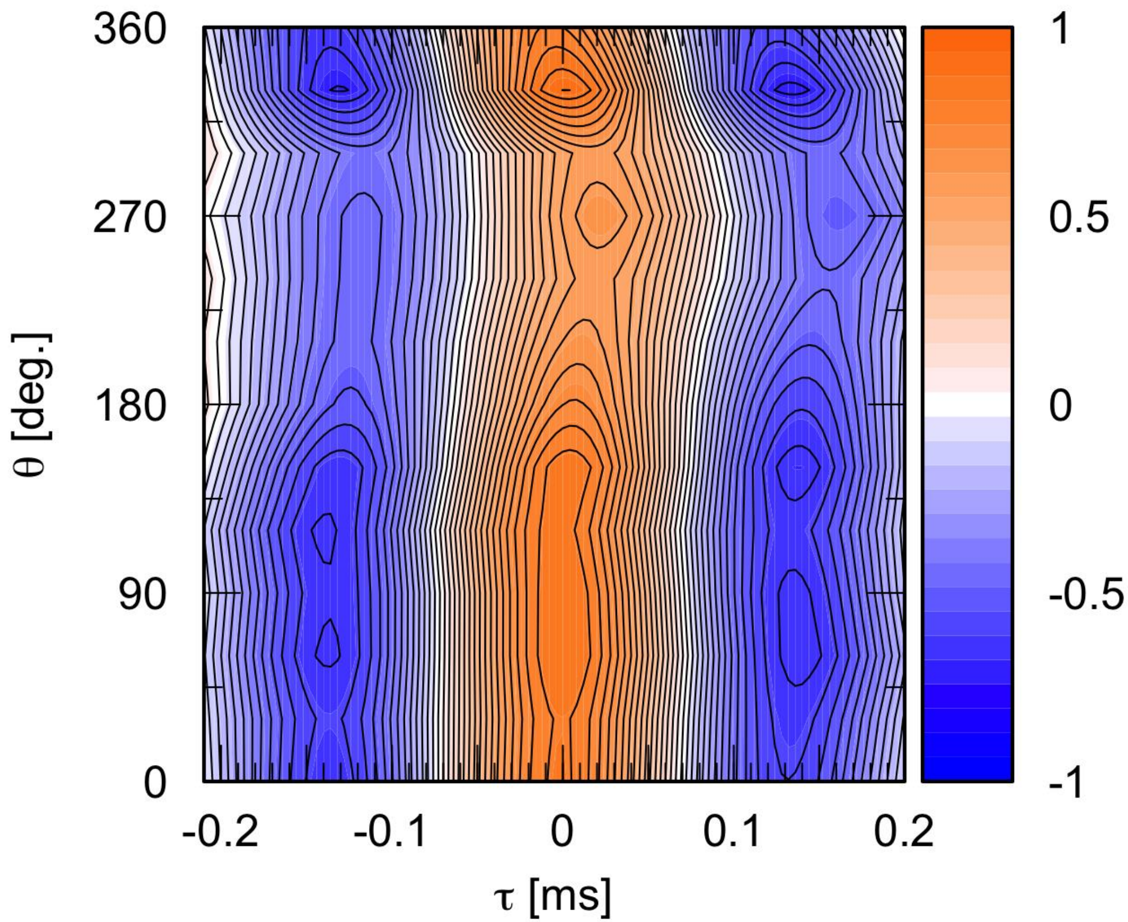
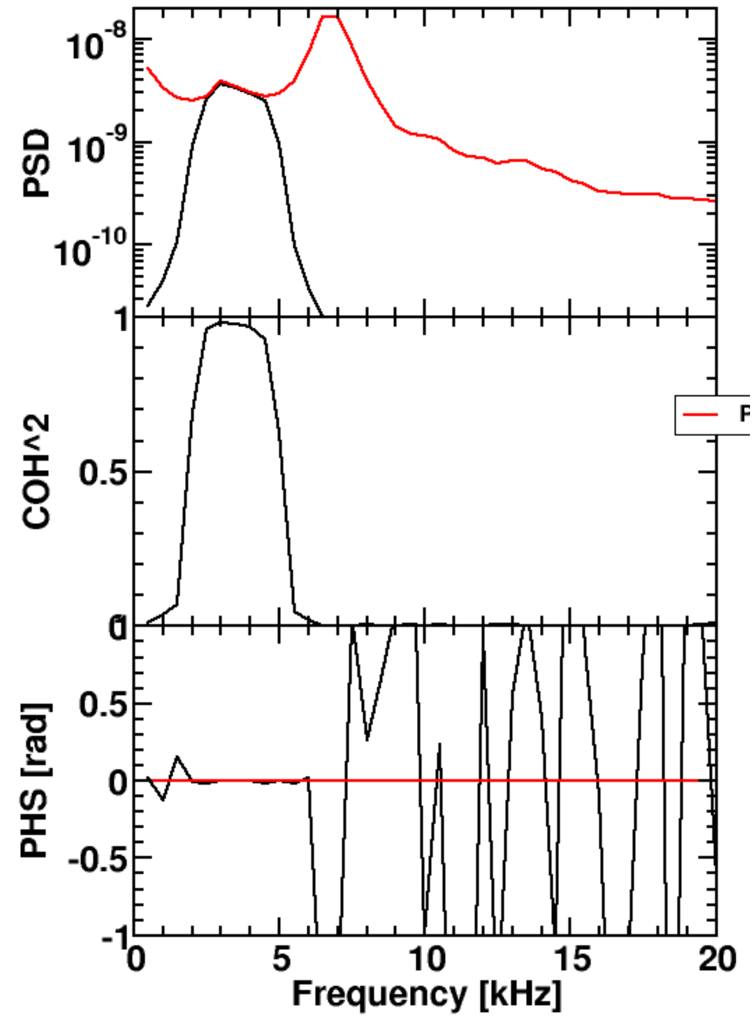
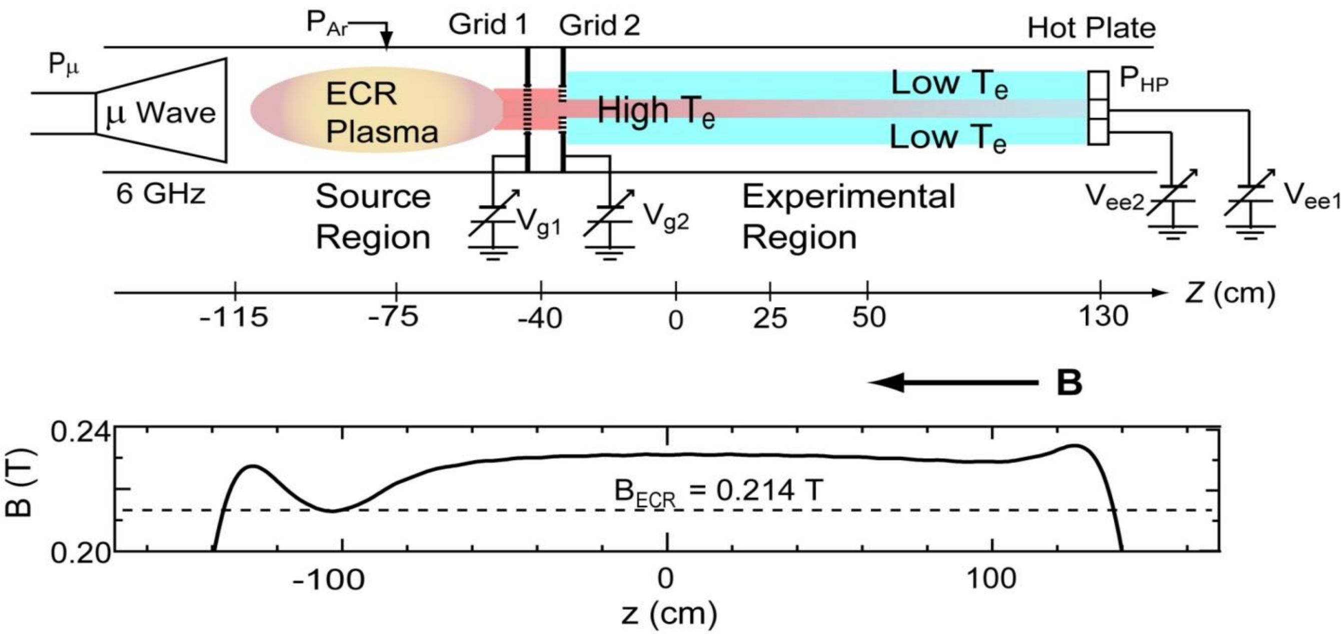
Nonlinear Energy Transfer



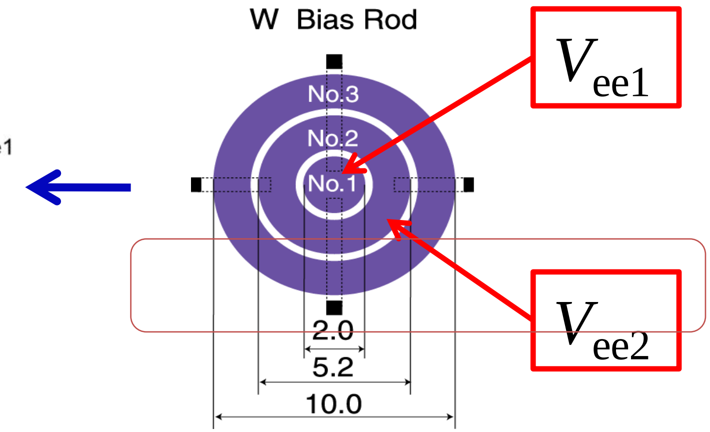


It is considered that the energy of the DW mode is transferred to the flute mode through the nonlinear interaction.

Effect of $E \times B$ Velocity Shear on ETG mode



Q_T **Upgrade Machine**



Electron emitter (W hot plate)

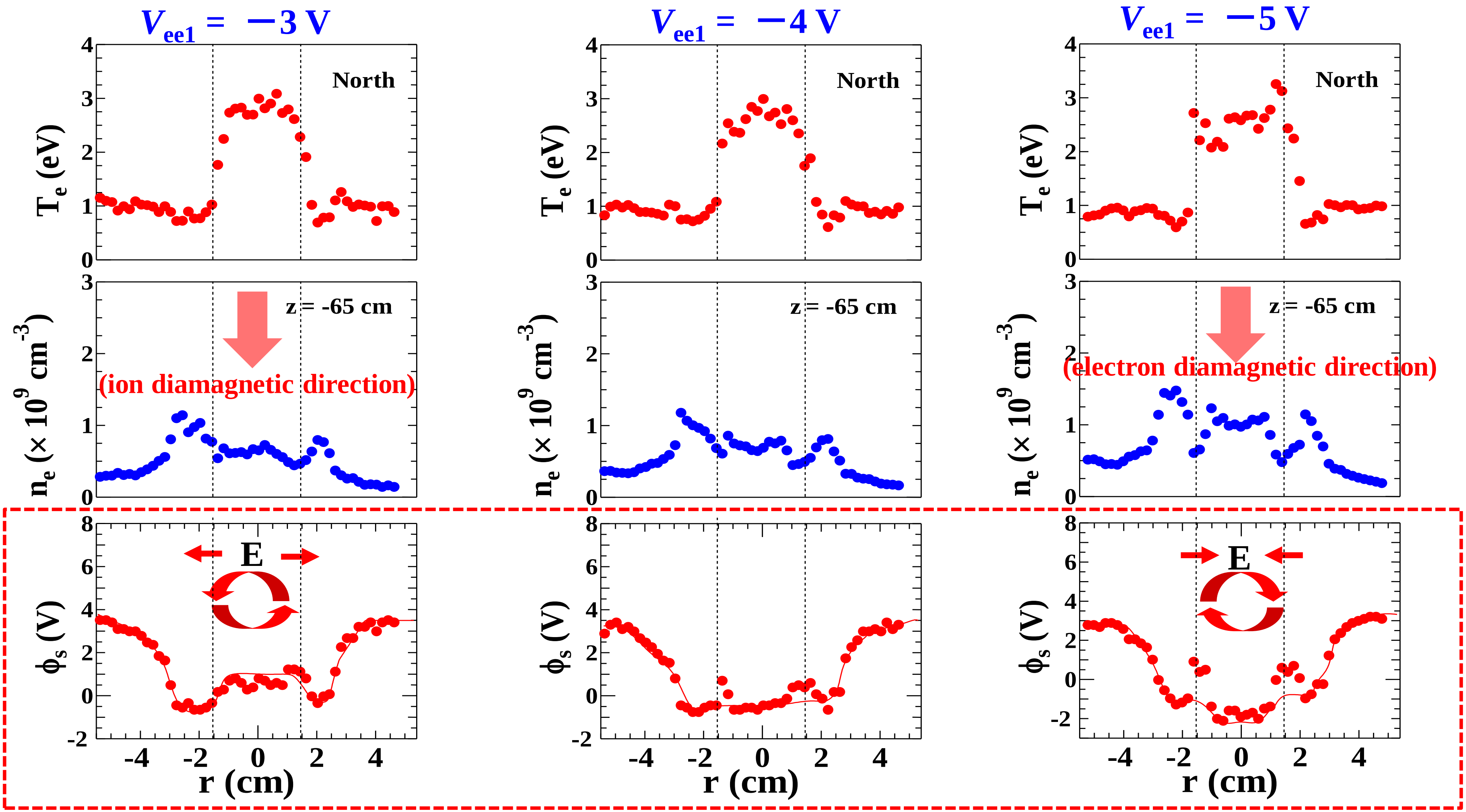
$$E_r = -\partial \phi(r)/\partial r$$

C. Moon, T. Kaneko, S. Tamura, and R. Hatakeyama, Rev. Sci. Instrum. **81** (2010) 053506.

Control of Radial Electric Field (E_r)

B ⊗

P_μ = 20 W, V_{g1} = −10 V, V_{g2} = −30 V, V_{ee2} = −1.5 V



$E_r \simeq$ 1.1 (V/cm)

$E_r \simeq$ −0.1 (V/cm)

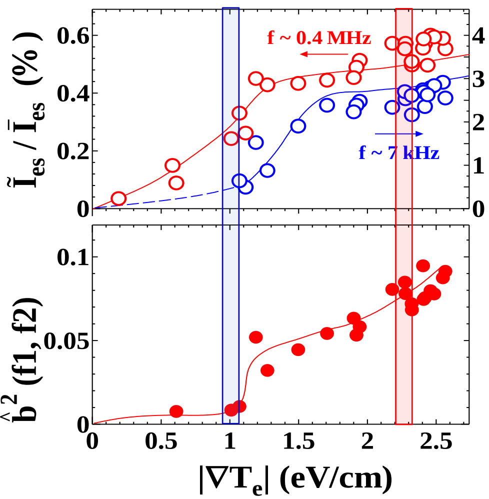
$E_r \simeq$ −1.0 (V/cm)

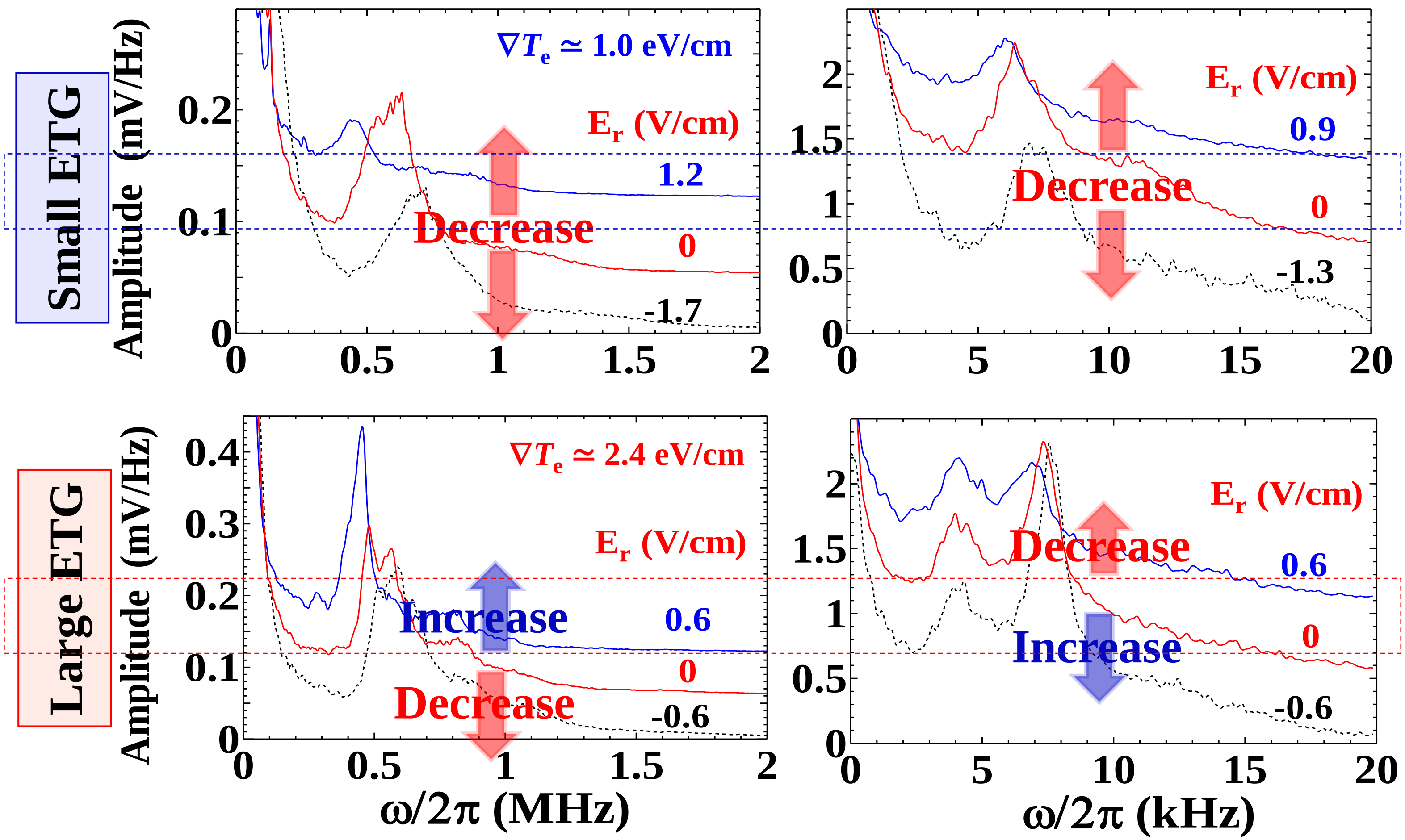
Effect of the E_r on Fluctuations

P_μ = 20 W, V_{g1} = −10 V,
V_{ee2} = −1.5 V, r = −0.9 cm

ETG mode | **Drift wave mode**

Nonlinear Coupling between ETG mode and Drift wave mode



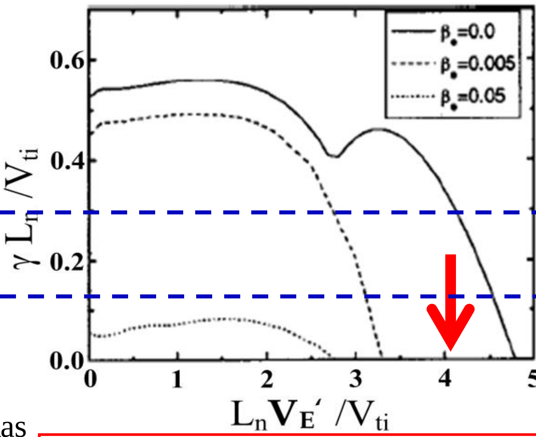


The effect of the E_r on ETG modes in the large ETG case is certainly different from the small ETG case.

Effect of the E_r on Fluctuations

Theories

ETG mode

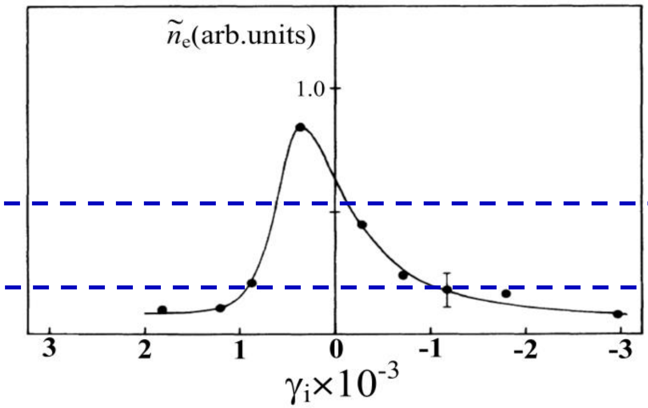


Z. Gao et al., Phys. Plasmas **11**, 3053 (2004).

V_E' : E × B Shear Strength

Experi.

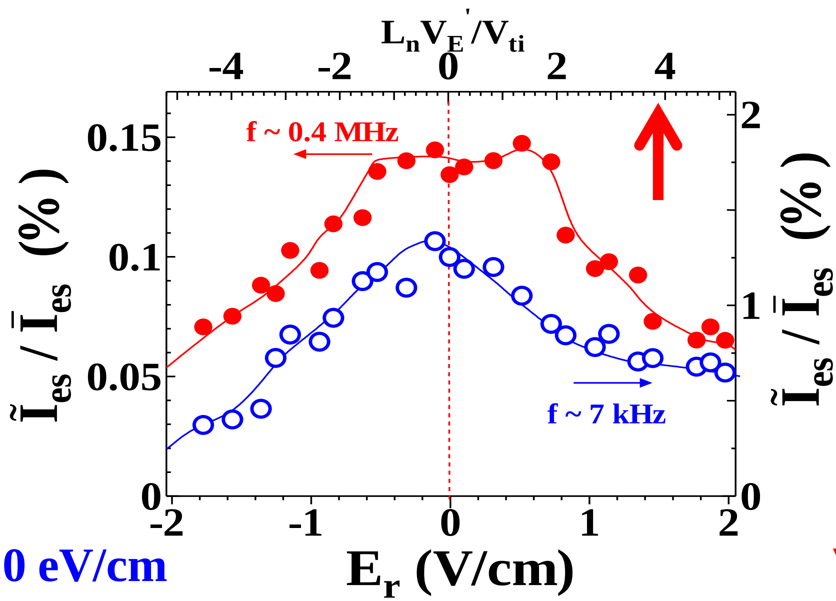
DW mode



A. Mase et al., Phys. Rev. Lett. **64**, 2281 (1990).

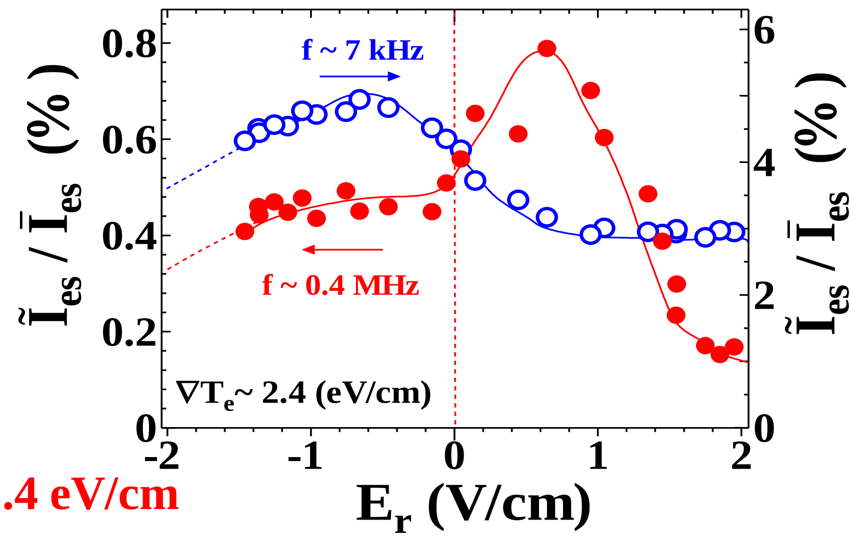
$\gamma_i \equiv -eE_r/m_i L_\phi \omega^2_{ce}$

Small ETG



$\nabla T_e \simeq 1.0$ eV/cm

Large ETG



$\nabla T_e \simeq 2.4$ eV/cm

The suppression tendency of ETG mode has a significant difference between the slightly negative E_r and positive E_r in the large ETG case.

Dependence of bicoherence on the E_r

Squared Bicoherence

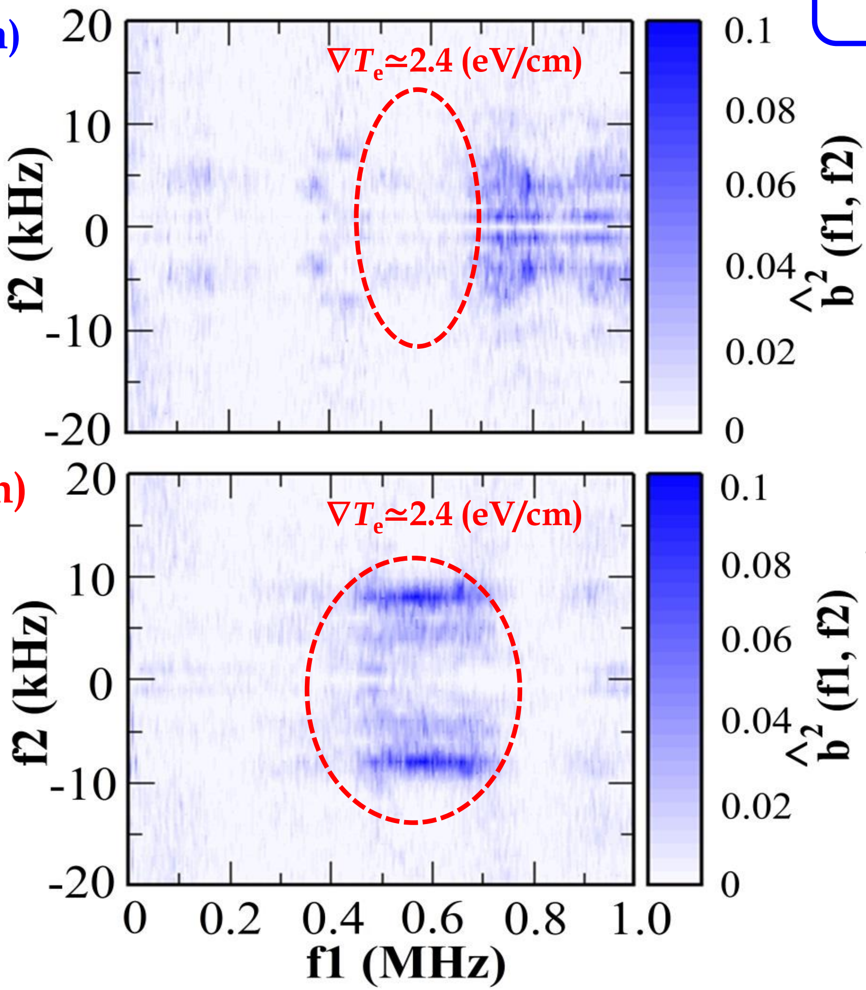
P_μ = 20 W, V_{g1} = −10 V, V_{g2} = −30 V, V_{ee2} = −1.5 V, r = −0.9 cm

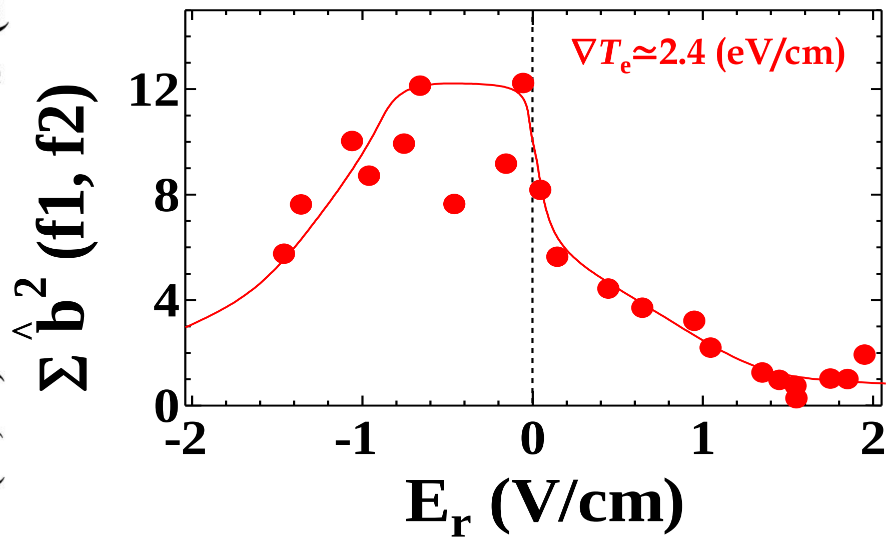
$E_r \simeq 1.5$ (V/cm)

Positive E_r

$E_r \simeq -1.0$ (V/cm)

Negative E_r





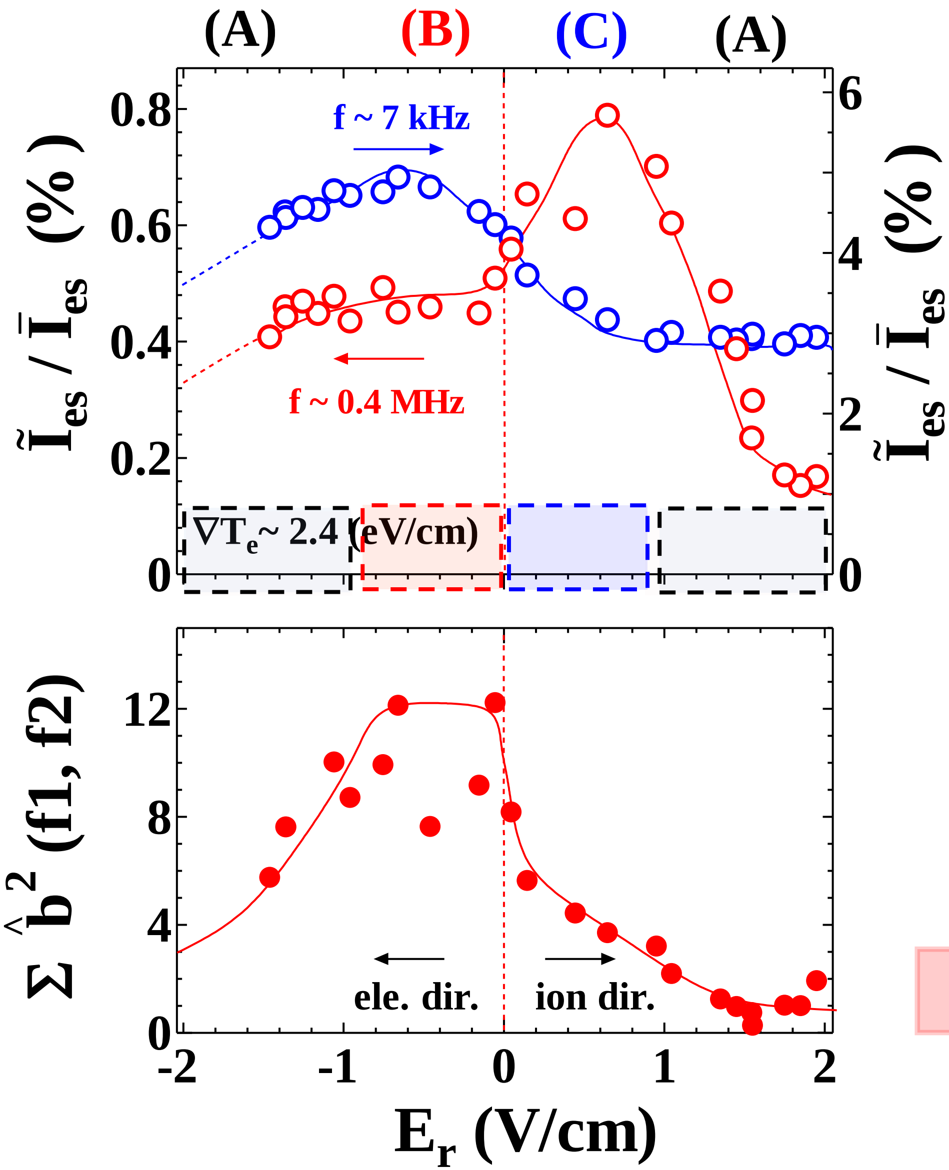
Total Bicoherence

(f0.4 ~ 0.7 MHz)

The nonlinear coupling between the ETG mode and drift wave mode become stronger when E_r becomes the slightly negative value.

Effect of E_r on the Nonlinear Interplay

P_μ = 20 W, V_{g1} = − 10 V, V_{g2} = − 30 V, V_{ee2} = − 1.5 V, r = −0.9 cm



(A) Suppression of ETG mode

=> Owing to the strong E_r Effects of $E \times B$ shear

(B) Suppression of ETG mode

=> Increasing the Nonlinear Interplay

=> Increasing the DW mode

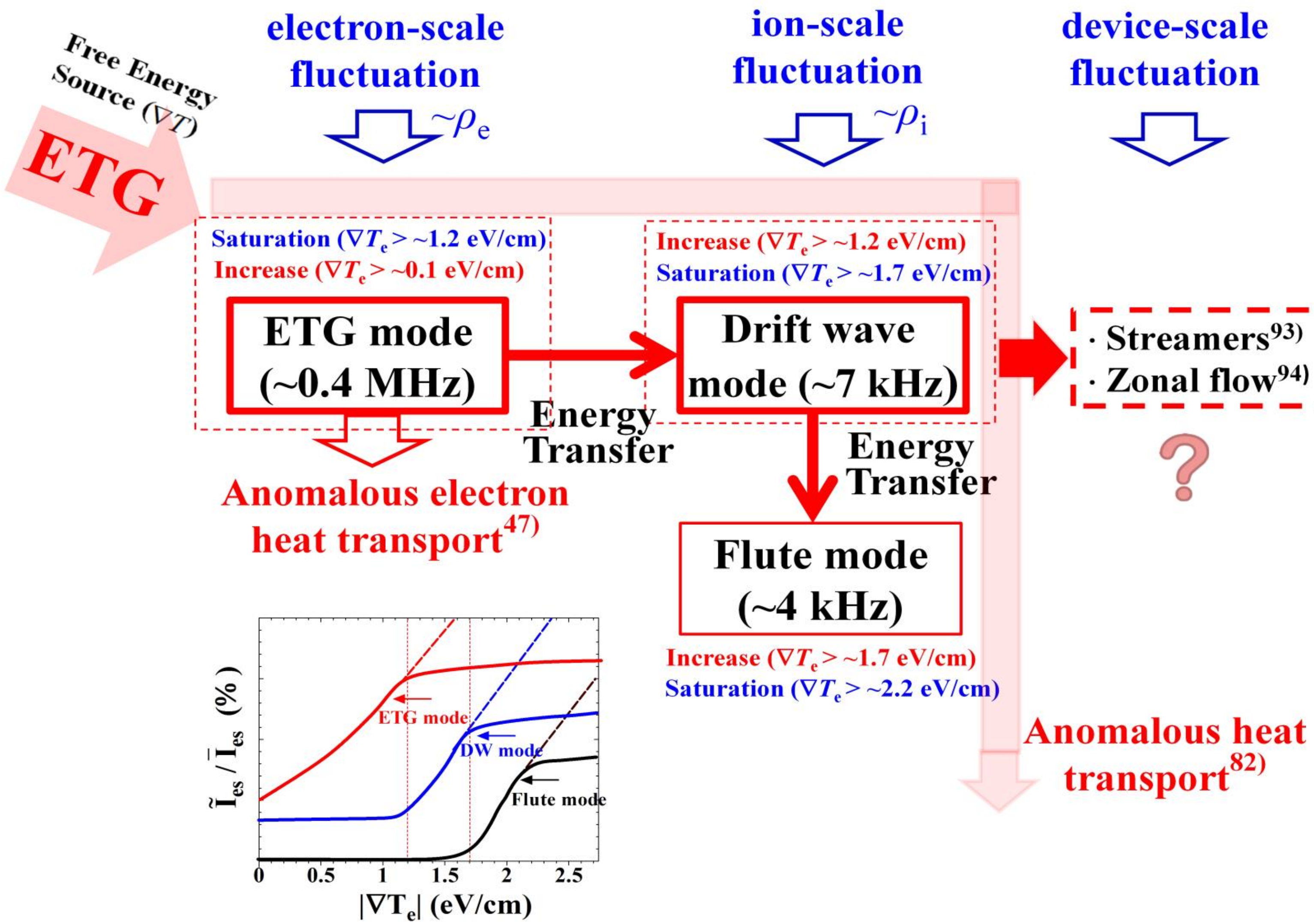
(C) Sustainment of ETG mode

=> Decreasing the Nonlinear Interplay

=>No energy transfer to the DW mode

The E_r affects the nonlinear interaction of the ETG and DW modes, which cause the resultant suppression of the ETG mode in the slightly negative E_r.

Effect of ETG on the Nonlinear Interplay



Ref

1) F.
2) C. Moon, et al., Phys. Rev. Lett. **111**, 115001 (2013).
3) Y. Nagashima, et al., Phys. Plasmas **16**, 020706 (2009).
4) T. Yamada, et al., Phys. Rev. Lett. **105**, 225002 (2010).