Mechanism of Low-Intermediate-High Confinement Transitions in HL-2A Tokamak

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Outline

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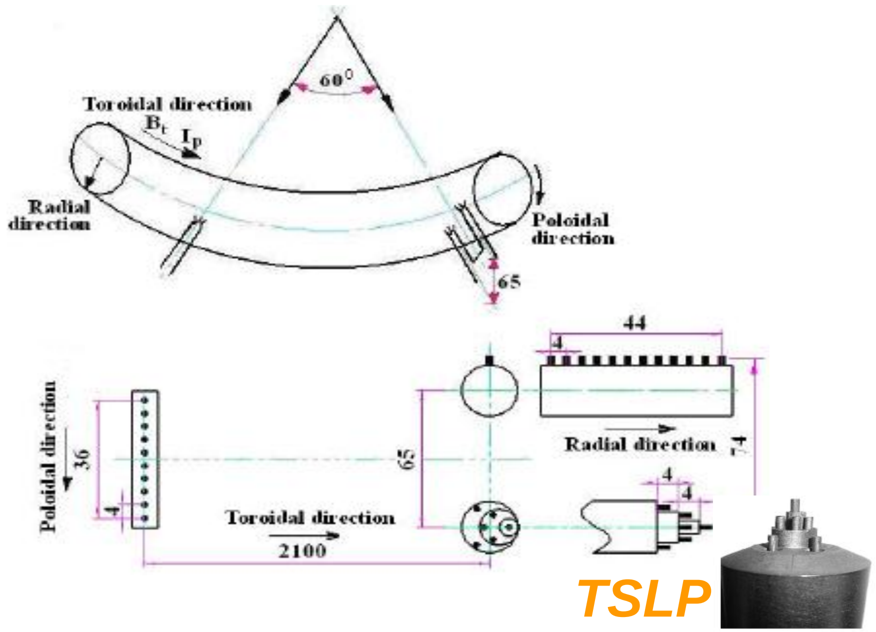
2. Experimental setup
3. Experimental results
4. Summary and discussion

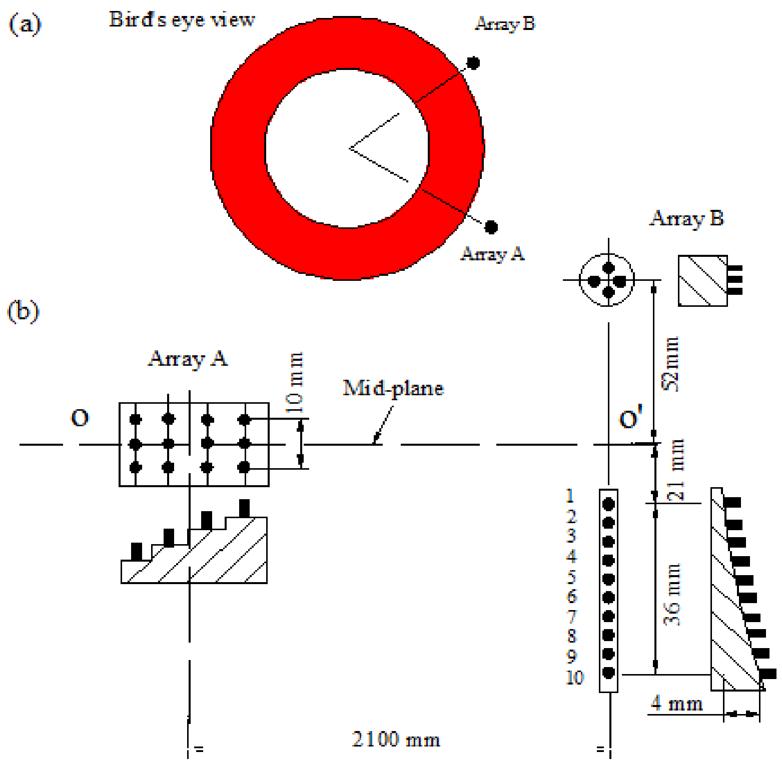
1. Introduction

- **Identification of the key plasma parameters, which control/determine the L-H transition and reveal its mechanism, has been a long term focus of investigation and a topic of interest.**
- **Understanding of transition physics is essential for assessing power threshold scaling and ensuring heating power requirements for future fusion reactors such as ITER.**
- **Study on dynamics of limit cycle oscillations (LCOs) with expansion of time scale provides an opportunity to investigate the subject quantitatively.**
- **The LCOs have been studied theoretically with predator-prey and bifurcation models, respectively.**
- **In experiment, spontaneous LCOs were observed on JET, JFT-2M, AUG, DIII-D, EAST, NSTX, H-1, and TJ-II.**
- **Mechanism, trigger and onset conditions of the L-I-H transitions are investigated on HL-2A tokamak.**

2. Experimental setup

3D Langmuir probe arrays





- Sampling rate = 1 MHz
- Spatial resolution= 3 mm
- Diameter of tips is 1.5 mm.
- Height of tips is 3 mm.

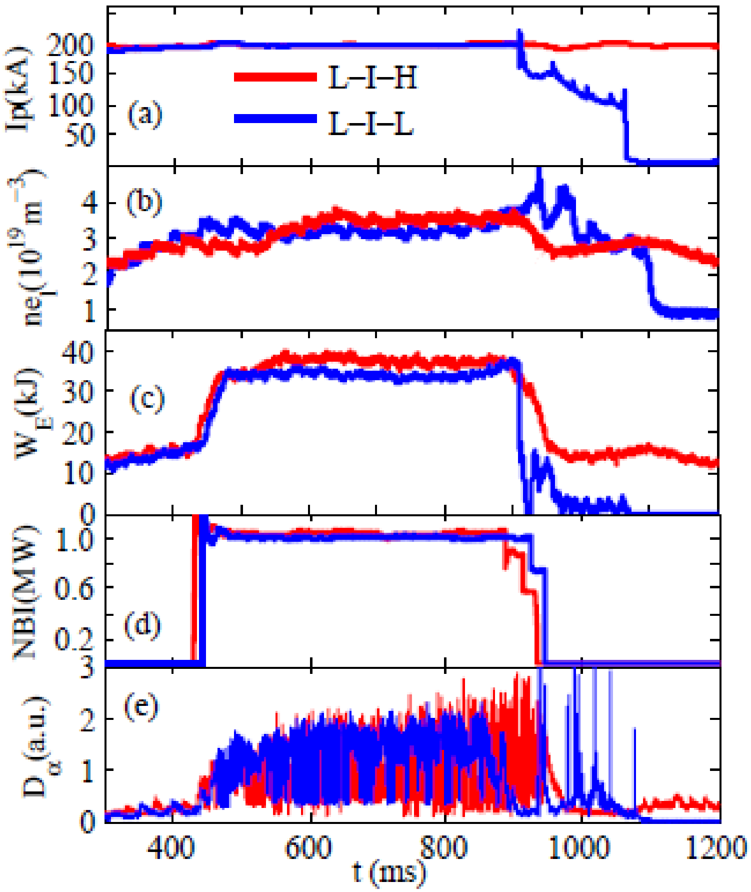
Parameters measured simultaneously:

$T_e, n_e, \phi_f, \tilde{n}_e, E_r, P_e, E'_r, P_e',$

etc. at a few radial and poloidal positions in two poloidal sections;

Complete data of edge turbulence in tokamak plasmas.

3. Experimental results



In the I-phases, all the fluctuations oscillate at same frequency of f_{LCO}~ 2.6 kHz which is identified to be close to the local Ion-ion collision frequency.

Shot I with L-I-H transitions

Bt=1.4 T, Ip=180 kA

P_{NBI}=1.0 MW

$$\bar{n}_e = (2.8-3.2)\times 10^{19} m^{-3}$$

Shot II with L-I-L transitions

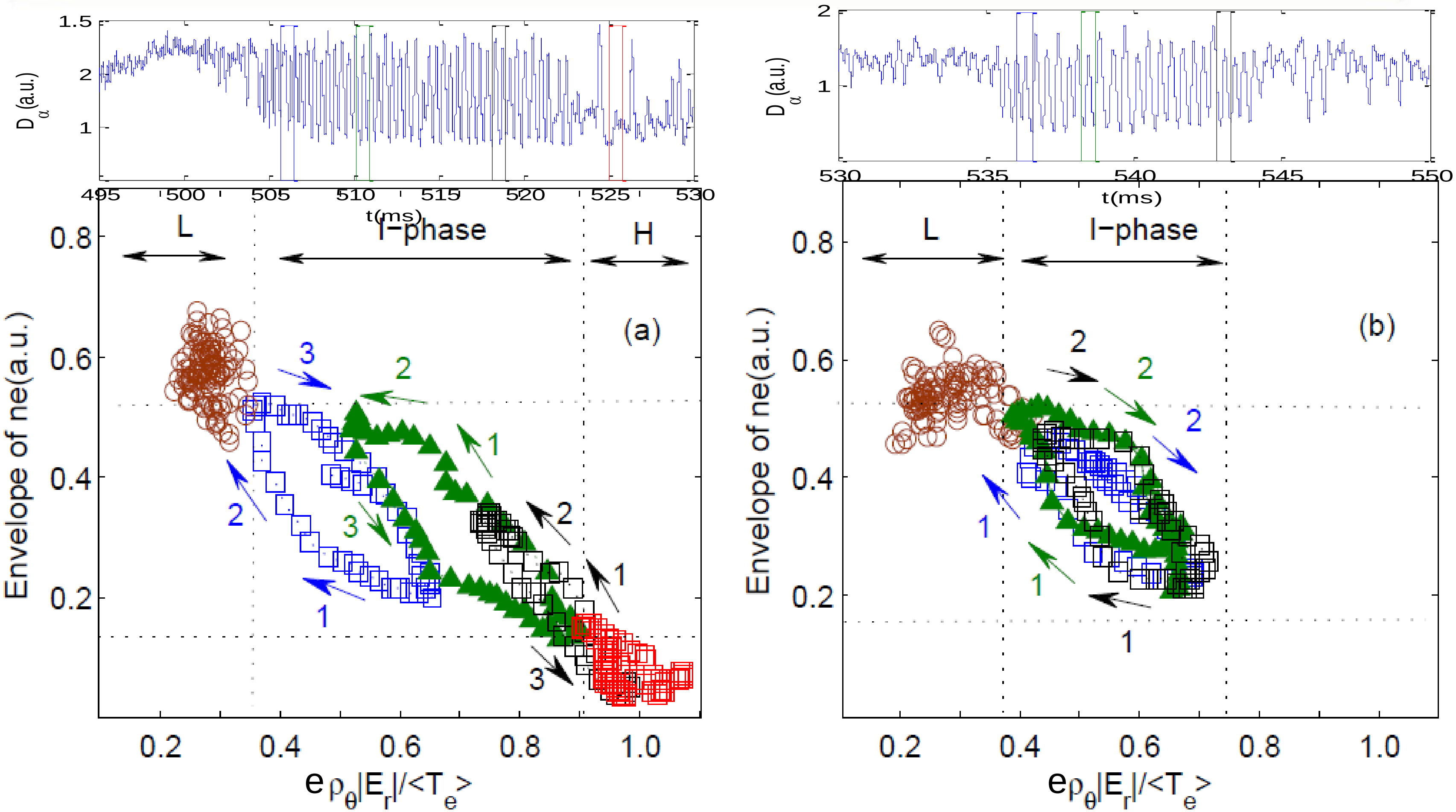
Bt=1.4 T, Ip=185 kA

P_{NBI}=1.0 MW

$$\bar{n}_e = (2.5-3.0)\times 10^{19} m^{-3}$$

- Strong turbulent fluctuations of floating potentials and densities, and weak radial electric fields in the L-modes.
- Weak fluctuations of floating potentials and densities but strong radial electric fields in the I-phases.
- Rather weak fluctuations of floating potential and density but very strong radial electric field in the H-mode.

LCO in L-I-H & L-I-L transitions

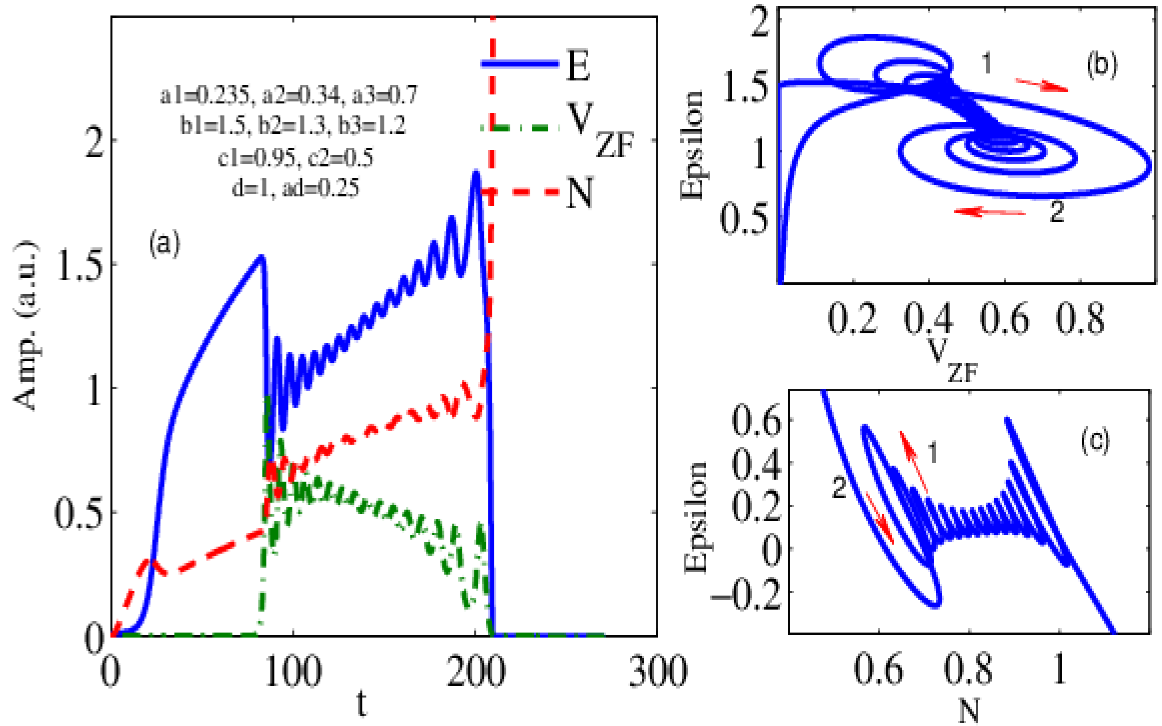


t=506-506.5 ms, t=510-510.5 ms, t=518-518.5 ms, t=525-525.5 ms.

t= 536-536.5 ms, t=538.5-539 ms, t=543-543.5 ms.

[Cheng & Dong et al., PRL 110, 265002 (2013)]

Brief numerical analysis of LCOs



$$\frac{\partial \varepsilon}{\partial t} = N\varepsilon - a_1\varepsilon^2 - a_2V^2\varepsilon - a_3V_{zf}\varepsilon - a_dV\varepsilon,$$

$$\frac{\partial V_{zf}}{\partial t} = \frac{b_1\varepsilon V_{zf}}{1+b_2V^2} - b_3V_{zf},$$

$$\frac{\partial N}{\partial t} = -c_1\varepsilon N - c_2N + Q,$$

$$V = dN^2.$$

Kim, E.J.et al., 2003, PRL. 90185006.

(a) ε, V_{zf} and N as functions of Q=0.01 t,

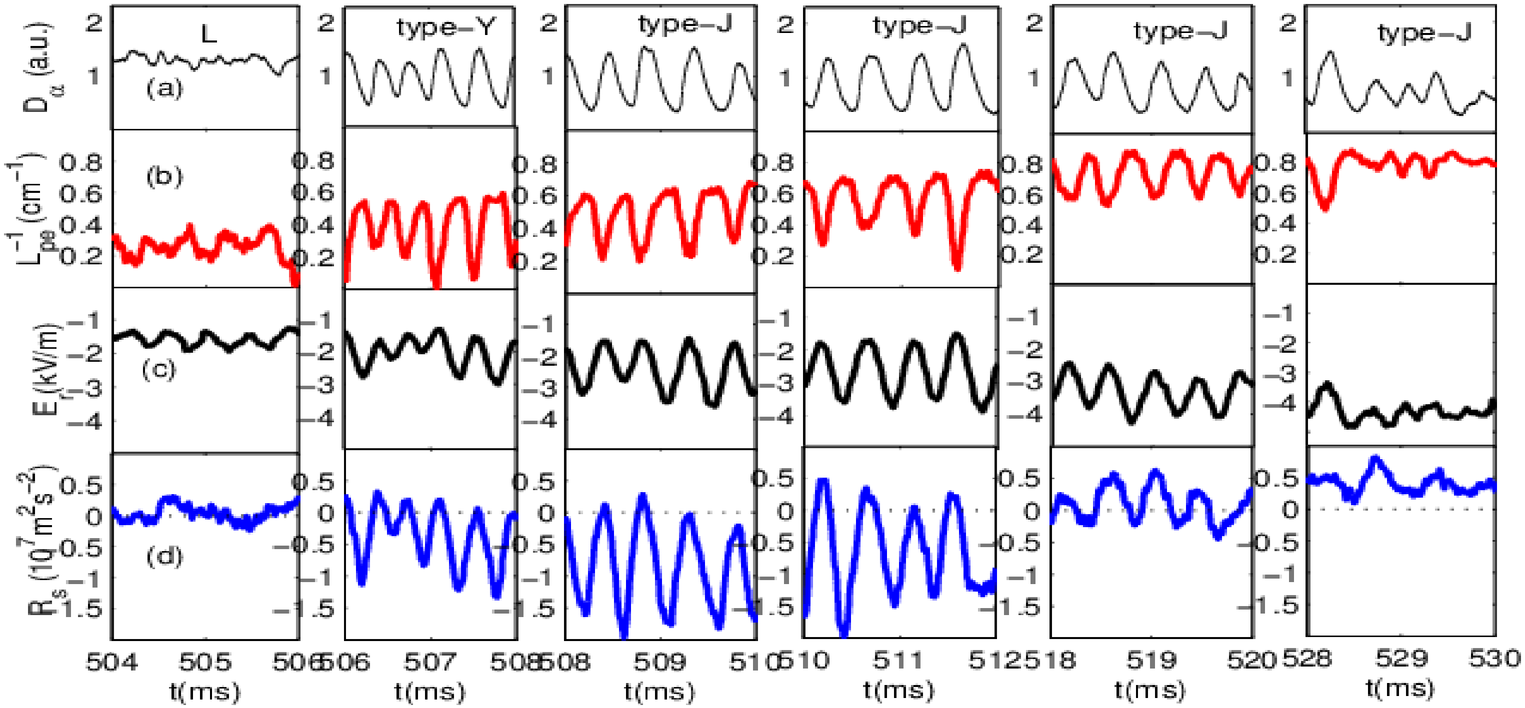
(b) the Lissajous diagram for ε vs. V_{zf} type-Y,

(c) the Lissajous diagram for ε vs. N type-J,

Plausible loops for LCOs and I/L-H transition

Green for type-Y (CW) LCO,
Red for type-J (CCW) LCO,
yellow for I/L-H transition

LCOs of plasma parameters in L-I-H transitions

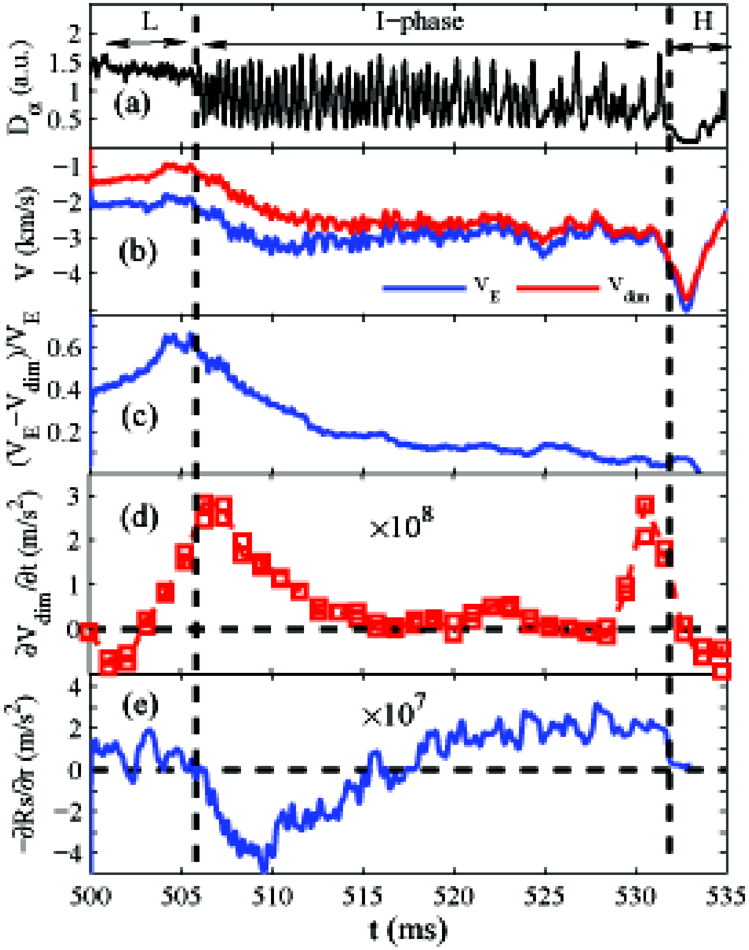


•The temporal evolutions of (a) D_α emission, (b) inverse of the electron pressure gradient scale length $1/L_{pe}$, (c) the radial electric field E_r, and (d) the Reynolds stress R_s.

• $1/L_{pe}$ and $|E_r|$ gradually increase; their oscillations are in phase

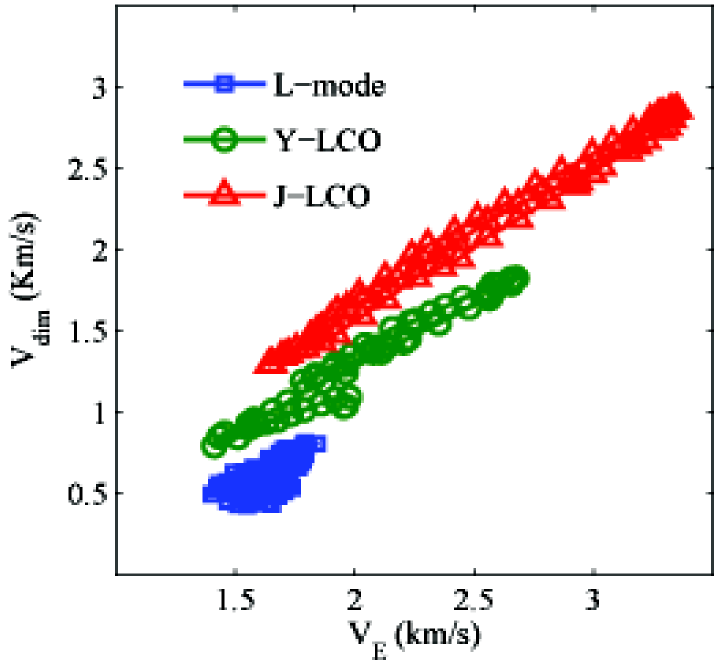
•R_s is high/low and in/out of phase with $|E_r|$ in early/late LCO phase,

E×B and diamagnetic flows averaged over LCOs



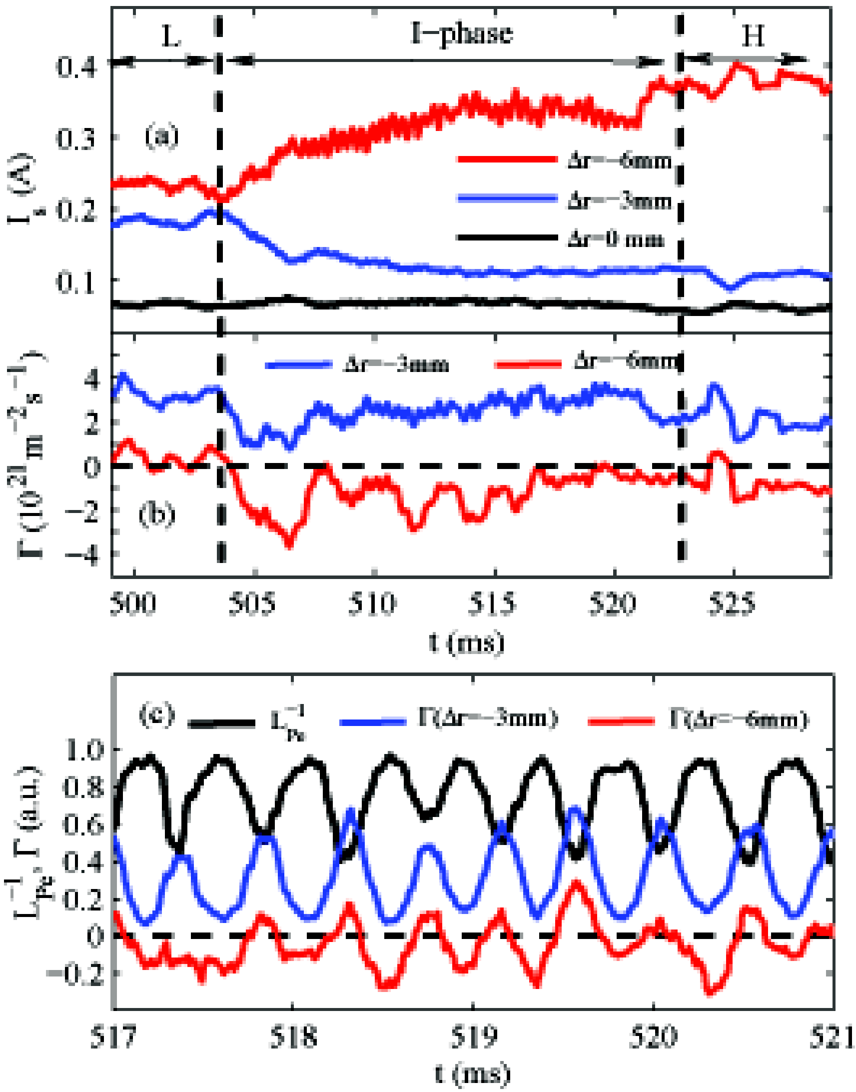
Force balance equation of ions

$$E_r = \underbrace{\frac{1}{n_i Z_i e}\nabla_r P_i(f)}_{E_{r,dia}} \underbrace{- v_{\theta i}B_\phi + v_{\phi i}B_\theta}_{\Delta E_r}$$



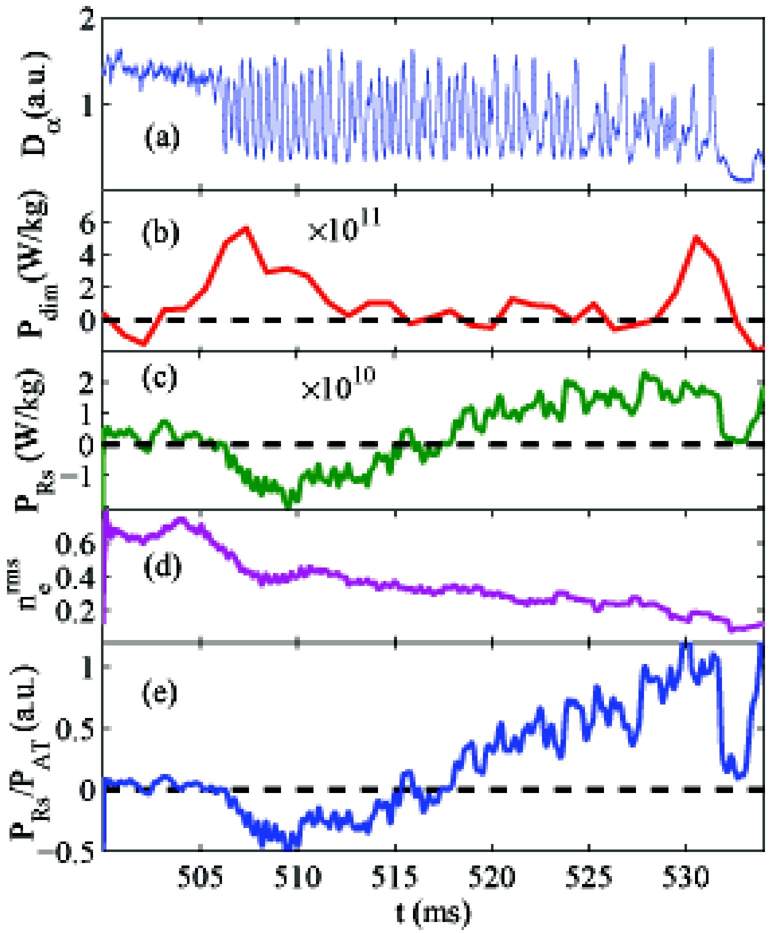
- (V_E-V_{dim})/V_E > 60% in L-mode & early I-phase but <10% prior to I-H transition.
- Evolutions of $\partial V_{dim}/\partial t$ and V_E or V_{dim} are strongly correlated.
- No evident correlations between $\partial R_s/\partial r$ and V_E are observed.

Formation of density ETB



- The evolutions of (a) $I_s \sim n_e$, (b) Γ, (c) the phase relations between Γ and $1/L_{pe}$ in LCO.
- The density increases/decreases at Δr = -6 mm/-3 mm
- The turbulent particle flux is negative/positive at Δr= -6 mm/-3 mm
- The $1/L_{pe}$ at Δr = -6 mm is in/out of phase with the particle flux Γ at Δr = -6 mm /-3 mm
- The diffusion in this region is dominated by pressure gradient induced turbulence which leads to inward particle pinch in the process of particle ETB formation.

Rates of energy production



- The temporal evolutions of (a) D_α emission, the flow energy production rates from (b) pressure gradient P_{dim} and (c) Reynolds stress P_{RS}, (d) RMS of the density fluctuations n_e^{rms}, (e) the ratio of P_{RS}/ P_{AT},

- P_{dim} fast increases twice prior to the L-I and I-H transitions while P_{RS} does not .

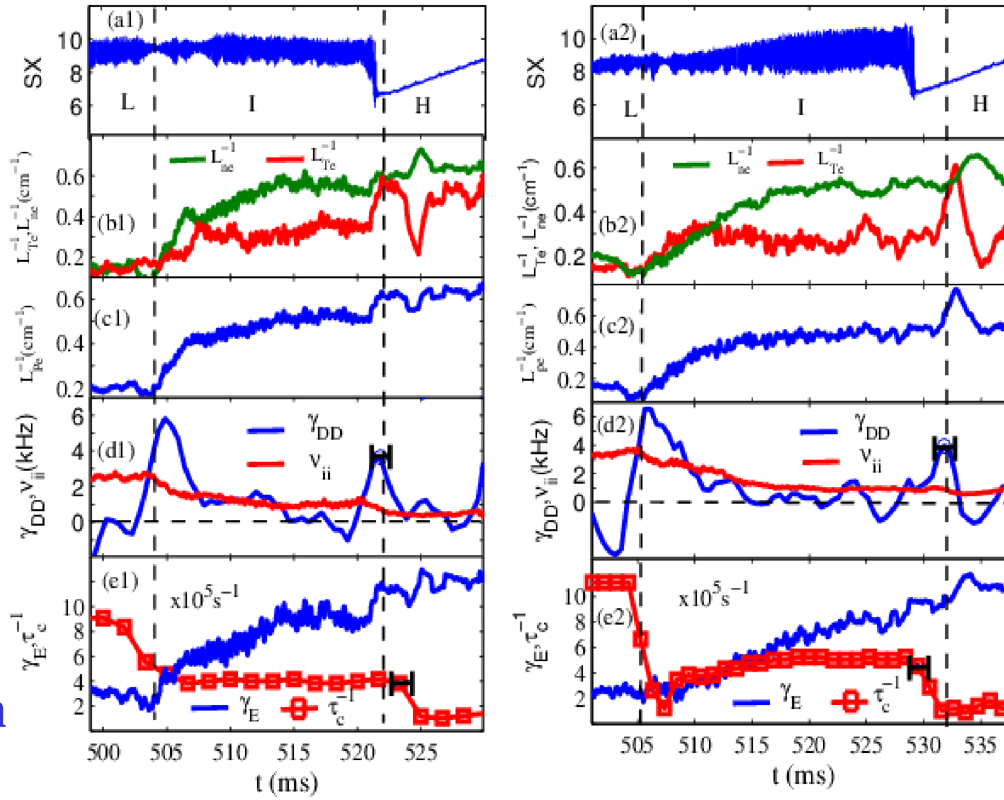
- P_{RS} is negative/positive in early/late I-phase.

- N_e^{rms} increases/decreases in L-mode/I-phase.

- The ratio of P_{RS} /P_{AT} has a peak prior to the I-H transition.

Conditions for I-H transition

The time evolutions of (a) soft X-ray, (b)inverses of the scale lengths of electron temperature and density, and (c) pressure, (d) the ion-ion collision frequency and the growth rate of the diamagnetic drift flow, (e) the E×B flow shearing rate and the turbulence decorrelation rate.



The conditions for I-H transition

(1) the I-phase has type-J LCOs,

(2) the plasma pressure gradient scale length is less than a critical value (~ 1.7 cm)

(3) the growth rate of the diamagnetic drift flow is equal to or slightly higher than the ion-ion collision frequency,

(4) the E×B flow shearing rate is higher than a critical value (~10^6/ s) and the turbulence decorrelation rate ($4x10^5$ /s).

4. Summary

- Two types of LCOs were observed in L-I-H transitions.
- Three plausible loops of zonal flow vs. turbulence and turbulence vs. pressure gradient are proposed for the LCOs and I-H transition.
- The dominant roles played by the diamagnetic drift flow in I-phase and I-H transition are demonstrated.
- The formation process of density ETB reveals that inward particle pinch is responsible for the barrier formation.
- The rates of energy production from diamagnetic drift and turbulent Reynolds stress for E×B flow in L-I-H transitions are compared.
- The triggering mechanism and conditions for I-H transition are discussed.
- Much more theoretical and experimental investigations are in progress.

Thank you

for your attention!