Overview of Recent Experiments on HL-2A

M. Xu on behalf of HL-2A team & collaborators

Southwestern Institute of Physics, Chengdu, China

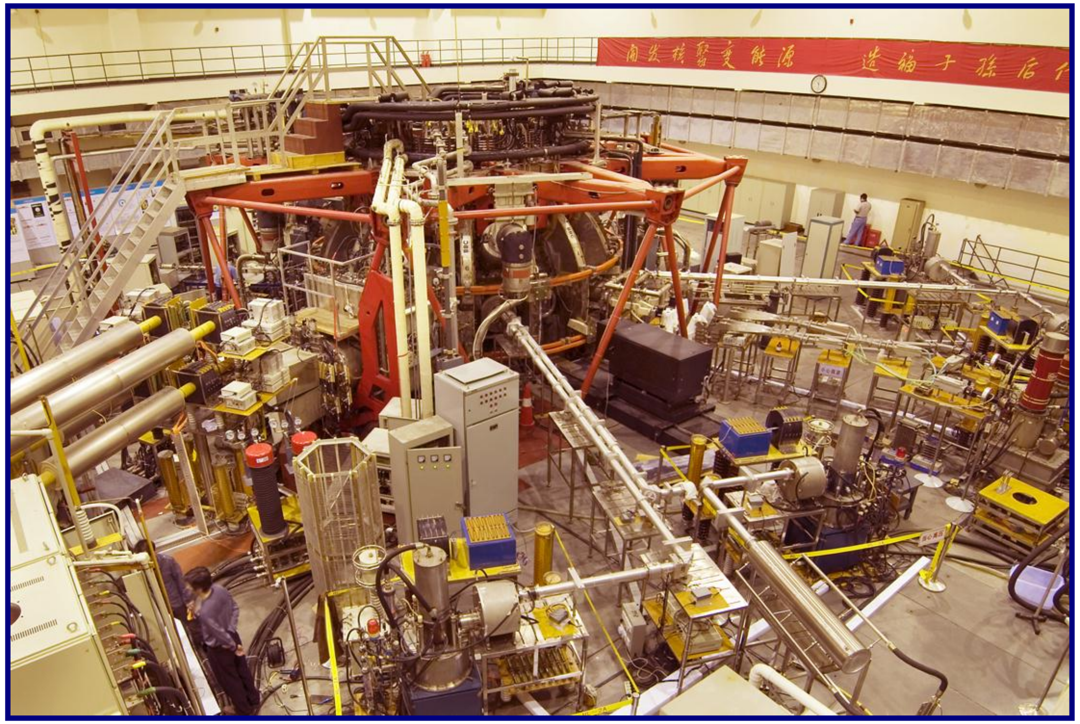
In collaboration with

USTC, ASIPP, Hefei, China
CEA\IRFM, Cadarache, France
University of California, San Diego, USA
MPI für Plasmaphysik, IPP-Juelich, Germany
NIFS, Toki, Japan
CCFE, Abingdon, UK

Acknowledgements

GA, PPPL, LLNL, UCI, UCLA, UCSD, USA
JAEA, Kyushu Uni., Japan
FOM Institute DIFFER, The Netherlands
ENEA, Frascati, Italy
Kurchatov Institute, Russia
WCI, NFRI, Korea
HUST, IOP, Tsinghua Uni.,PKU,SCU, China

HL-2A tokamak-present status



- *R:* 1.65 m
- *a:* 0.40 m
- B_t: 1.2~2.7 T
- *Configuration:*
  Limiter, LSN divertor
- I_p: 150 ~ 480 kA
- n_e: 1.0 ~ 6.0 x 10^{19} m^{-3}
- T_e: 1.5 ~ 5.0 keV
- T_i: 0.5 ~ 2.8 keV

Heating:

ECRH/ECCD: 5 MW

(6 X 68 GHz/0.5MW/1s, 2 X 140 GHz/1W/1s)

NBI (tangential): 3 MW

LHCD: 2 MW (4/3.7 GHz/500 kW/2 s)

Diagnostics: over 30, e.g. CXRS, MSE, ECEI…

Fuelling system (H_2/D_2):

Gas puffing (LFS, HFS, divertor)

Pellet injection (LFS, HFS)

SMBI /CJI (LFS, HFS)

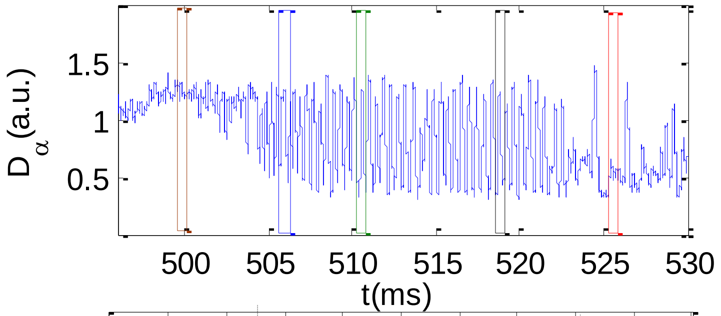
LFS: f =1~80 Hz, pulse duration > 0.5 ms

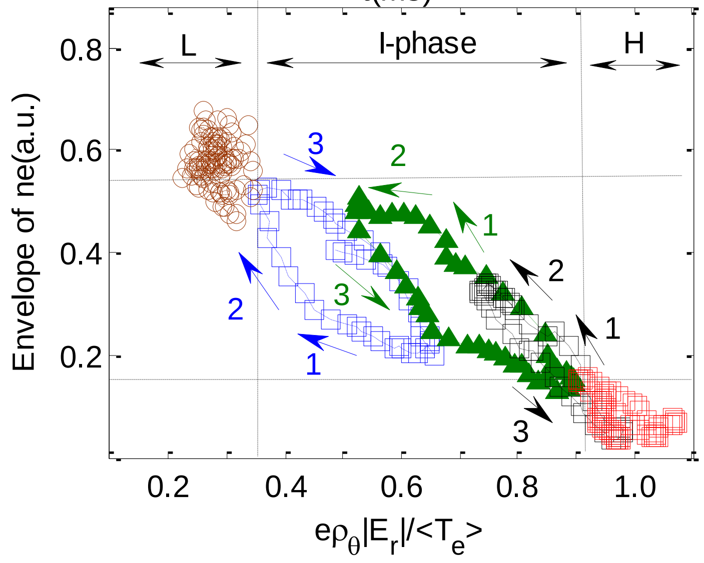
gas pressure < 3 MPa

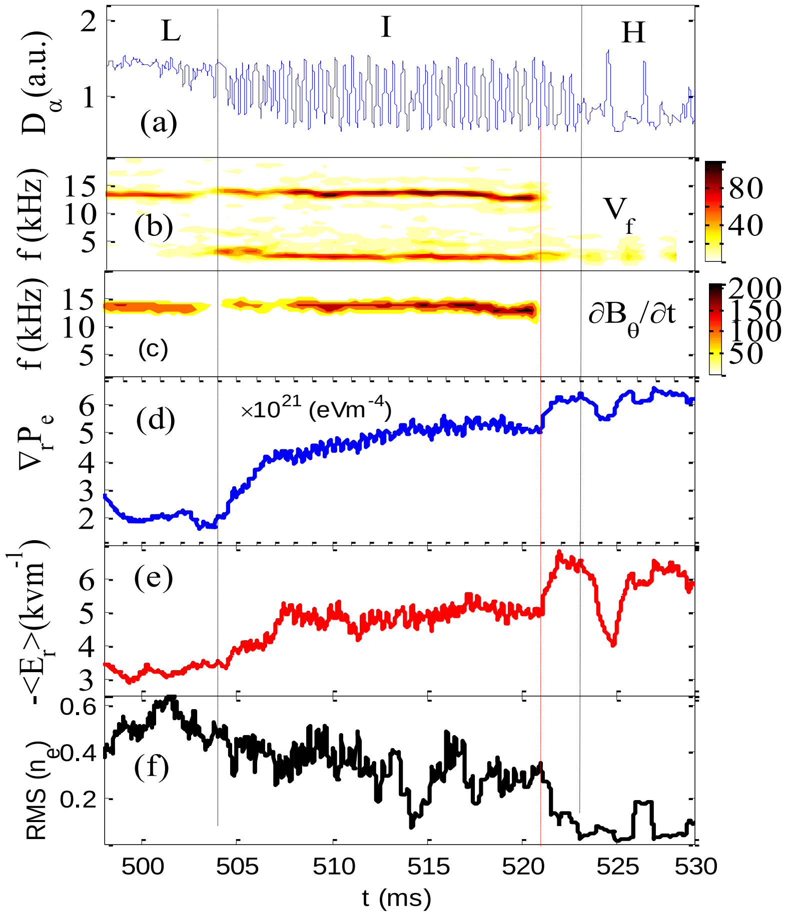
Outline

- ◆ **H-mode physics and pedestal dynamics**
  - Two types of LCO in the I-phase of L-I-H transition
  - Role of MHD modes in triggering I-H transition
  - Role of impurities in H-I transition
  - Quasi-coherent mode before and between ELMs
- ◆ **MHD & energetic particle physics**
  - Shear Alfven wave & nonlinear interaction with TMs
  - Transitions among low-frequency MHD modes
  - Energetic particle loss induced by MHD instabilities
  - Interaction b/w NTMs & non-local transport
- ◆ **ELM mitigation**
- ◆ **Impurity transport**
- ◆ **Summary & outlook**

Two types of LCO during L-I-H



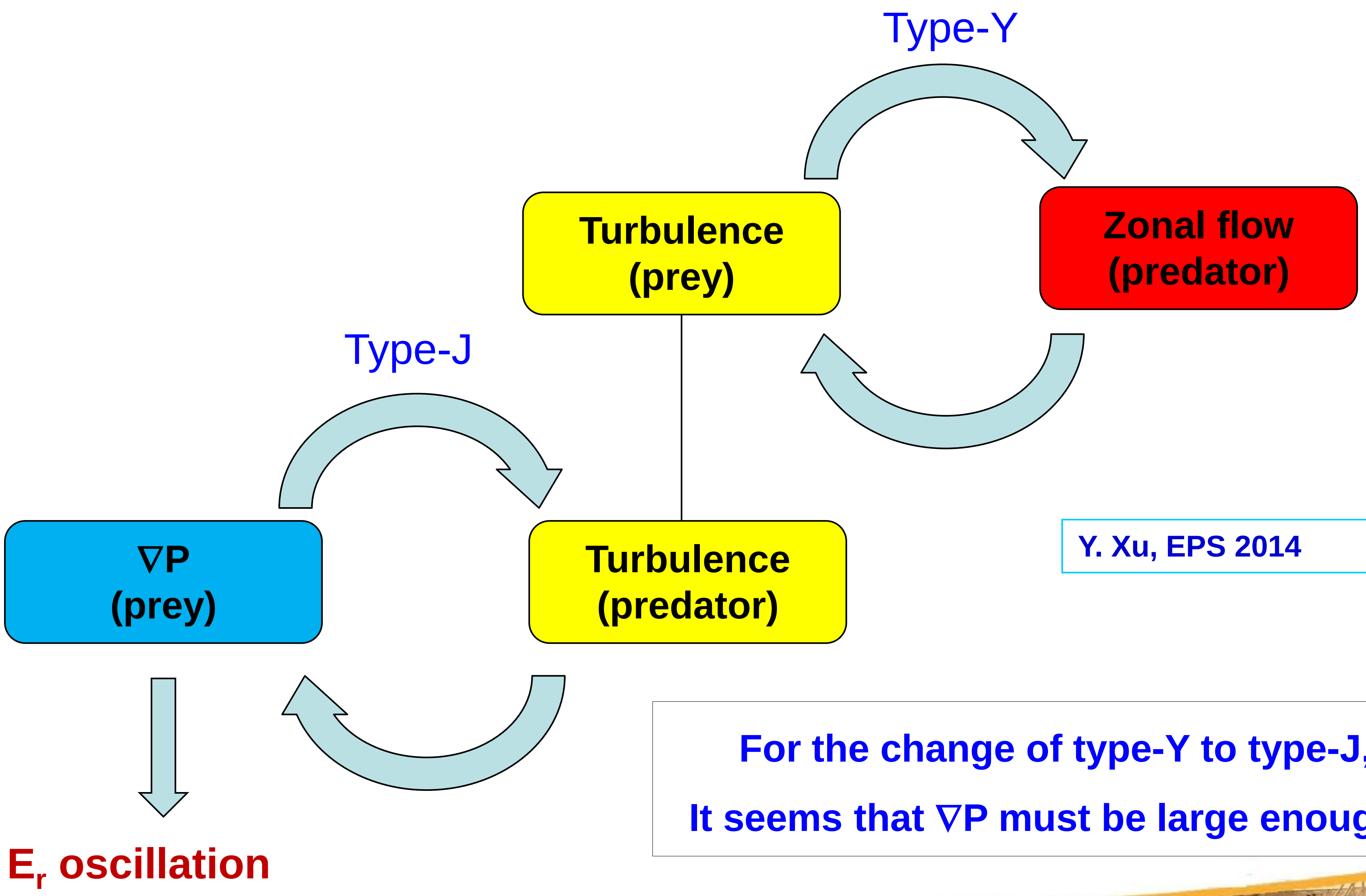




- **Two types of LCO (type-Y and type-J) observed during L-I-H**
- **Type-Y: turbulence leads E_r, Type-J: E_r leads turbulence**
- **∇P is the key, and jumps before I-H**

J. Cheng, PRL 2013; J. Dong, FEC 2014, EX/11-3; Y. Xu, EPS 2014

Possible interpretation of different LCOs



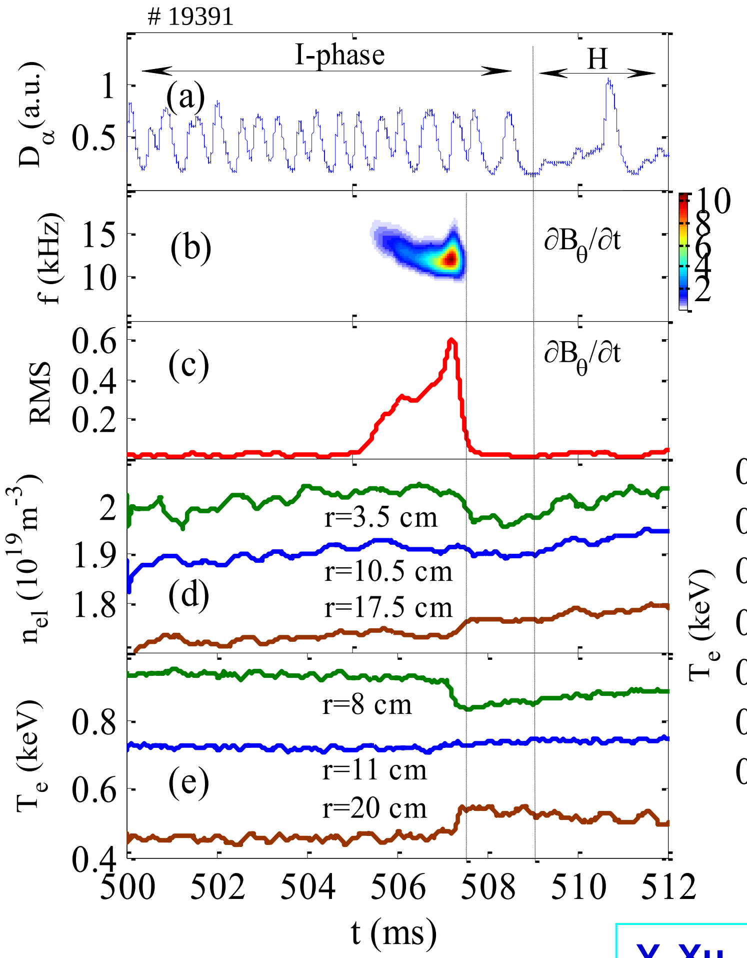
Y. Xu, EPS 2014

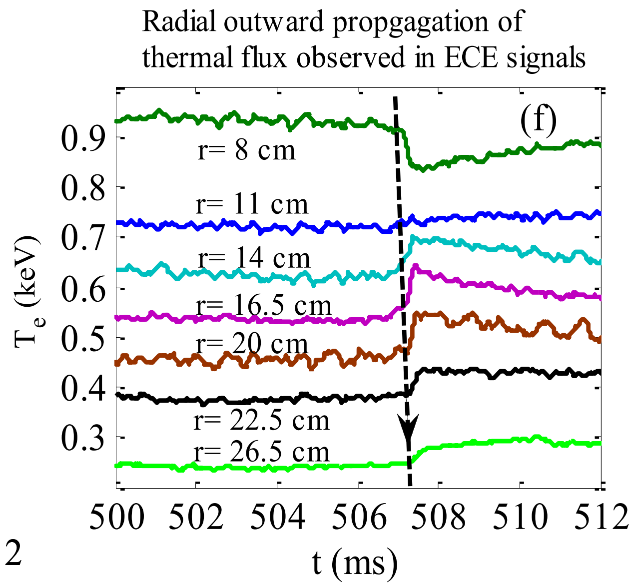
For the change of type-Y to type-J,

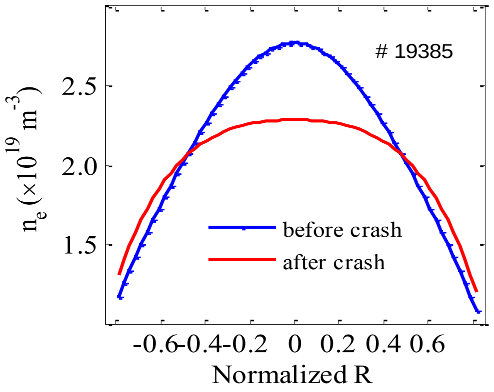
It seems that ∇P must be large enough !

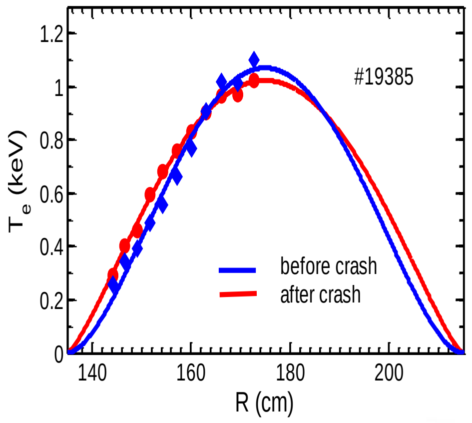
Outward propagation w/ MHD crash

After the mode crash, plasma profile becomes flat: ⇒ Edge ∇P increases ! ⇒ E_rxB shear flow increases ⇒ suppress turbulence ⇒ H-mode









Y. Xu, EPS 2014 & PPCF 2014

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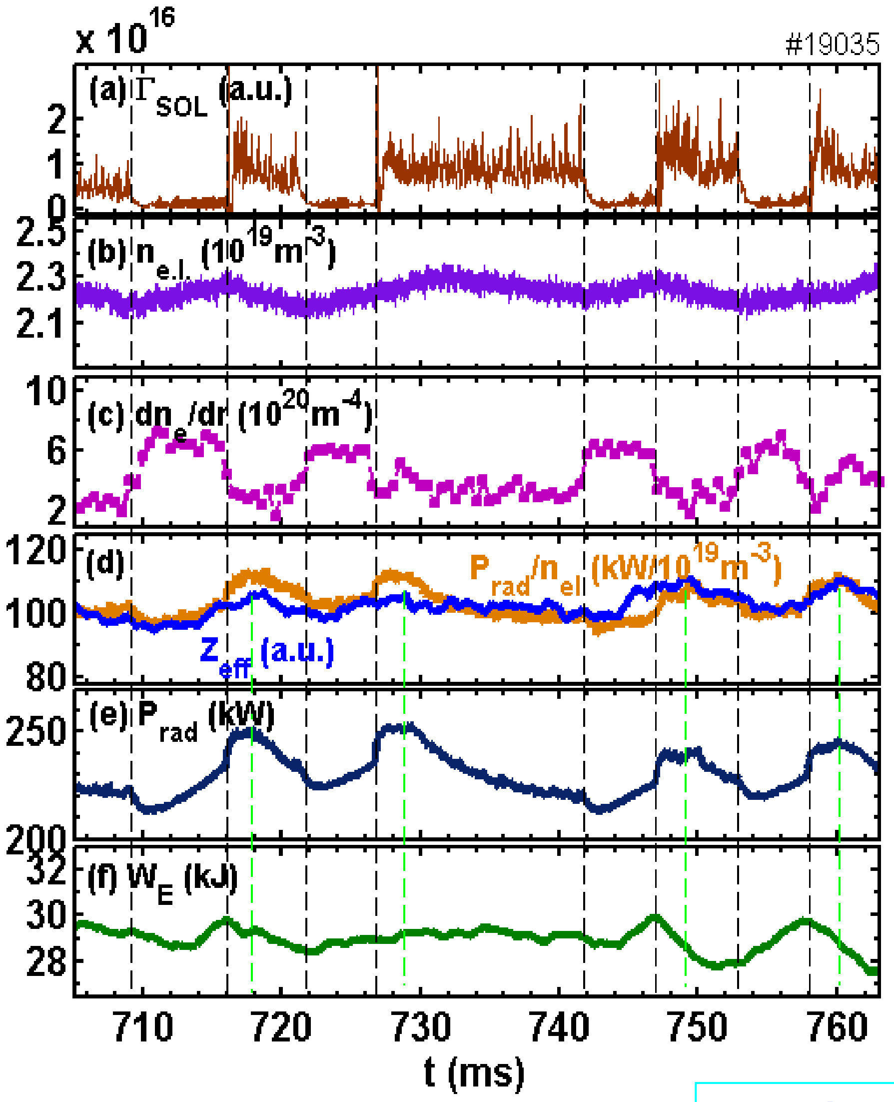
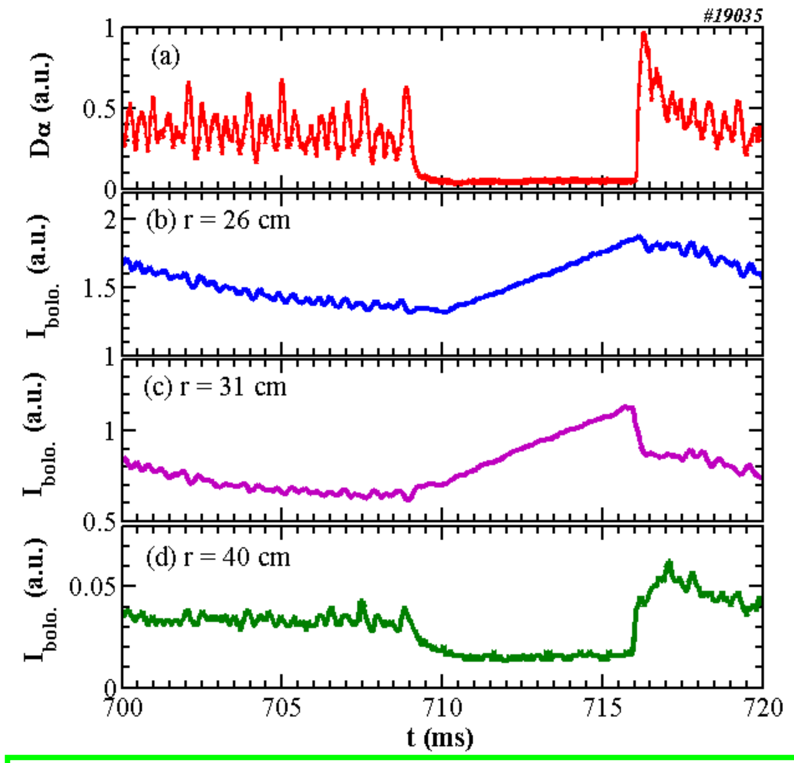
Impurity induced H-I-H transitions



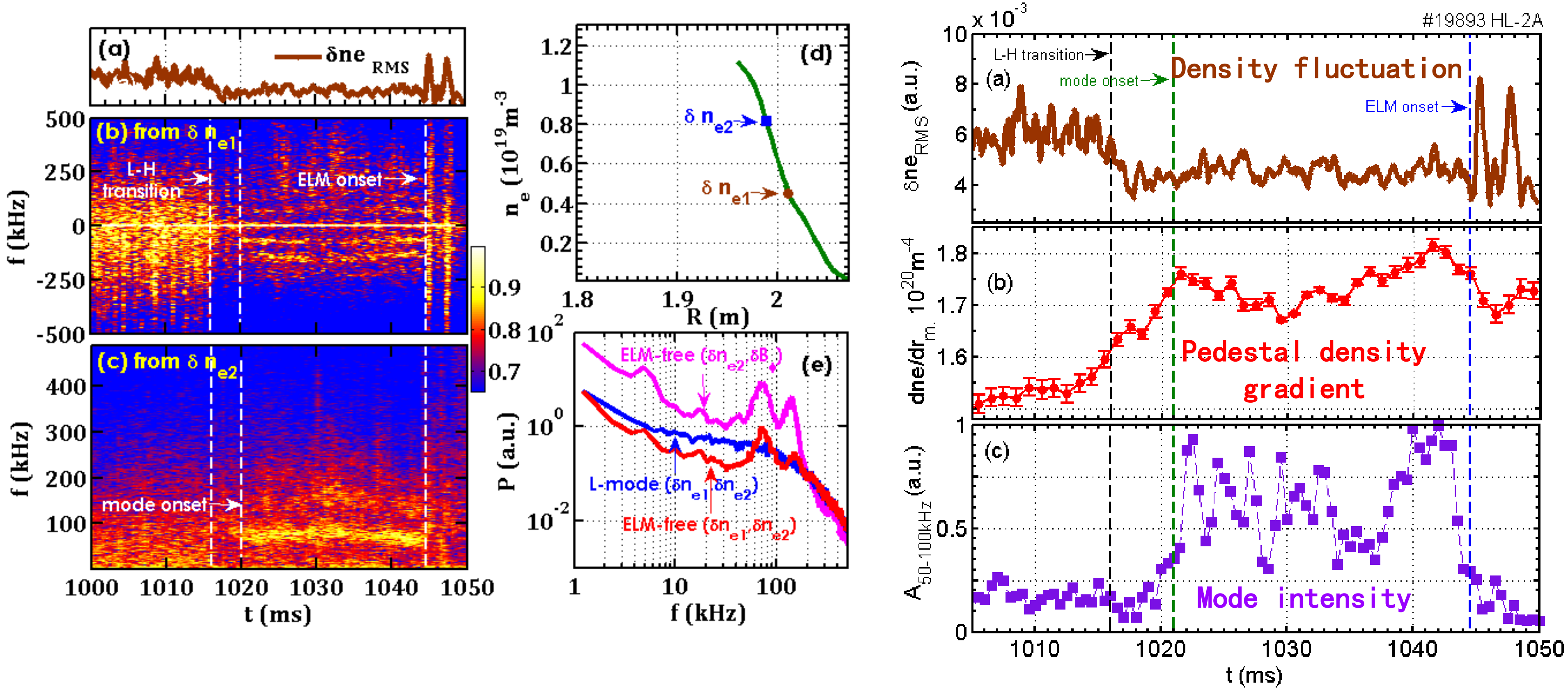


◆Oscillations lead to: Considerable particle loss; Reduce the pedestal gradient; Reduce impurity density.

◆ Impurity induced H-I transition

W.L. Zhong, EPS 2014

Quasi-coherent mode before and between ELMs



- ➢ Quasi-coherent modes observed during ELM-free period & b/w ELMs;
- ➢ Quasi-coherent mode: 50-100kHz; k_θ~0.43 cm^{-1} (electron diamagnetic direction ~8km/s), k_r~1 cm^{-1} (inward) , n =7 (counter I_p);
- ➢ Mode excitation relates to pedestal saturation.

W. Zhong, FEC 2014, EX/P7-23

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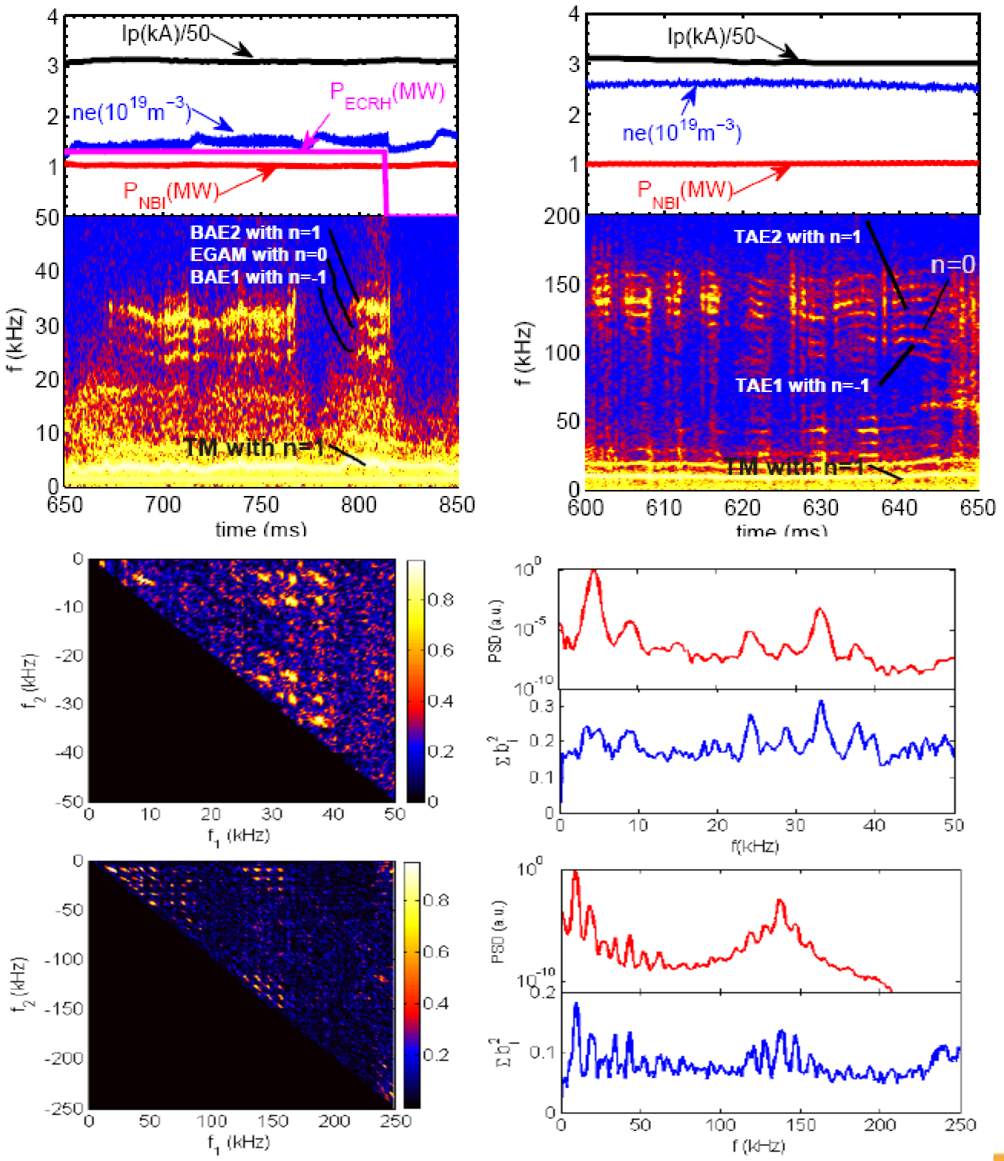
Generation of n=0 mode by coupling

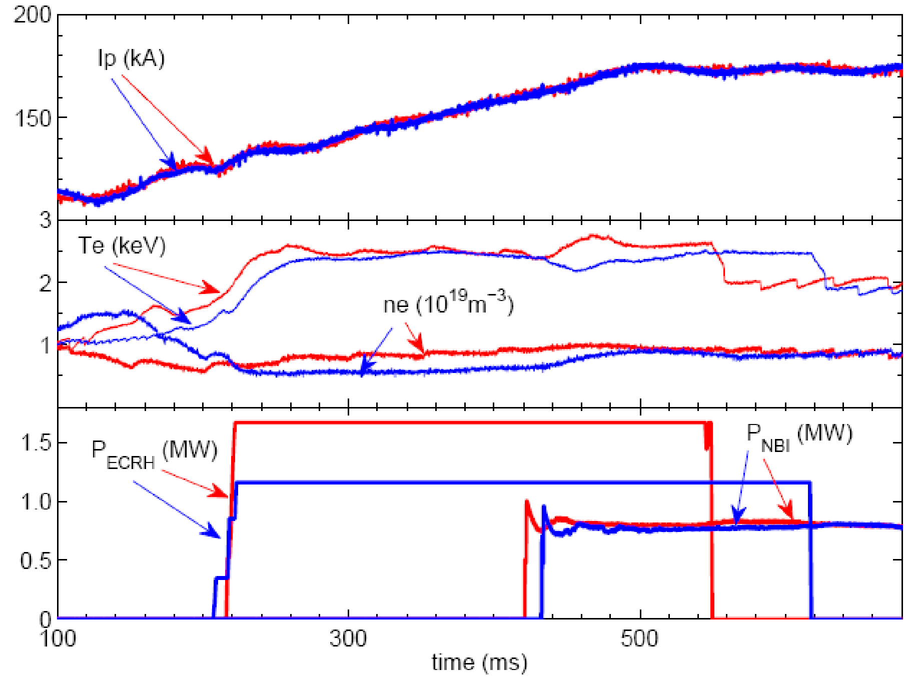


- Axis-symmetric n=0 MHD mode was observed in the presence strong AEs & TMs;
- Nonlinearly generated via
  i) BAE & TM coupling $\Rightarrow$ EGAM
  ii) TAE & TM coupling
- Could be one of the mechanisms for energy cascade in EP driven turbulence.

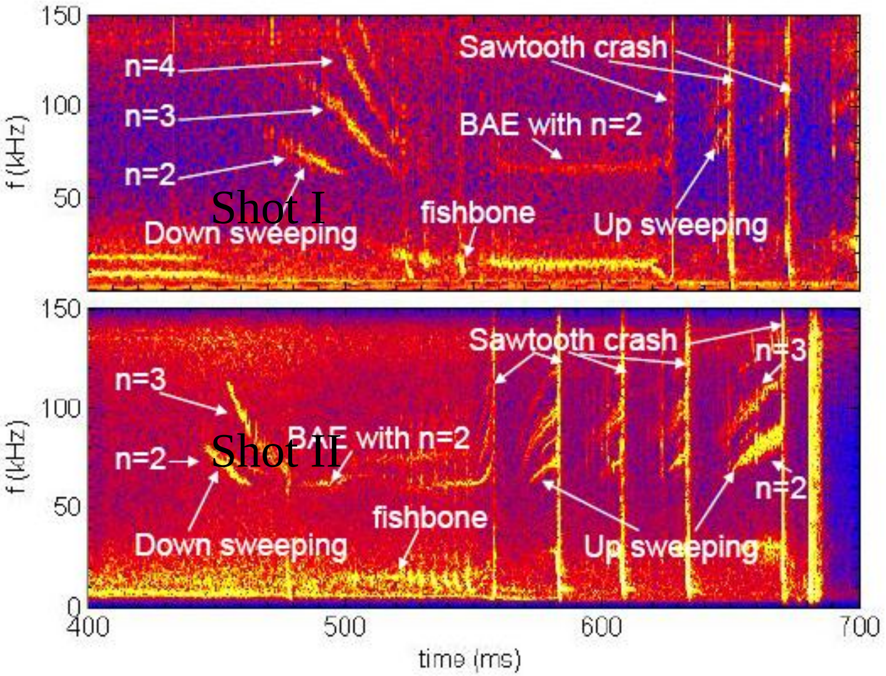
Auto-bicoherence & summed auto-bicoherence of Mirnov signals, indicating nonlinear interaction among low-frequency fluctuations and AEs.

W. Chen, FEC 2014, EX/P7-27

Up- and down sweeping RSAEs



Typical discharges with the sweeping modes on HL-2A. The blue and red lines are corresponding to shot I and shot II, respectively.

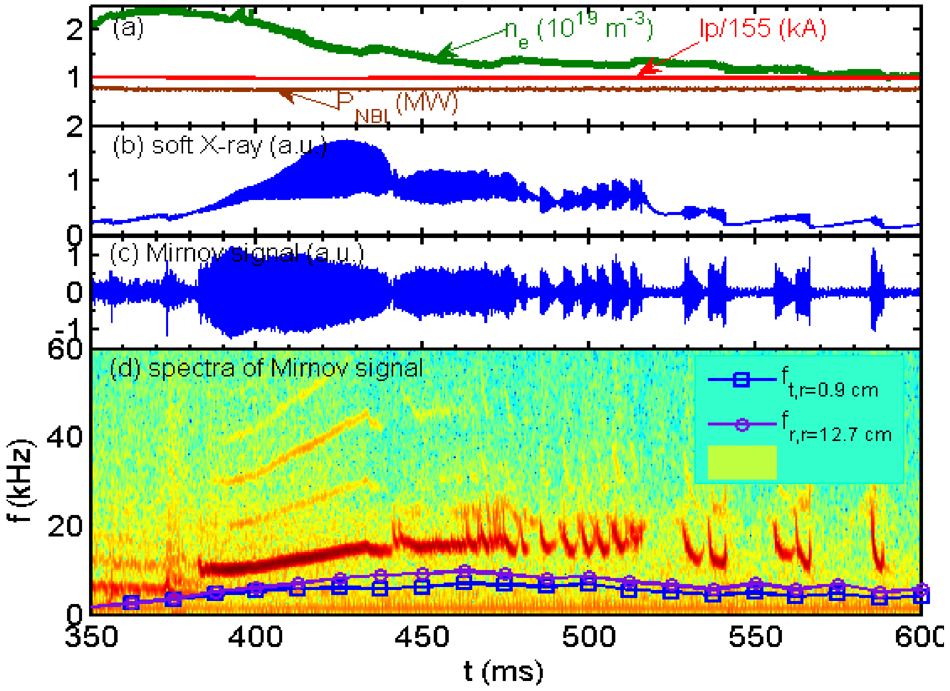


Spectrogram of Mirnov signal for shot I (top) and shot II (bottom).

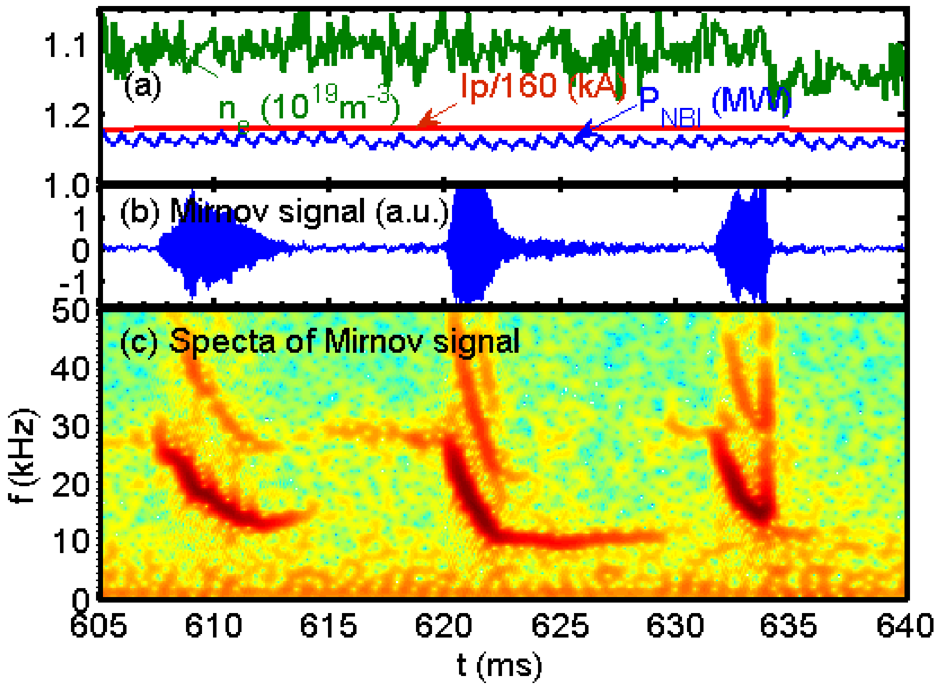
W. Chen, NF, 2014

- **Down-sweeping frequency MHD modes during I_p ramp-up (NBI+ECRH); up-sweeping frequency MHD modes before sawtooth crash during I_p plateau and NBI.**
- **Both propagate poloidally in ion diamagnetic drift direction and toroidally co-current direction in the lab frame, with n=2-5, and m=n.**
- **By kinetic Alfven eigenmode simulation, down-sweeping identified to be KRSAE, and up-sweeping is RSAE in ideal or kinetic MHD limit.**

Transitions b/w fishbone & LLM



Transition from LLM to fishbone



Transition from fishbone to LLM

- Transition from LLM to fishbone and backward transition from fishbone to LLM were observed during NBI heating;
- f_{LLM} is higher than toroidal rotation frequency, but close to the precessional frequency of trapped energetic ions generated by NBI.
- This observed LLM is energetic particle mode or saturated fishbone excited by the trapped energetic ions.

L. Yu, FEC 2014, EX/P7-25

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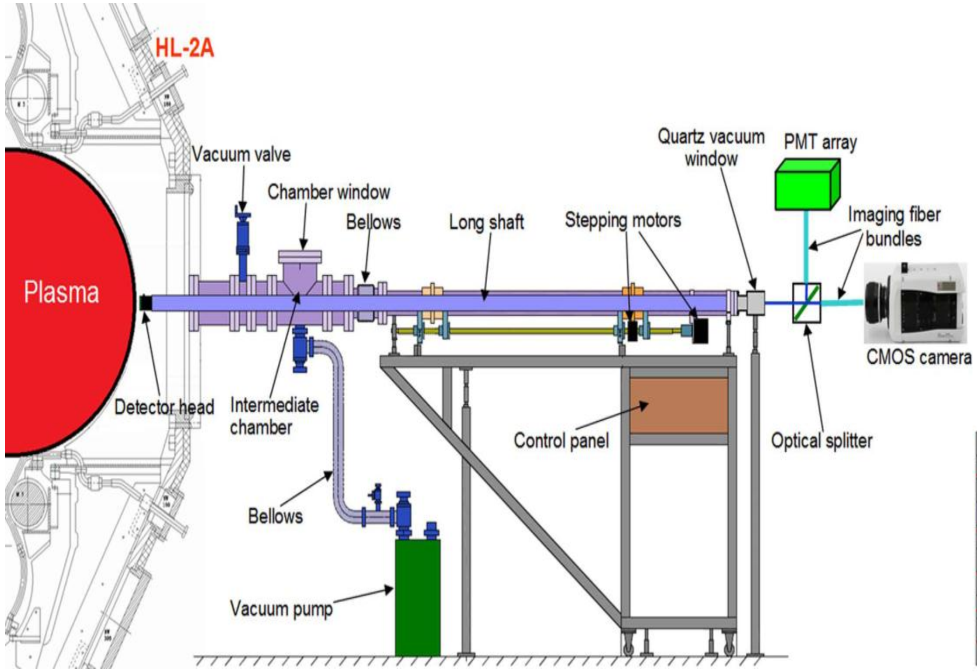
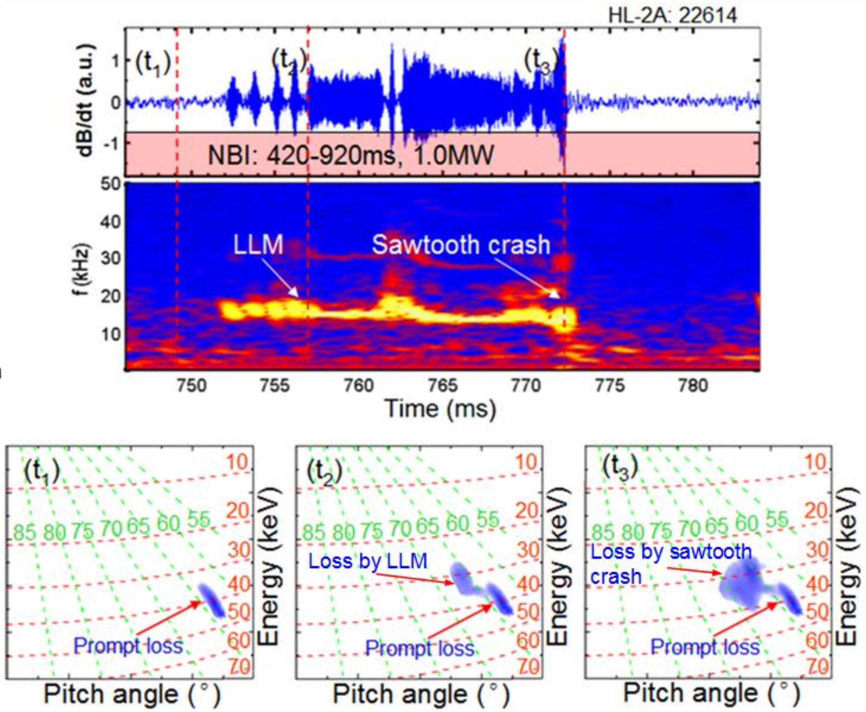
Observation of fast ion loss by SLIP





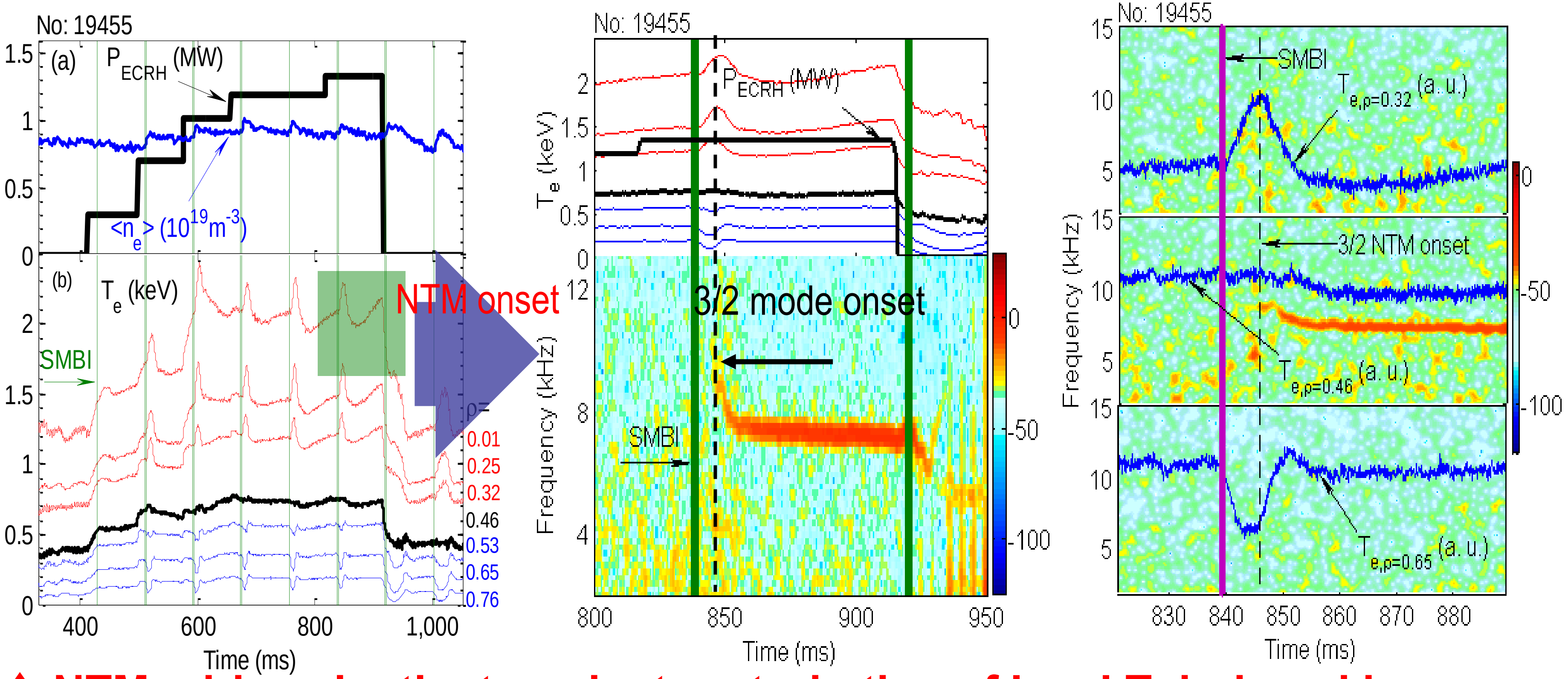
◆ **Fast-ion loss induced by MHD instabilities measured by a fast-ion loss probe (SLIP).**

◆ **Compared with long-lived mode (LLM), the spot induced by sawtooth crash has a broad range in energy and pitch.**

◆ **Interactions between MHD instabilities and energetic ions causes the fast-ion losses with the wide range of energy and pitch angle.**

Y. Zhang, FEC 2014, EX/P7-24 & RSI 2014

NTM onset during non-local transport



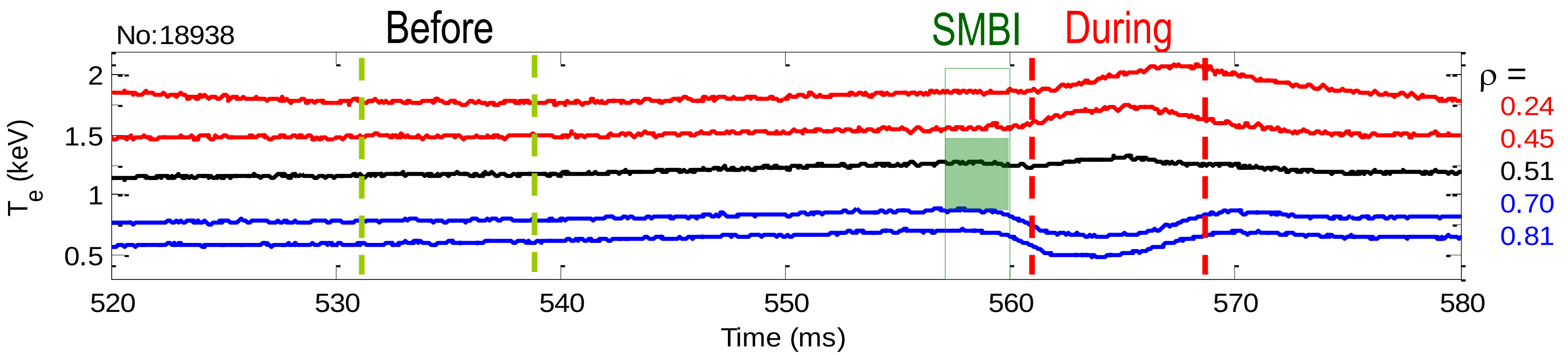
♦ **NTMs driven by the transient perturbation of local T_e induced by non-local transport.**

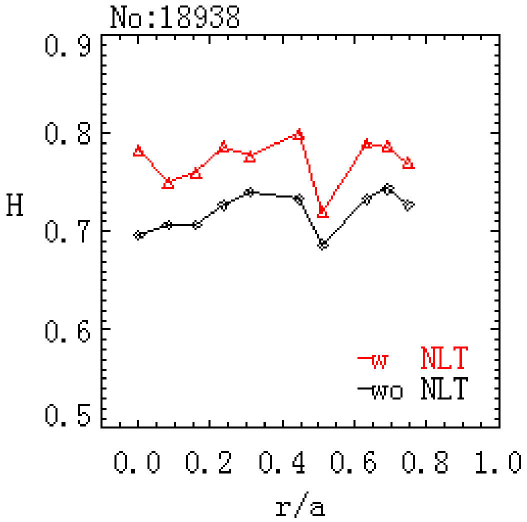
— **The NTM is located at the inversion surface of non-locality.**

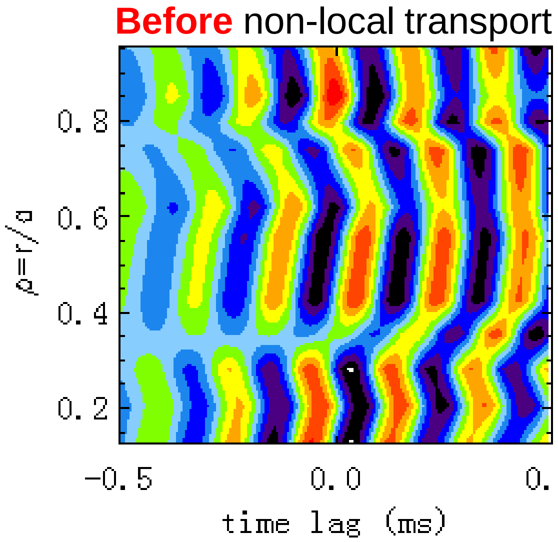
— **The NTM onset is related to largest ∇T_e around the reversion surface.**

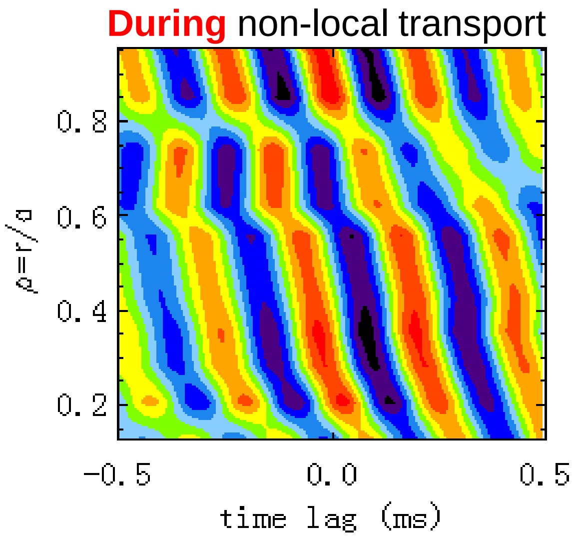
X. Ji, FEC 2014, EX/6-4

Avalanche characteristics for non-locality









♦ Enhanced-avalanche characteristics during non-local transport

— During non-locality, larger decorrelate time lag and Hurst parameters

— Longer range of inward and outward radial heat flux propagation

— Long radial propagation broken near the q=3/2 surface (NTM)

X. Ji, FEC 2014, EX/6-4

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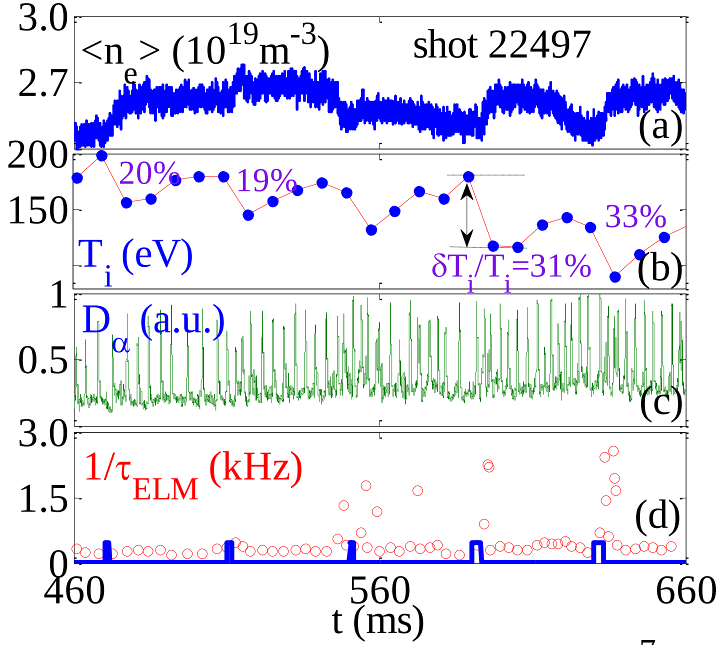
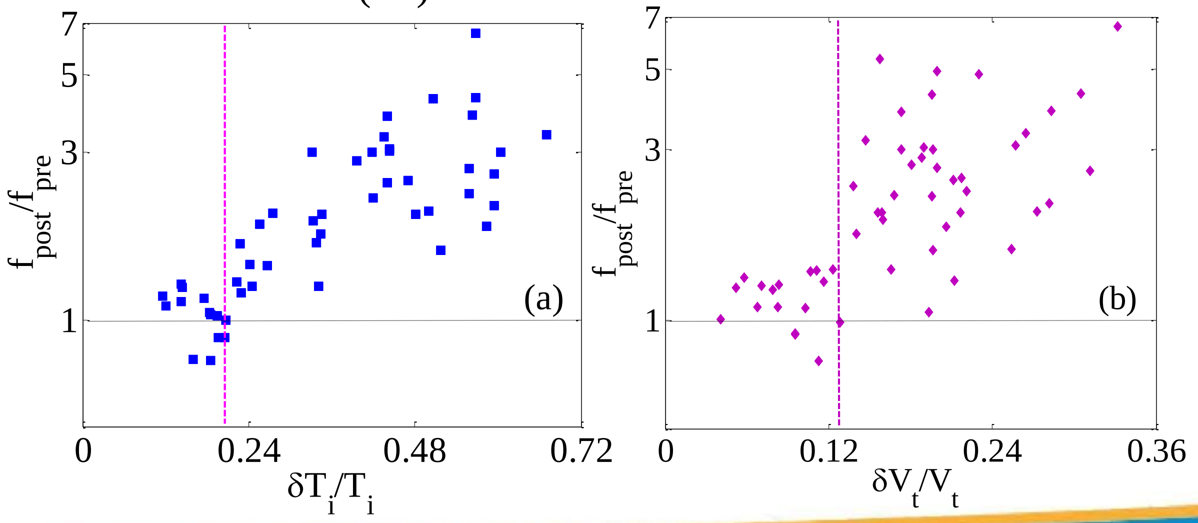
T_i & V_T decrease associated with ELM mitigation



- ELM mitigation only induced by significant amount of SMBI injection. NO mitigation for first 2 SMBI (Ti dropped by ~20%) and mitigation for the last 3 SMBI (Ti dropped by ~ 30%);

- Seems that thresholds of ~20% on δTi/Ti and 13% on $\delta V_T/V_T$ are associated with successful mitigation

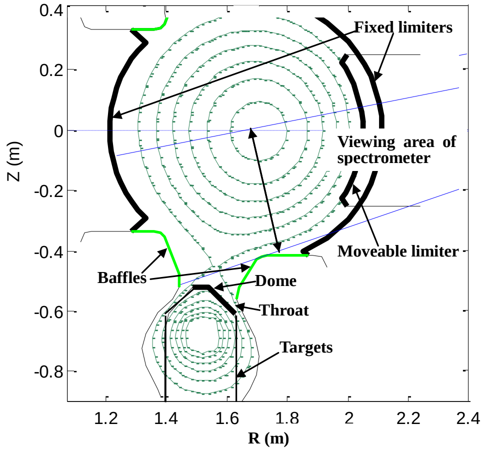


D. Yu, FEC 2014, EX/P7-20

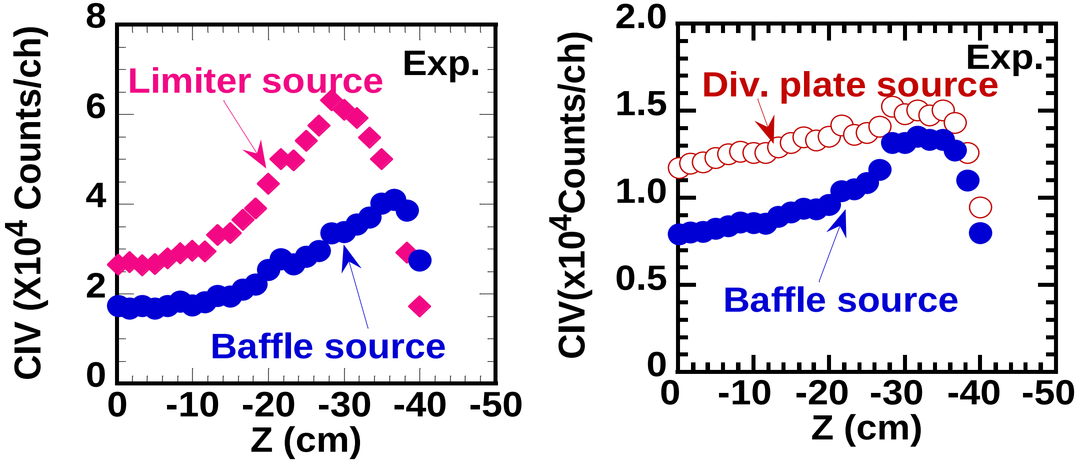
Impurity transport studies in SOL

Z. Cui, FEC 2014, EX/P7-26

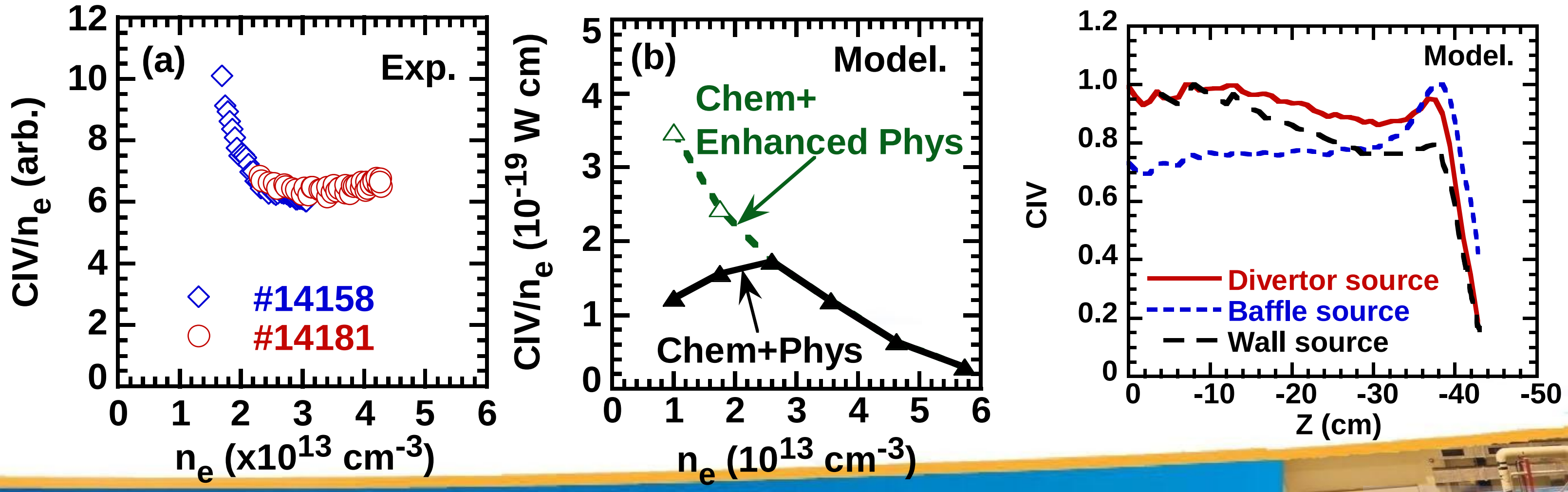
Vertical profile of CIV and CIII measured in HL-2A



Impurity profile changes for different source locations



3D modeling suggests that both poloidal asymmetry of impurity flow profile and an enhanced physical sputtering play important role in impurity distribution and its screening efficiency in SOL



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Summary

◆ H-mode physics and pedestal dynamics

- Two types of LCO, type-Y & type-J observed, ∇P is the key for LCO transition.
- MHD mode crash $\Rightarrow$ edge ∇P increases $\Rightarrow$ triggering I-H transition
- LCOs lead to particle loss, reduce grad_n & impurity, impurity induced I-H-I transition
- Quasi-coherent mode relates to pedestal saturation.

◆ MHD & energetic particle physics

- BAEs and TAEs can interact with TMs and generate n=0 axi-symmetric mode;
- Up- and down sweeping RSAEs were identified.
- Transitions between fishbone and LLM observed.
- Energetic particle loss by MHD was measured by SLIP.
- SMBI induced non-locality can be explained by avalanche, and NTM at q=3/2 breaks non-local transport

◆ ELM mitigation & impurity transport

- T_i & V_T reduction associated by ELM mitigation was measured
- Impurity profiles found to be sensitive to different impurity source locations.

Outlook

◆ HL-2A

- Heating upgrade: 2MW LHCD, 5MW ECRH, 3MW NBI,
- Diagnostics development: ECEI, MSE, BES, GPI, DBS, CXRS …
- Transport: H-mode physics, impurity transport, momentum transport
- MHD instability (RWM, NTM), NTM & saw tooth control by ECRH;
- 3D effects: on ELM control, plasma flow, ZF and turbulence, L-H transition threshold, plasma displacement;
- Energetic particles: EP driven mode identification, EP loss and control of EP induced instabilities

◆ HL-2M (upgrade of HL-2A)

- Parameters: R=1.78m, a=0.65m, Bt=2.2T, Ip=2.5MA, Heating~ 25MW, triangularity=0.5, elongation=1.8-2.0
- Mission: advanced divertor (snowflake, tripod), PWI at high heat flux, high performance, high beta, and high bootstrap current plasma
- *Commission planned end of 2015*

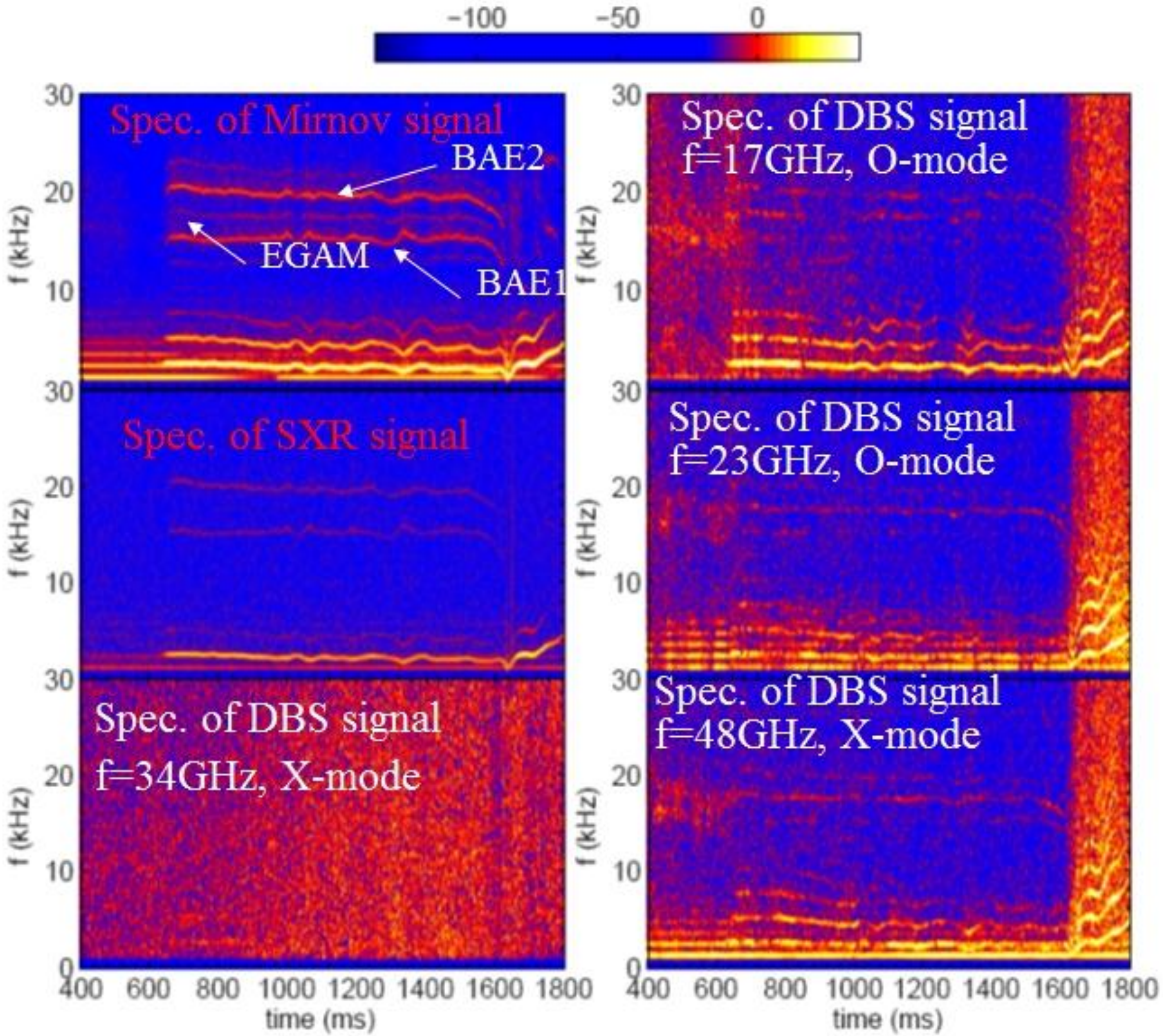
HL-2A Contributions to this conference

Dong, J.	*EX/11-3*	*Sat. 11:30 AM*	*Xu, Y.*	*EX/P8-18*	*Fri. PM*
Ji, X.	*EX/6-4*	*Thu. 3:20 PM*	*Xu, Yuan*	*EX/P7-19*	*Fri. AM*
Zhong, W.	*EX/P7-23*	*Fri. AM*	*Yu, D.L.*	*EX/P7-20*	*Fri. AM*
Yu, L.	*EX/P7-25*	*Fri. AM*	*Nie, L.*	*EX/P7-22*	*Fri. AM*
Cheng, J.	*EX/P7-32*	*Fri. AM*			
Chen, W.	*EX/P7-27*	*Fri. AM*	*Wang, A.*	*TH/P5-5*	*Thu. AM*
Cui, Z.	*EX/P-26*	*Fri. AM*	*Wang. Z.*	*TH/P7-30*	*Thu. AM*
Zhang, Y.	*EX/P7-24*	*Fri. AM*	*He, H.*	*TH/P2-13*	*Tue. PM*
Liu, Y.	*EX/P7-18*	*Fri. AM*			
Dong, Y.	*EX/P7-31*	*Fri. AM*	*Zheng, G.*	*TH/3-1Rb*	*Wed. 17:00 PM*
			....		

Thanks for your attention!

Backup: Why is EGAM?

Low density Ohmic heating



Internal fluctuations of EGAM observed by different diagnostic methods.

Density fluctuations of BAEs and EGAM measured by Doppler back scattering (DBS).

Experimental results indicate the EGAM structure is global and frequencies are constant (eigenmode) in the radial direction.

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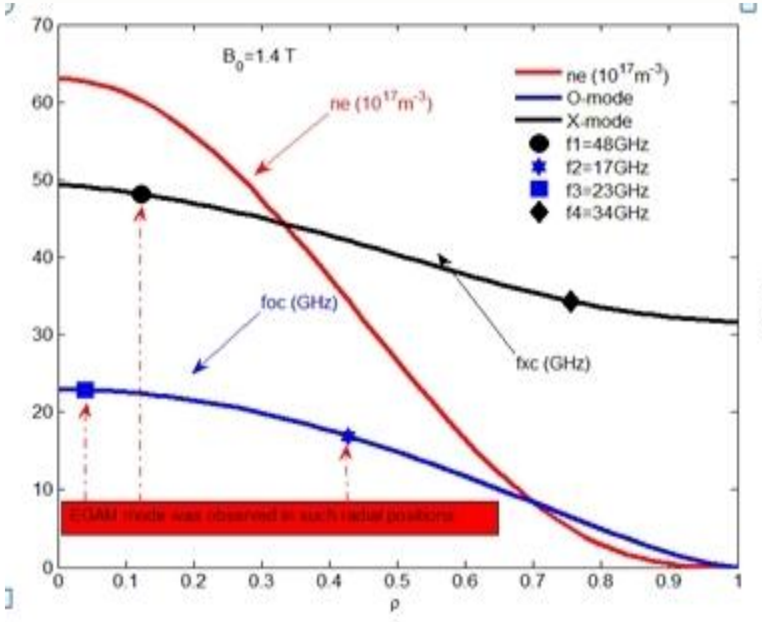
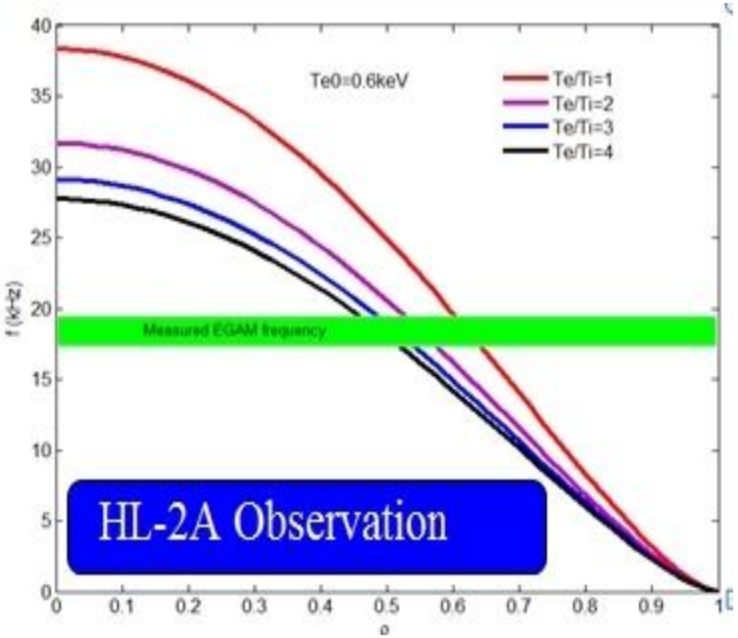
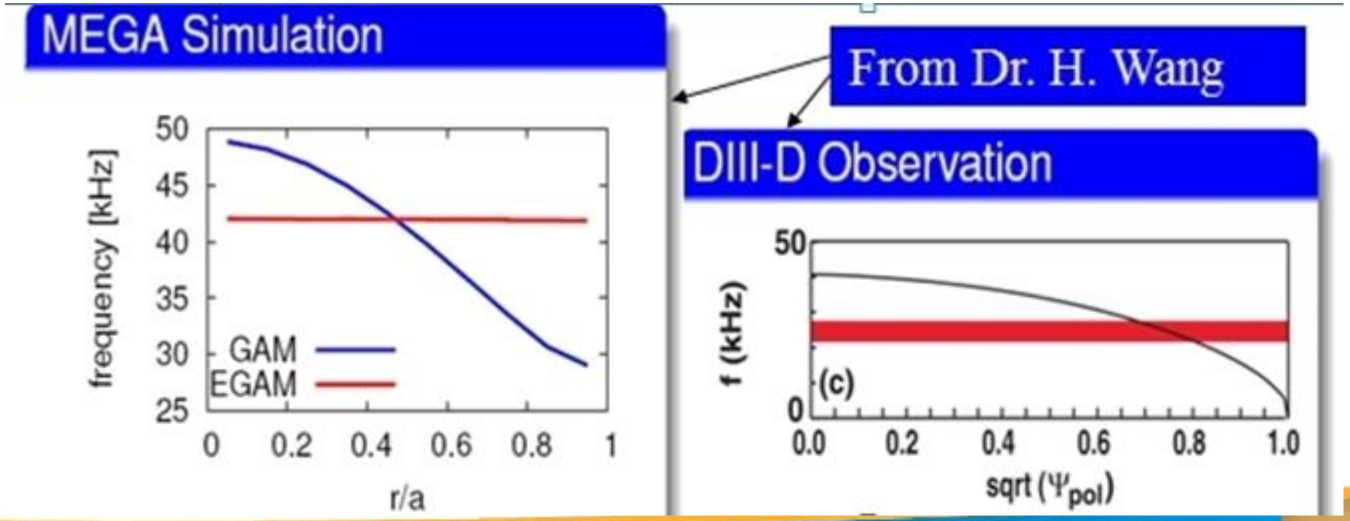






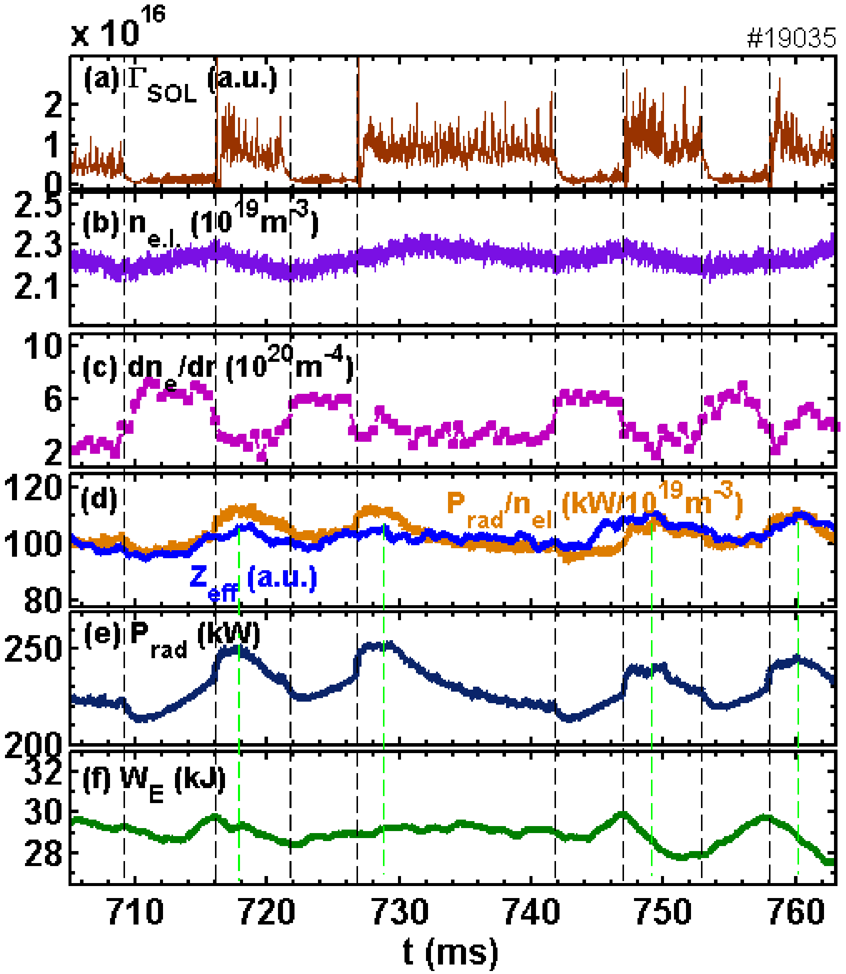
$f_{EGAM}/f_{GAM}<1$

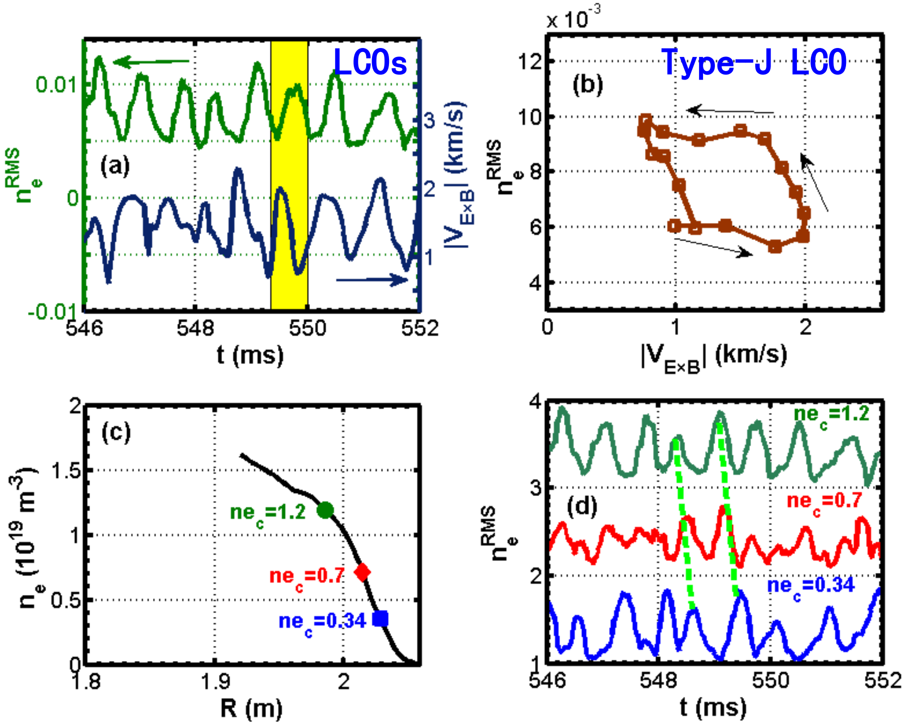
in core plasma.

Consistent with theory and simu. predictions.

Fu, PRL08; Nazikian, PRL08; Wang, PRL13

Multi-transition between I-phase and H-mode





◆A counter-clockwise direction between $|V_{E\times B}|$ and n_e^{RMS},

◆LCO radially propagates outward in pedestal region.

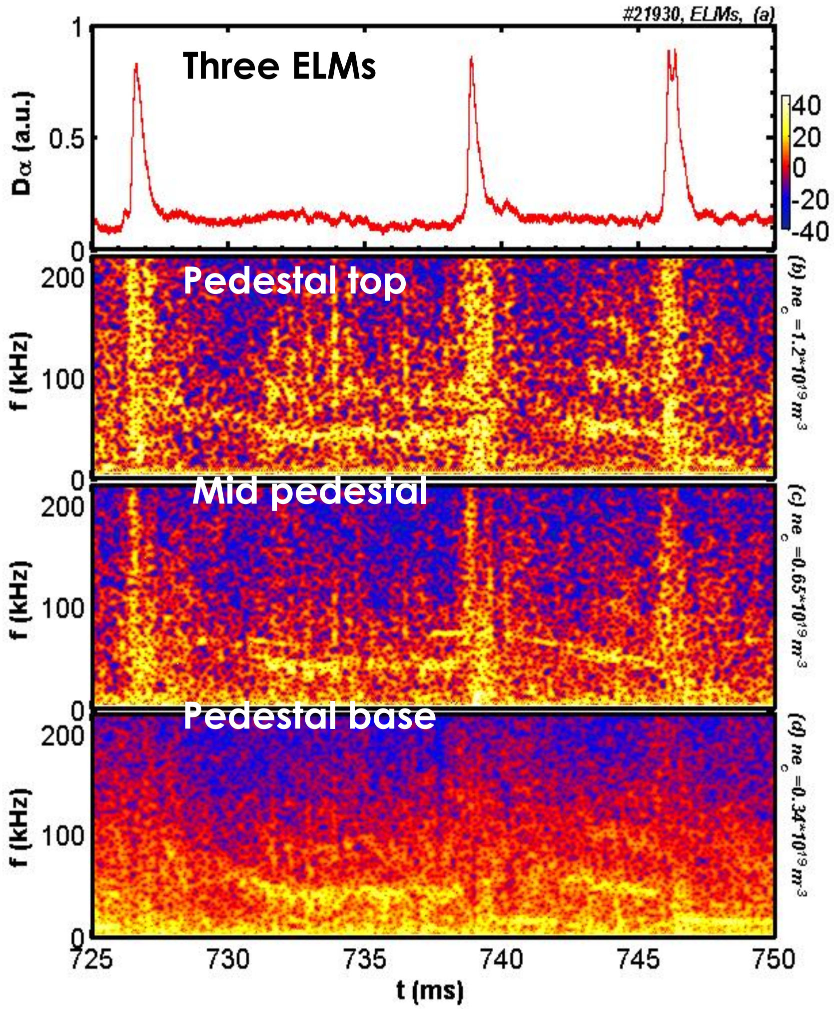
W. L. Zhong, and *et. al.* 2014 *EPS, Berlin, Germany*

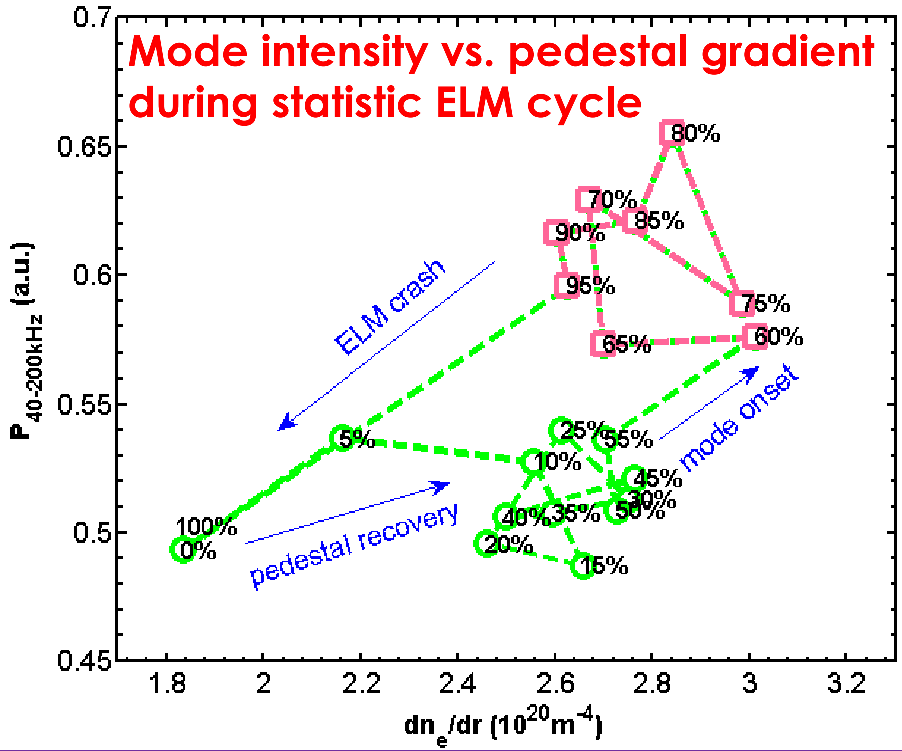
◆LCOs cause considerable particle loss and reduce the pedestal gradient and the impurity density.

◆ The radiation power is increasing during the H-mode phase .

◆Impurity density and radiation power continually increases for around 2 ms after the H-I transition.

Pedestal instabilities during Inter-ELMs





✓ The mode is also observed during inter-ELMs by reflectometers.

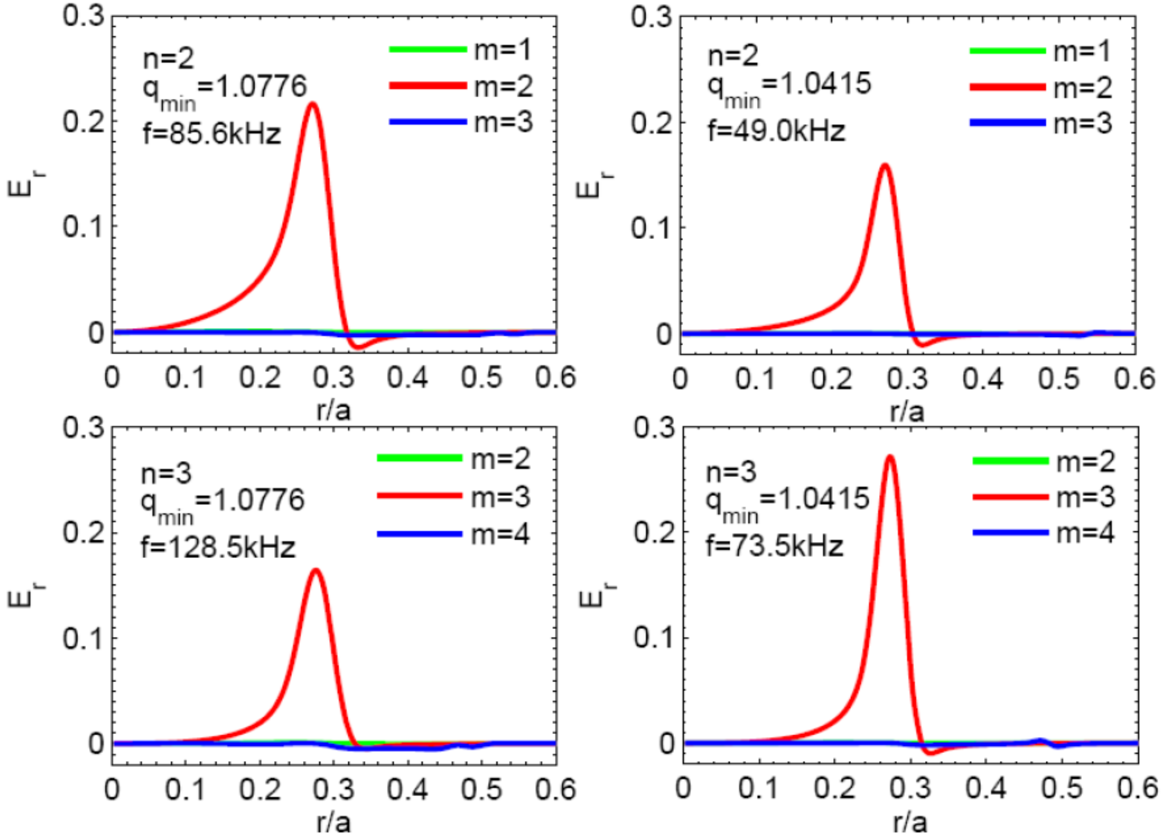
✓ n =7 (counter current direction), k_θ ~ 0.43 cm^{-1}(Electron diamagnetic direction)

✓ Mode excitation is related to the saturation of the pedestal

Simulation of RSAE by KAEC

Simulation for DS-RSAE Activities

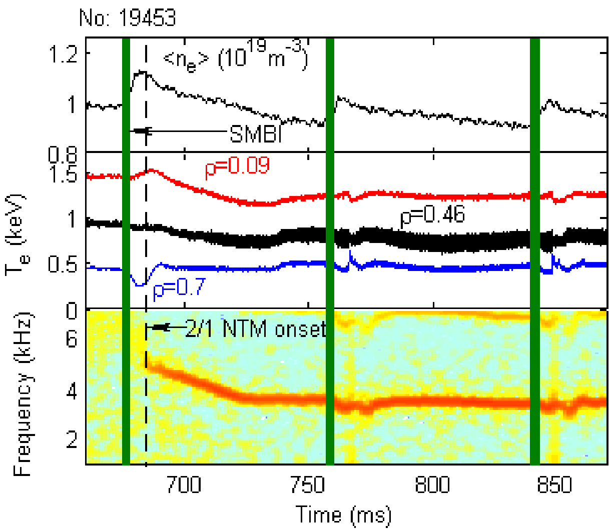
The radial eigenfunction of a RSAE is obtained by a kinetic Alfvén eigenmode code (KAEC), which is a non-perturbative kinetic MHD eigenvalue code. By solving the vorticity equation using the finite element method, The KAEC can calculate the mode structures in general tokamak geometry with finite pressure.

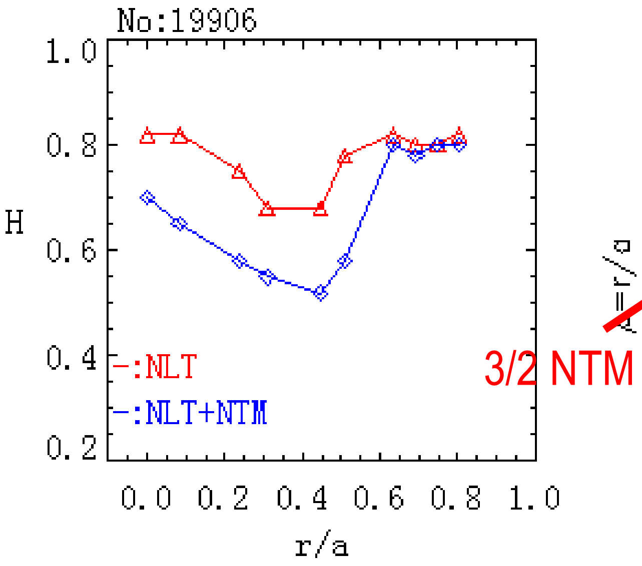


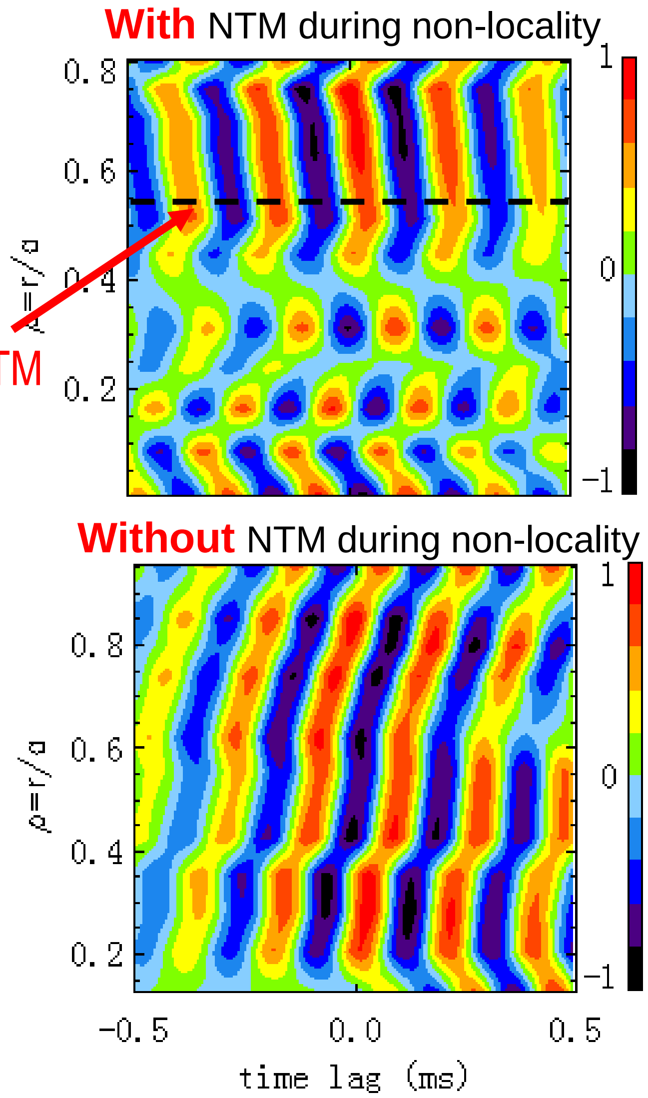
KAEC calculations of the eigenfunction of n=2 and n=3 down-sweeping RSAEs with the two different q_{min}.

- ◆The RSAEs are highly localized near qmin.
- ◆The m=n poloidal harmonic are dominant. The mode frequency drops as qmin decreasing.
- ◆If ignoring the FLR effects, the modes do not occur. So the RSAEs are kinetic, but not ideal instabilities.
- ◆In the same case, the ideal MHD code, NOVA-K, does not find the down-sweeping modes.

Impact of NTM on non-local transport







♦**The damping effect of NTM on non-local transport**

♦**Reduction of avalanche features with NTM in non-locality**

— With NTM, lower intensity of avalanches

— H parameter much smaller than without NTM in plasma core

— Long radial propagation clearly broken near the q=3/2 surface (NTM)