ELM Control by the SMBI Induced Pedestal Small Scale Turbulence

X.L. Zou[1], A.D. Liu[2], X.Z. Gong[3], J.S. Hu[3], H.Y. Guo[3,4], L.Q. Hu[3], J.G. Li[3], B.N. Wan[3], W.W. Xiao[5,6], P.H. Diamond[6,7], C.X. Yu[2], Y.F. Liang[8], G.S. Xu[3], J.H. Li[3], K.F. Gan[3], L. Wang[3], S.B. Zhang[3], J.P. Qian[3], B. Shen[3], S.Y. Lin[3], A. Ti[3], X.W. Zheng[3], F.K. Liu[3], J.F. Shan[3], B.J. Ding[3], M. Wang[3], Y.P. Zhao[3], X.J. Zhang[3], C.M. Qin[3], C. Zhou[2], X.H. Zhang[2], J.Q. Hu[2], Z.W. Wu[3], W. Gao[3], L. Zhang[3], T.H. Shi[3], T. Zhang[3], Y.M. Wang[3], Y.X. Jie[3], L.Q. Xu[3], J.Z. Zhang[3], Y.M. Duan[3], B. Lu[3], F.D. Wang[3], Y.Y. Li[3], and the EAST Team[3]

[1]CEA, IRFM, France
[2]USTC, Hefei, China
[3]ASIPP, Hefei, China
[4]General Atomics, San Diego, USA
[5]SWIP, Chengdu, China
[6]UCSD, San Diego, USA
[7]WCI Center for Fusion Theory, NFRI, Daejeon, Korea
[8]Association EURATOM-FZJ, Jülich, Germany

This work is supported within the framework of the cooperation between CEA (France) and the Chinese Academy of Science (China).

Why Control ELMs?

ASIPP

- One of the major challenges for the magnetic fusion community is how to extract energy from the plasma core of the fusion reactor without damaging the plasma facing components, in particular the divertor plates.

- Large edge instabilities, known as type-I ELMs, can eject a large quantity of particles and energy from the core plasma, causing significant erosion at the divertor target.

- For ITER, in order to not damage the divertor plates, the peak heat load on the target plates is limited to $10MW/m^2$ in steady condition and $20MW/m^2$ in transient condition during Type-I ELMs. (A.S. Kukushkin, NF 2002, M. Sugihara, JPFR 2002)

- Simulation and scaling predict the diveror peak heat load in ITER significantly exceeding the limit.

- How to reduce the power flux density on the divertor plates is a critical issue.

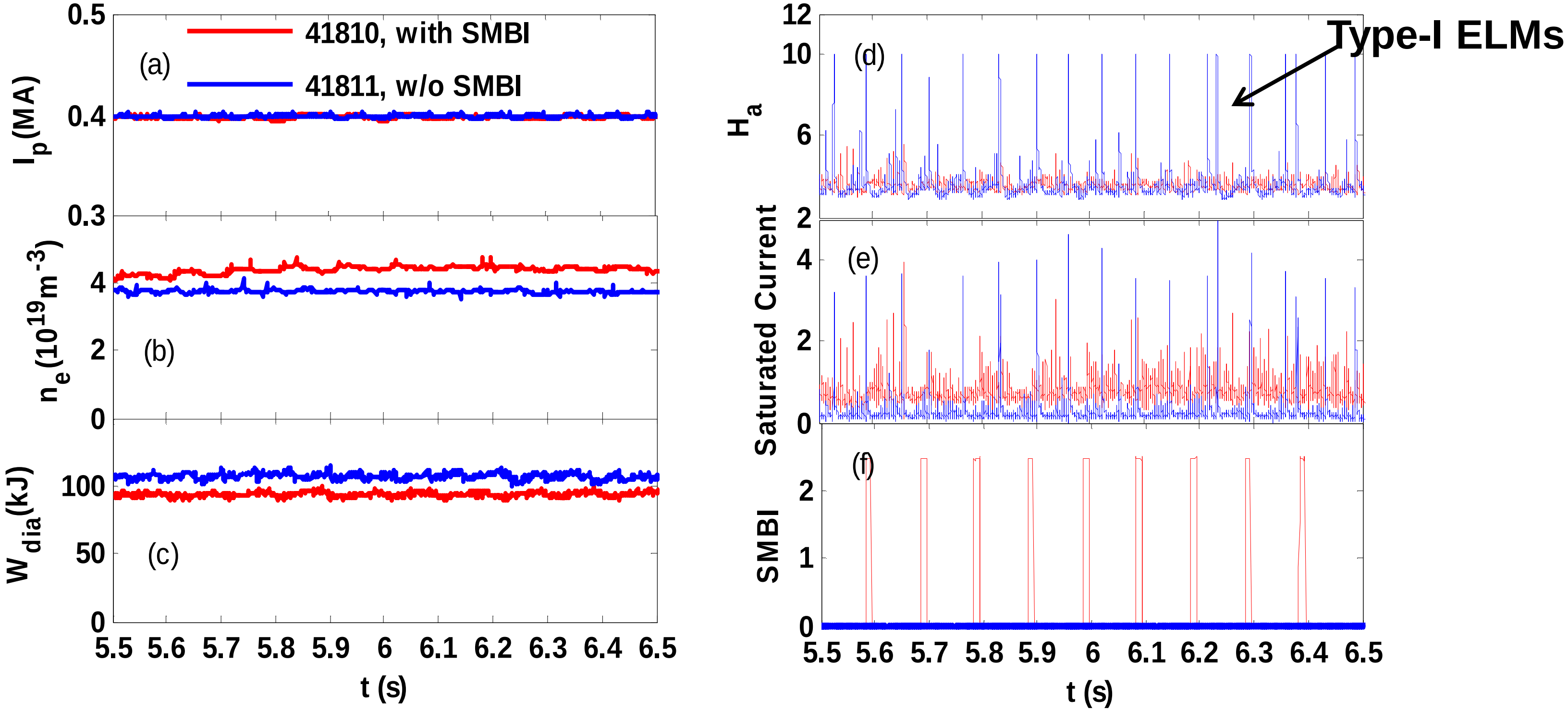
ELM Control Technique

- Existing ELM control techniques:
  - Pellet pacing (P.T. Lang, NF 2003)
  - Resonance Magnetic Perturbation (RMP) (T. E. Evans, PRL 2004)
  - Other external perturbation fields (M.J. Schaffer, NF 2008)
- ELM mitigation using single pulse of SMBI has been demonstrated in HL-2A (W.W. Xiao, P.H. Diamond, X.L. Zou, NF 2012), then in KSTAR (W.W. Xiao, P.H. Diamond, W.C. Kim, NF 2014)
- SMBI Experiments in EAST : 1) Understanding of the mechanism of the ELM mitigation by SMBI; 2) Demonstration of the steady state operation with multi-pulses of SMBI.

Multi - Pulses Steady State Operation

ASIPP

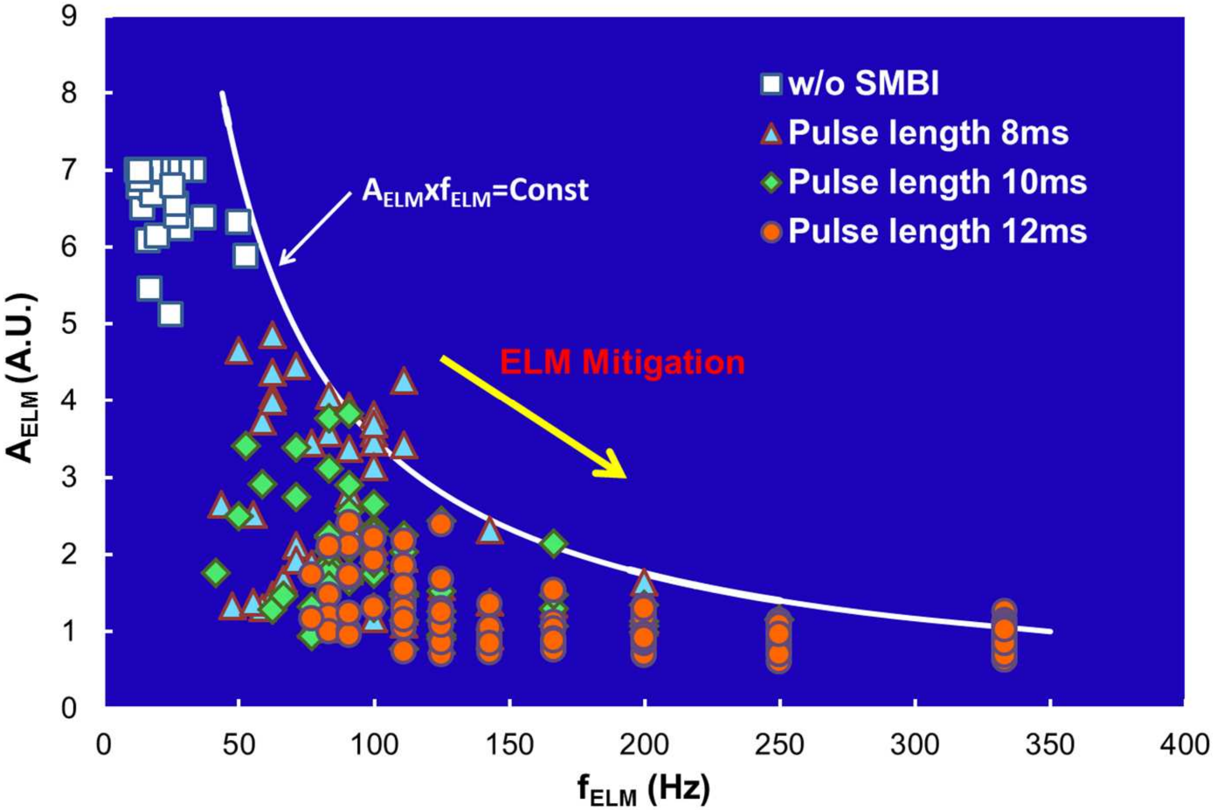
Comparison of 2 H-mode plasmas with (red) and without (blue) SMBI
(400kA/LSN/LHW-1.5MW/ICRF-1.1MW)



- **Strong reduction of the ELM amplitude with SMBI.**
- **ELM frequency increased of 5-10 times with SMBI.**
- **Energy confinement slightly degraded with ELM mitigation.**

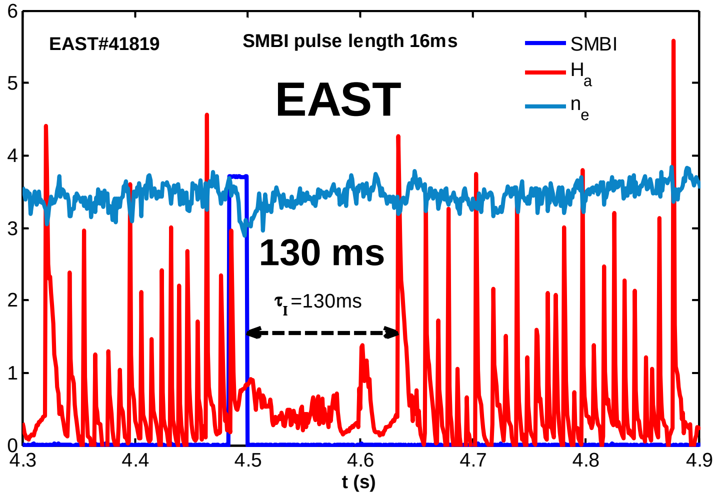
SMBI Pulse Length Effect on ELMs

ASIPP



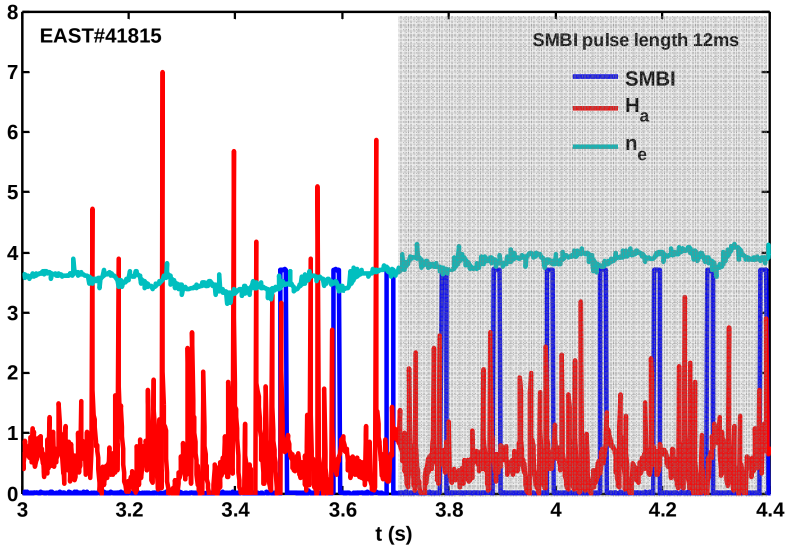
- **ELM mitigation effect increases with SMBI pulse length.**

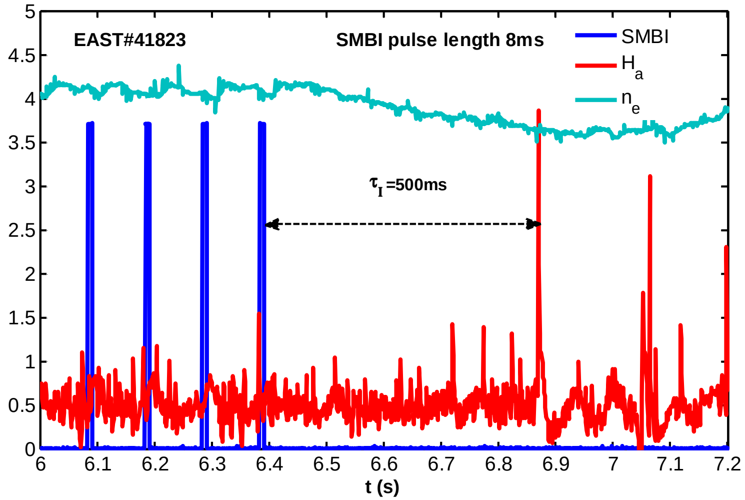
Influence Time of SMBI Pulse



In EAST, ELM mitigation has been observed for single SMBI pulse with pulse length of 16ms, and not observed for single SMBI pulse of 12ms and shorter.

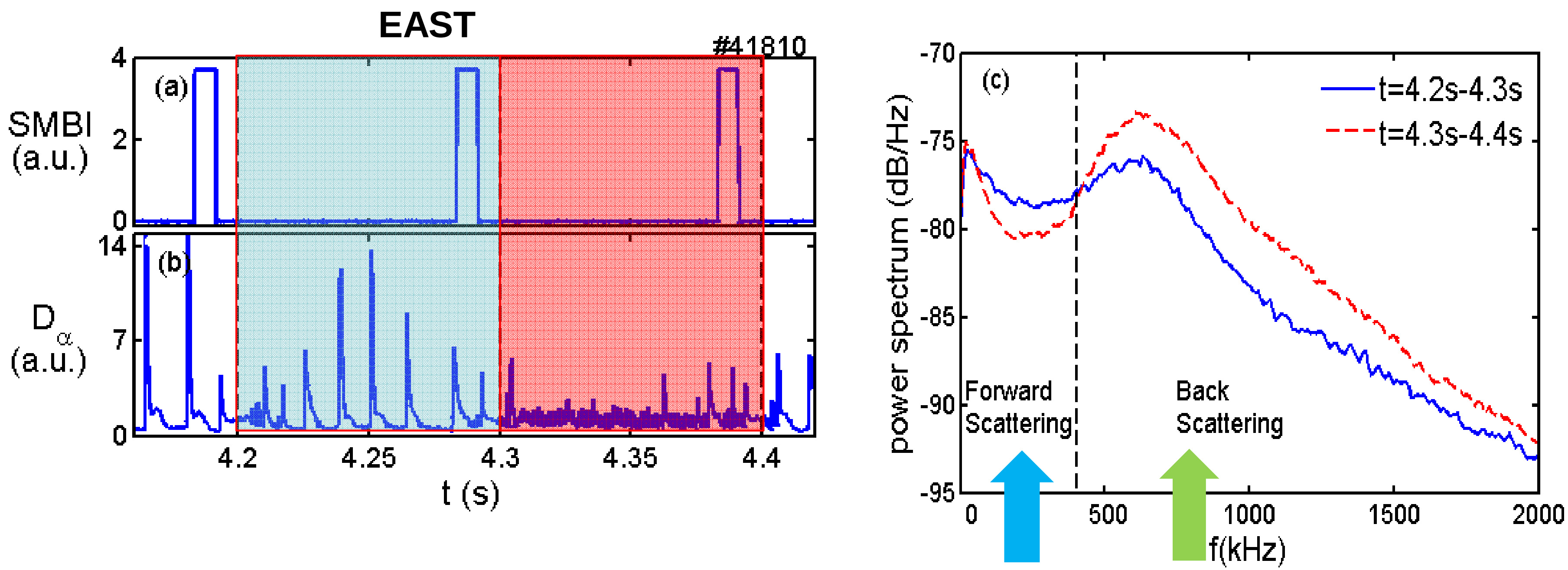
Accumulative effect of SMBI pulses for the ELM mitigation





Pedestal Turbulence

ASIPP



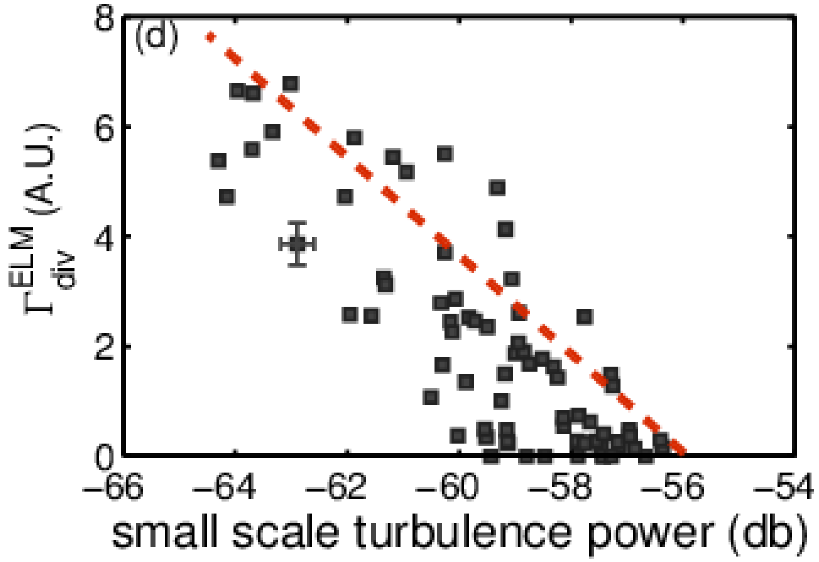
Doppler Reflectometry
f_0=74GHz
X-mode

Forward Scattering	**Backscattering**
▪ No spatial localization	▪ ρ_c=0.9
▪ Δk_θ=0.8cm^{-1}	▪ k_θ=7.3cm^{-1}
▪ Large scale turbulence	▪ Small scale turbulence

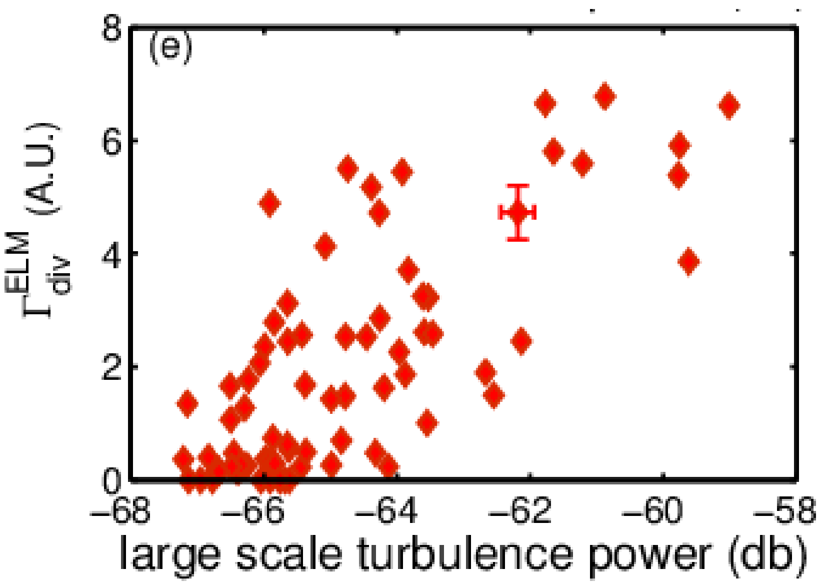
Correlation Turbulence / ELM

ASIPP

Small scale turbulence



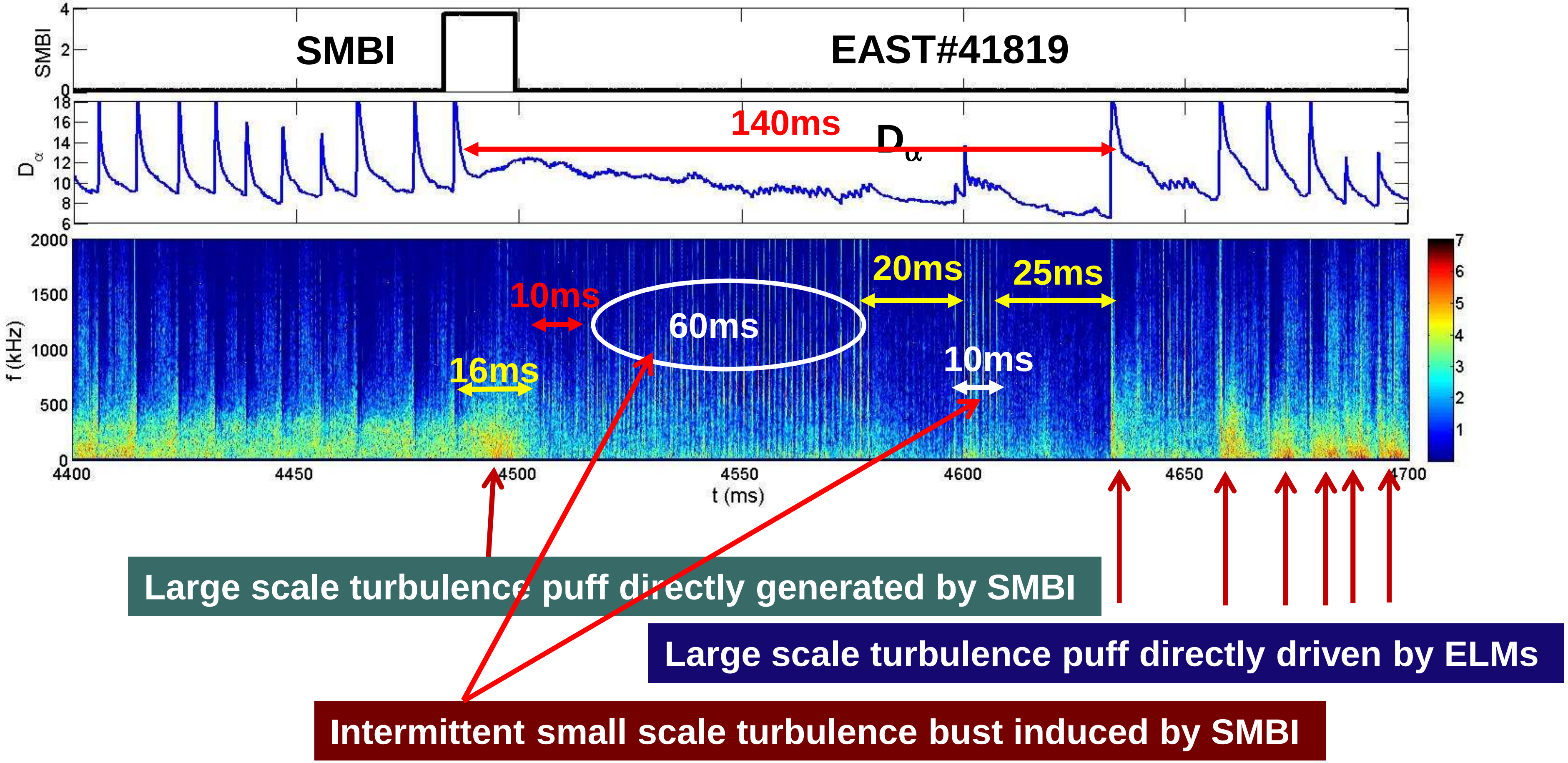
Large scale turbulence



- **Anti-correlation between small acle turbulence and ELMs.**
- **Existence of threshold in turbulence level for ELM suppression.**

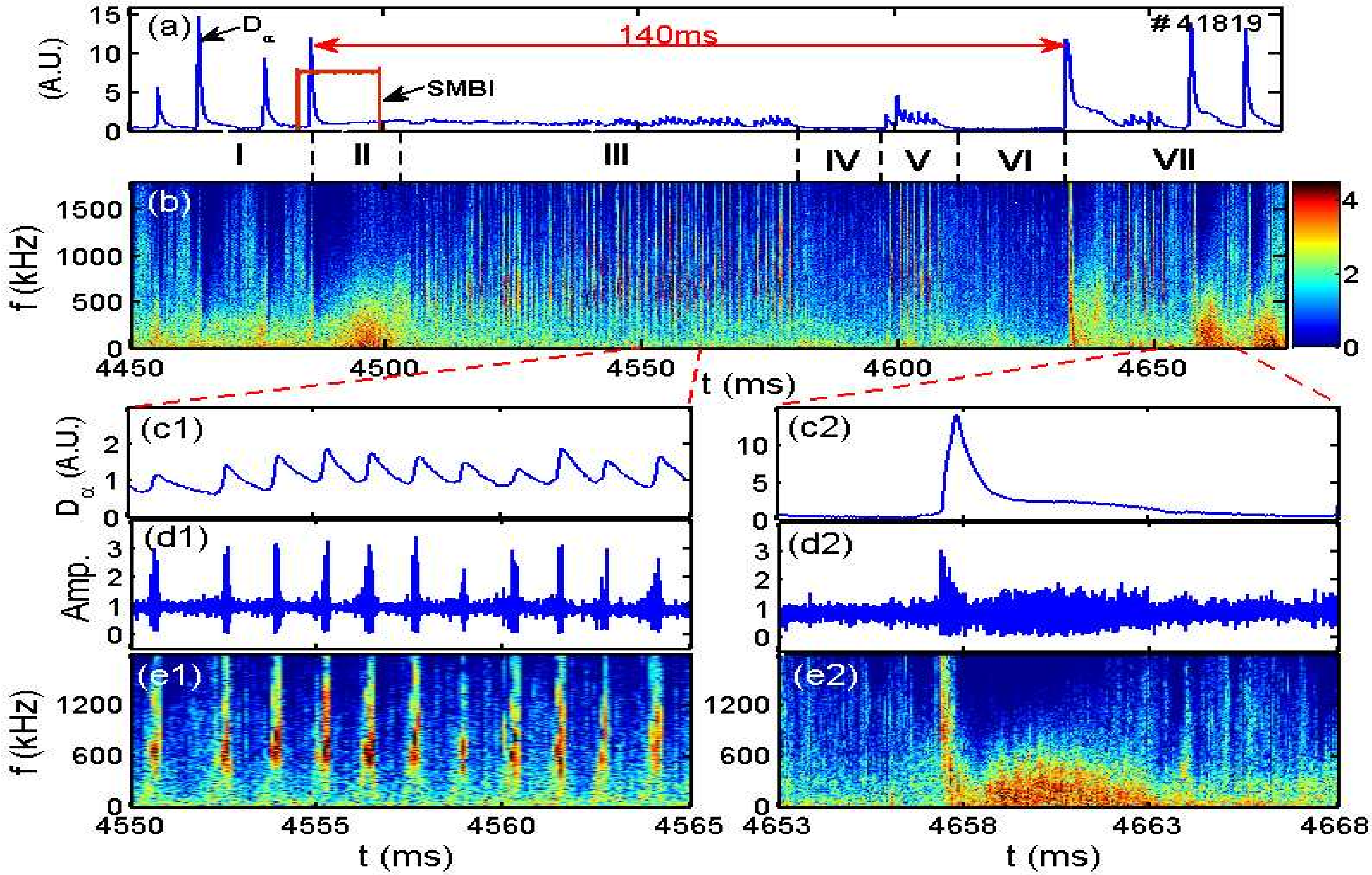
- **Correlation between large scale turbulence and ELMs.**

ELM Suppression by SMBI



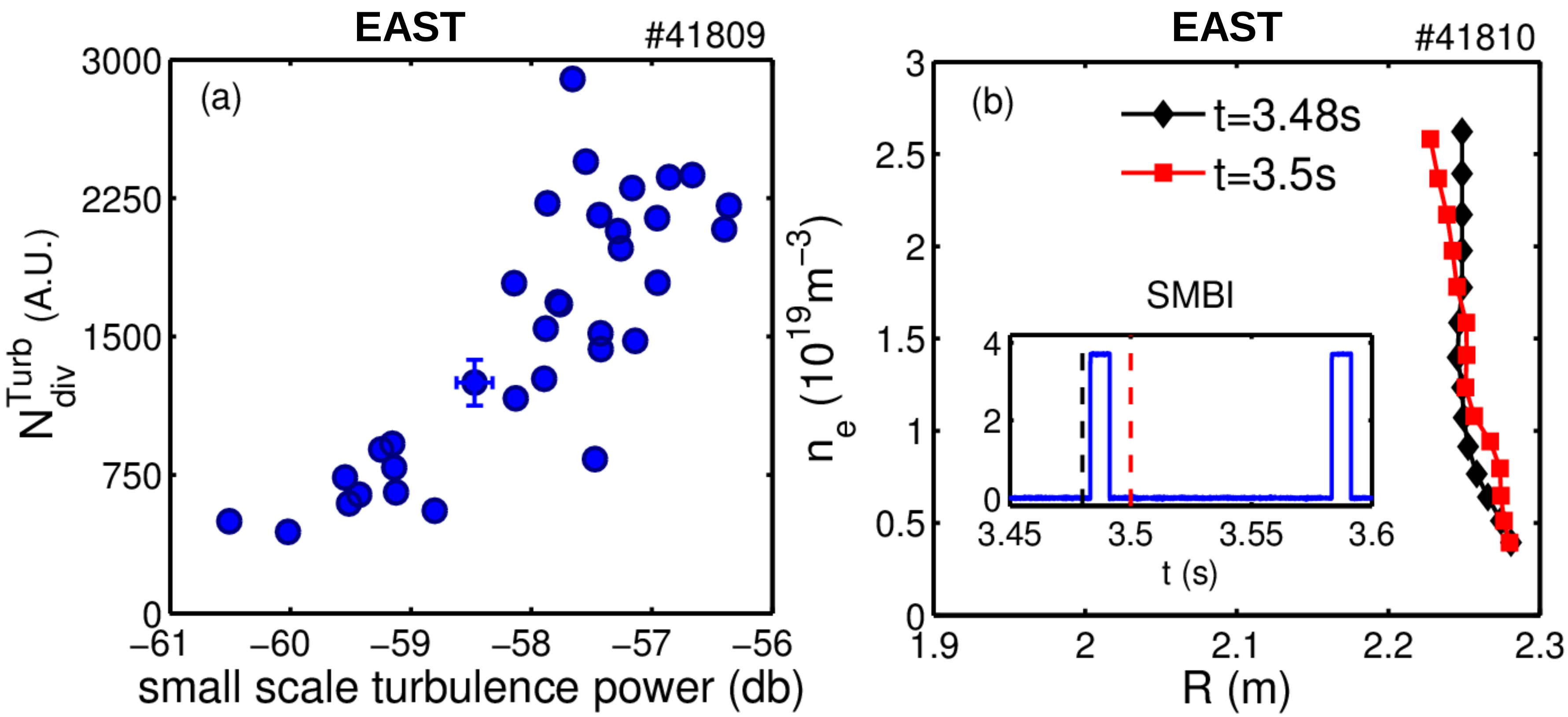
- Large scale turbulence (<400kHz) is triggered by the ELMs.
- Intermittent small scale turbulence (>400kHz) busts prevent the formation of the ELMs.
- SMBI influence time τ_I could be determined by the small scale turbulence duration.

Small Scale Turbulence Controlling ELMs



Particle Flux Driven by Small Scale Turbulence

ASIPP

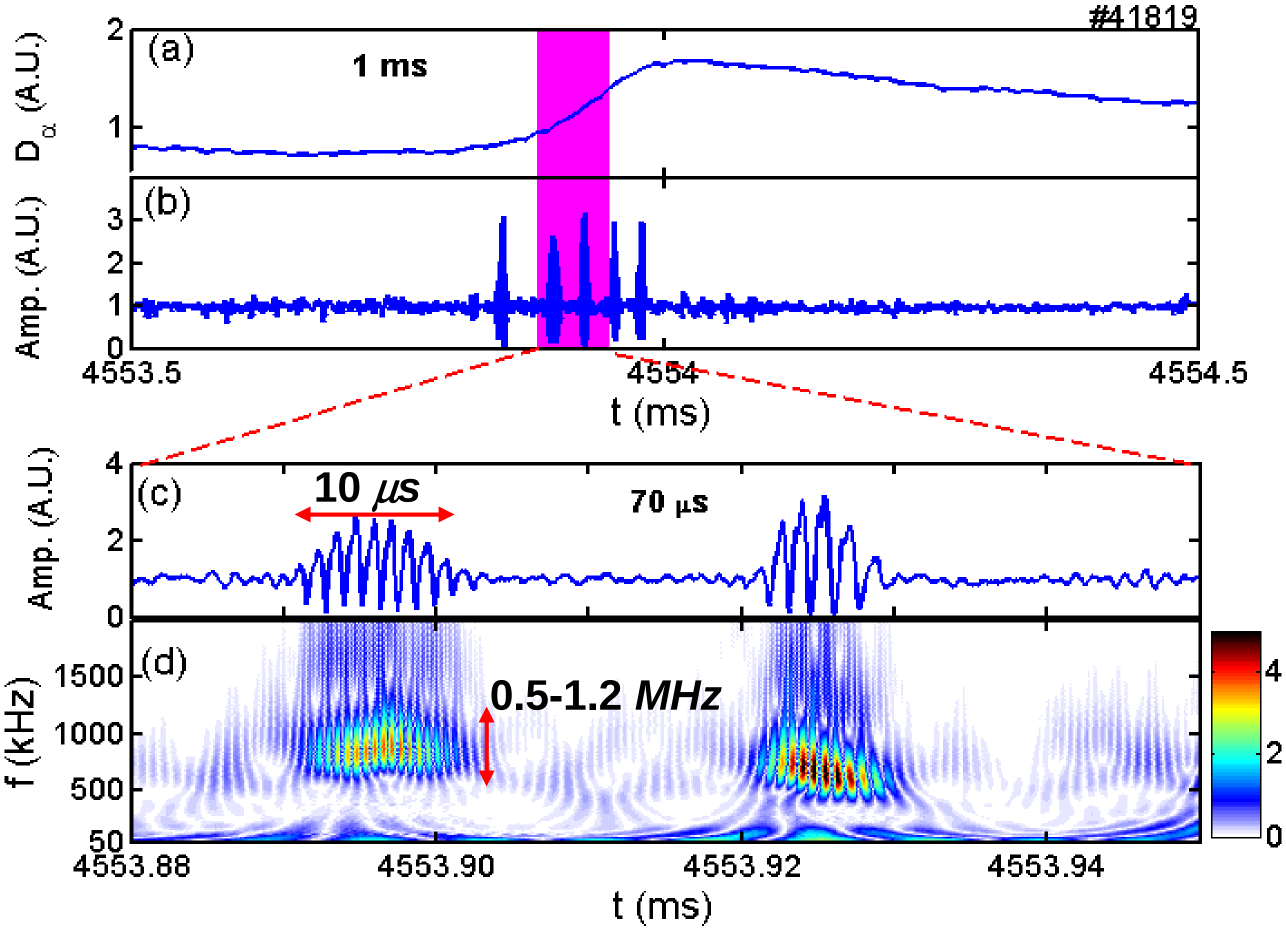


Density gradient decreases with the enhancement of the particle transport inside the pedestal due to the small scale turbulence.

Structure of Small Scale Turbulence

EAST

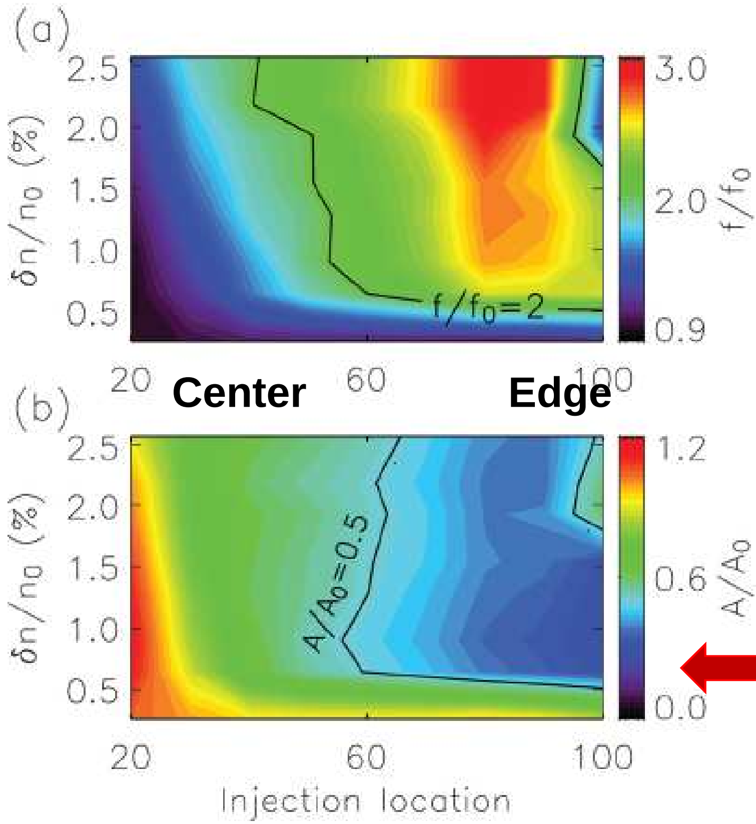
(k_θ~7.3cm^{-1}, *m* = 300, *n* = 66)

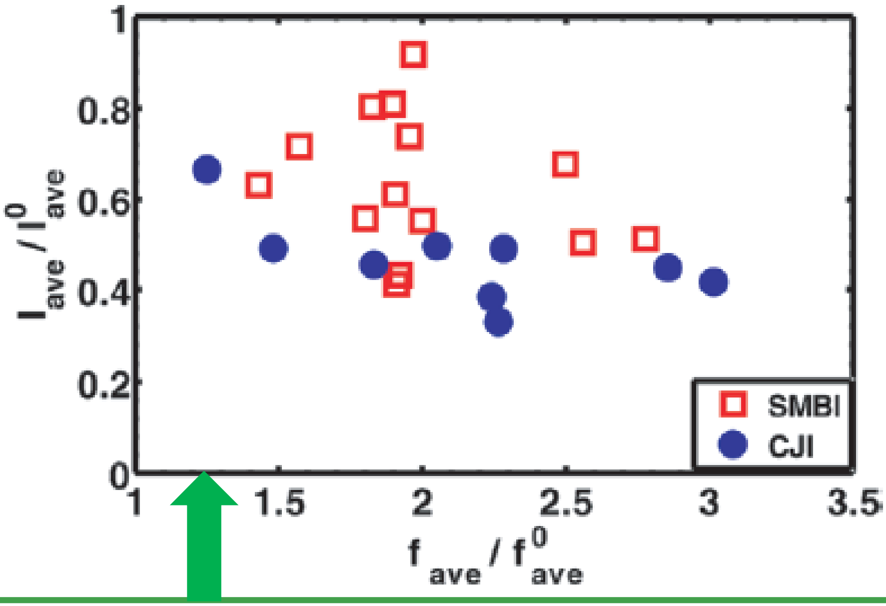


Effect of Particle Deposition

ASIPP

Simple and purely transport model with Avalanche theory





Mitigation effect is better with CJI (Cold SMBI) than with SMBI

(X.R. Duan, NF 2013)

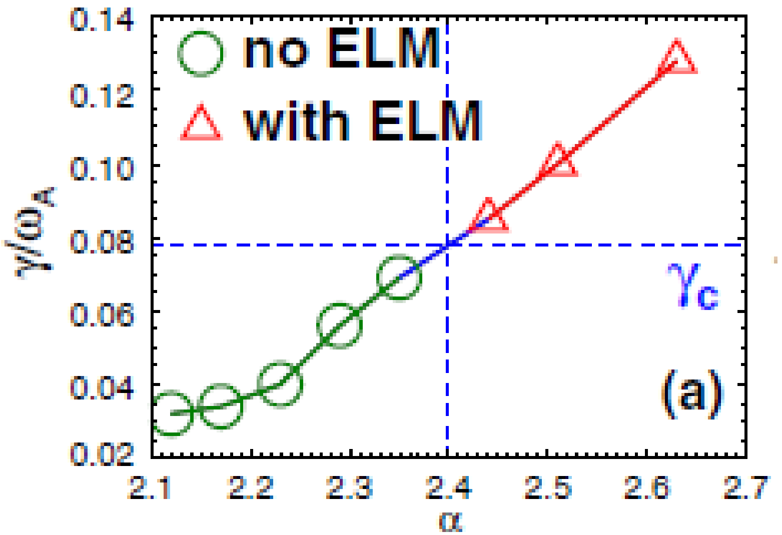
Best results for the particle source deposition inside the pedestal.

(T. Rhee, J.M. Kwon, P.H. Diamond and W.W. Xiao, PoP 2012)

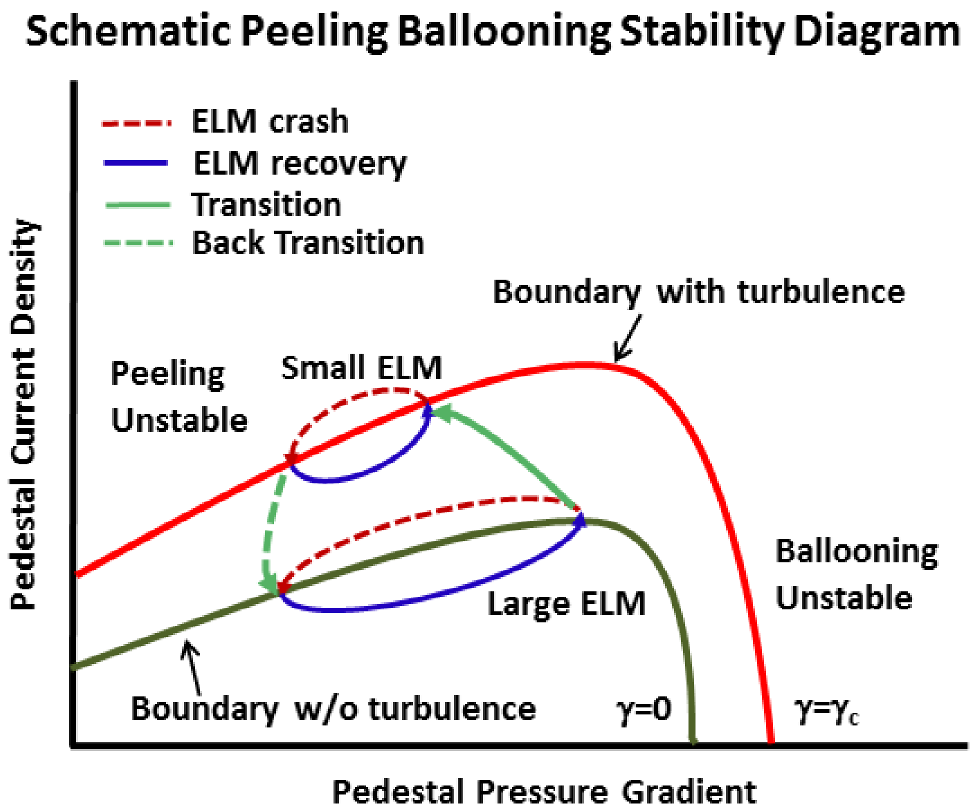
Nonlinear Peeling Ballooning Model

ASIPP

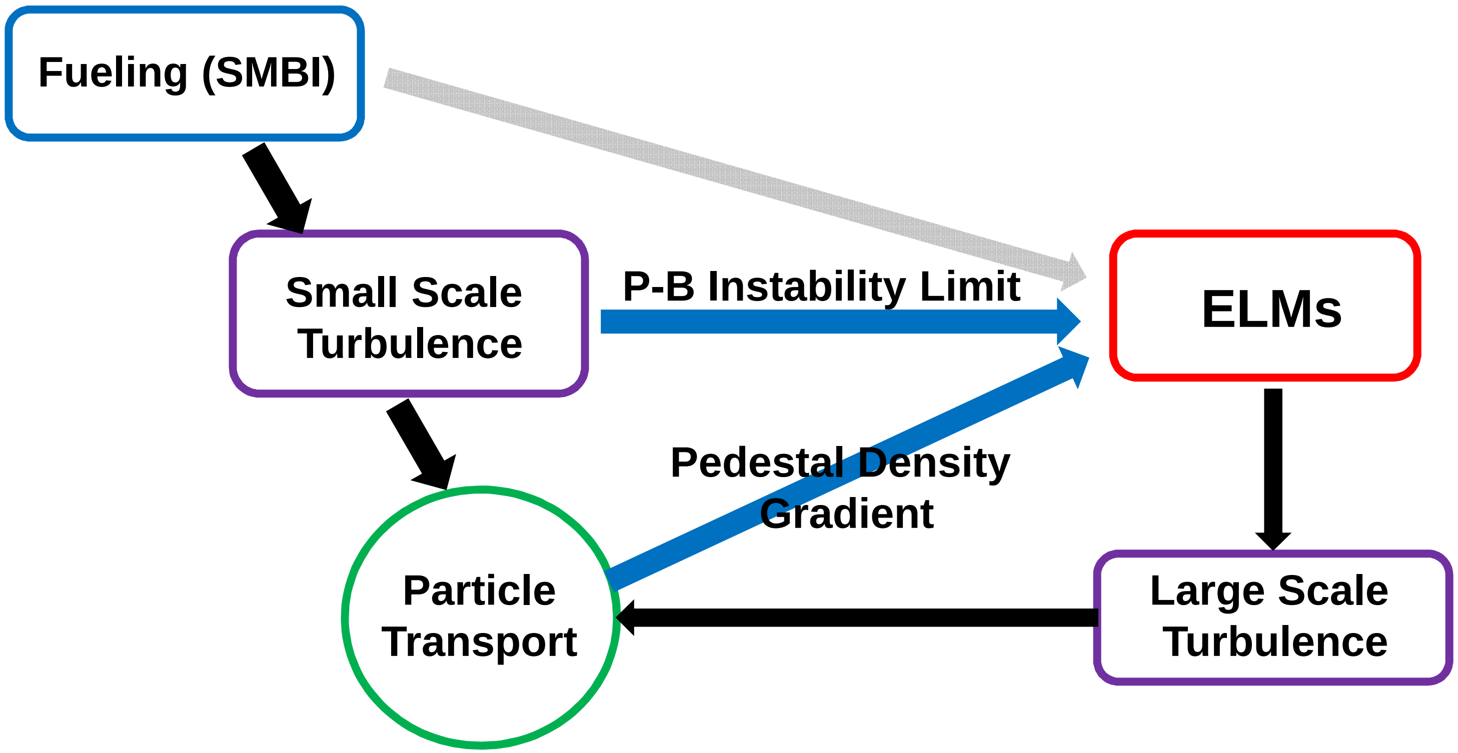
- Nonlinear interaction between turbulence and ELMs.
- Extension of the Peeling Ballooning instability limit.



(P.W. Xi, X.Q. Xu, P.H. Diamond, PRL 2014)



Turbulence Effects on ELMs



Summary

1) ELM mitigation with multi-pulses of SMBI has been demonstrated in EAST for quasi-steady state over 3 s.
2) Particles are deposited into the pedestal by SMBI in H-mode plasmas.
3) ELM mitigation is due to the enhancement of the particle transport in the pedestal, caused by intermittent small scale turbulence induced by SMBI.
4) A critical threshold on the small scale turbulence intensity is clearly observed for ELM suppression.
5) SMBI influence time is governed by the intermittent small scale turbulence.