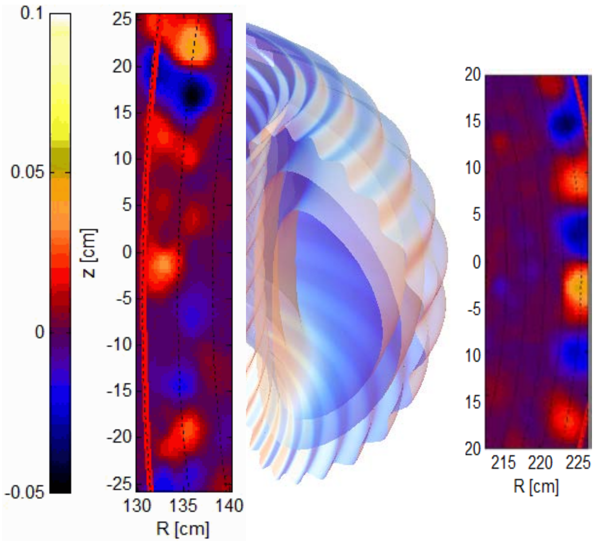
Simultaneous measurement of the ELMs at both high and low field sides and ELM dynamics in crash-free period in KSTAR



ELMs at the
high & low field sides

Hyeon K. Park

UNIST, Ulsan, Korea

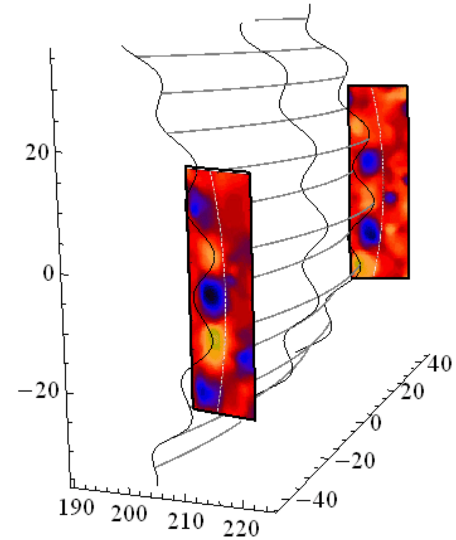
at

25th IAEA FEC Conference

Oct. 12 -18 2014,

St. Petersburg,

Russian Federation



ELMs in 3D
[low field side)

In collaboration with

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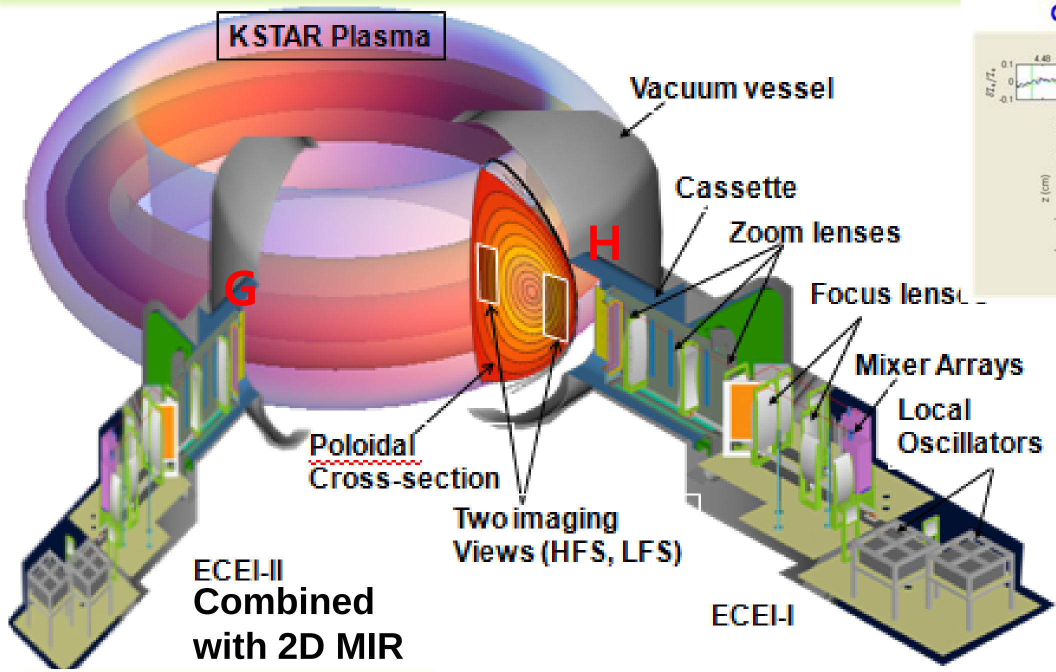
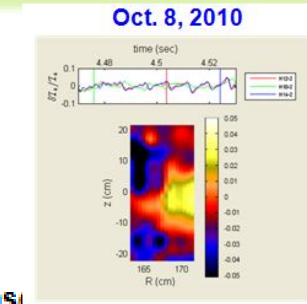
UNIST Ulsan National Institute of Science and Technology · UC DAVIS UNIVERSITY OF CALIFORNIA · NFRI 국가핵융합연구소 National Fusion Research Institute · COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK · POSTECH POHANG UNIVERSITY OF SCIENCE AND TECHNOLOGY

Outline

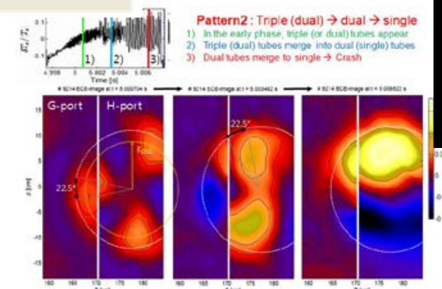
- KSTAR 2D/3D ECE Imaging and MIR system
  - 2D validation of the physics in modeling → predictive capability of MHD and transport physics modeling
- Images of the ELMs in H-mode plasma
  - Growth -> Saturation -> Crash
  - Validate the measured ELMs with synthetic images
- ELMs at High field side
  - Discrepancies with the current understanding
- ELM dynamics during the crash free period
  - Underlying dynamics of suppression/mitigation of the ELMs?

KSTAR 2D/3D Imaging systems



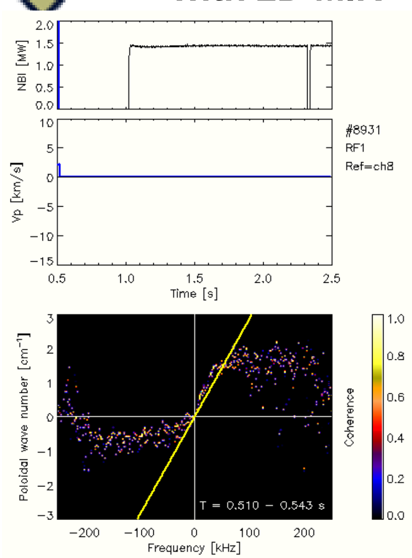


at 23rd FEC
Daejeon
Korea

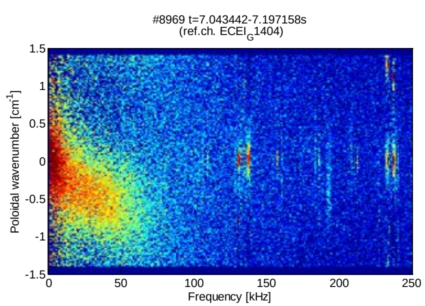


Modified sawtooth

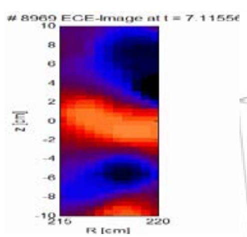
EX/P8-12, G. Yun



2D Density fluctuation



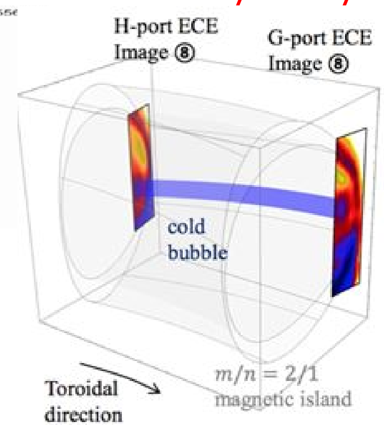
T_e fluctuation (k vs. ω)

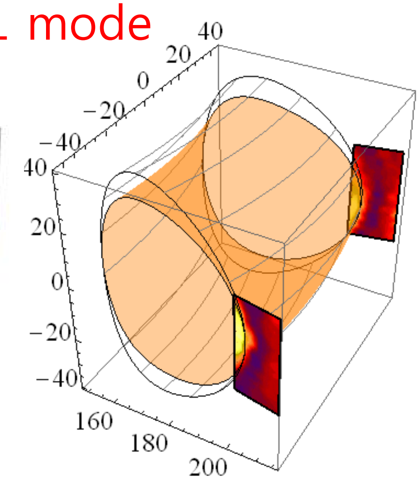


2D T_e fluctuation (30-50 kHz)

EX/P8-13, W. Lee

m/n=2/1 mode

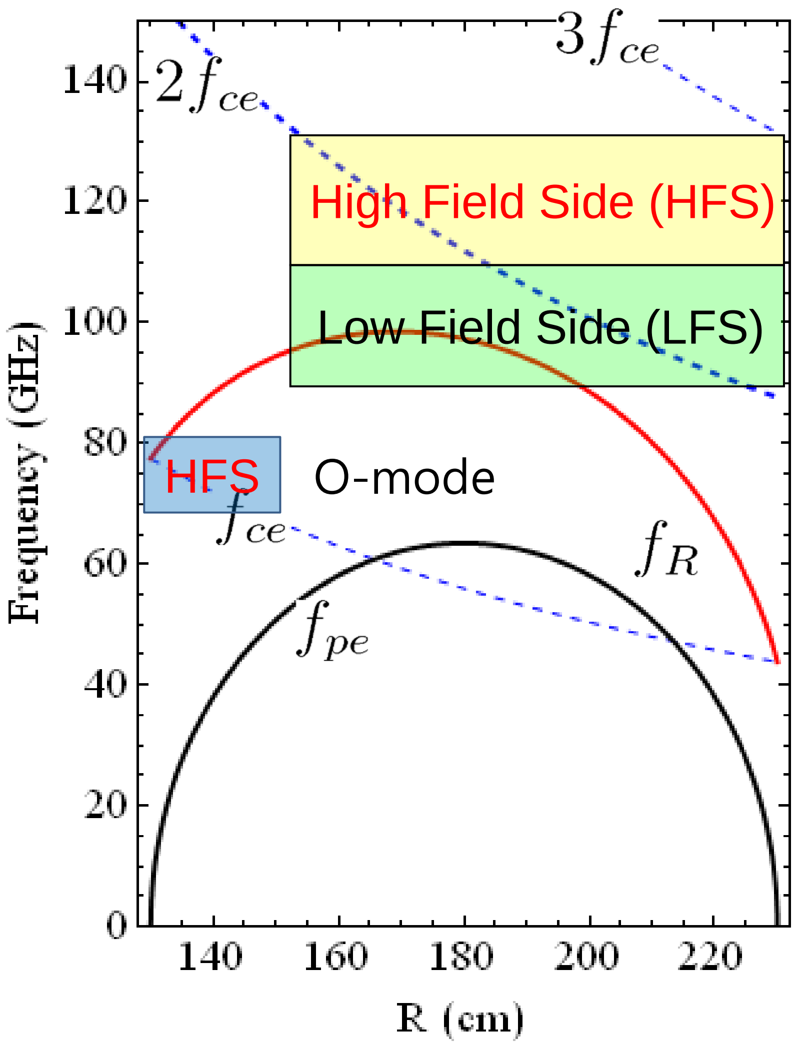




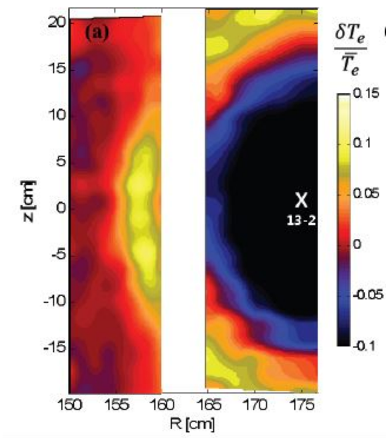
Cold bubble
Leads to disruption

EX/P8-15, Choi

KSTAR ECEI viewing windows (B_0=2.0 T)

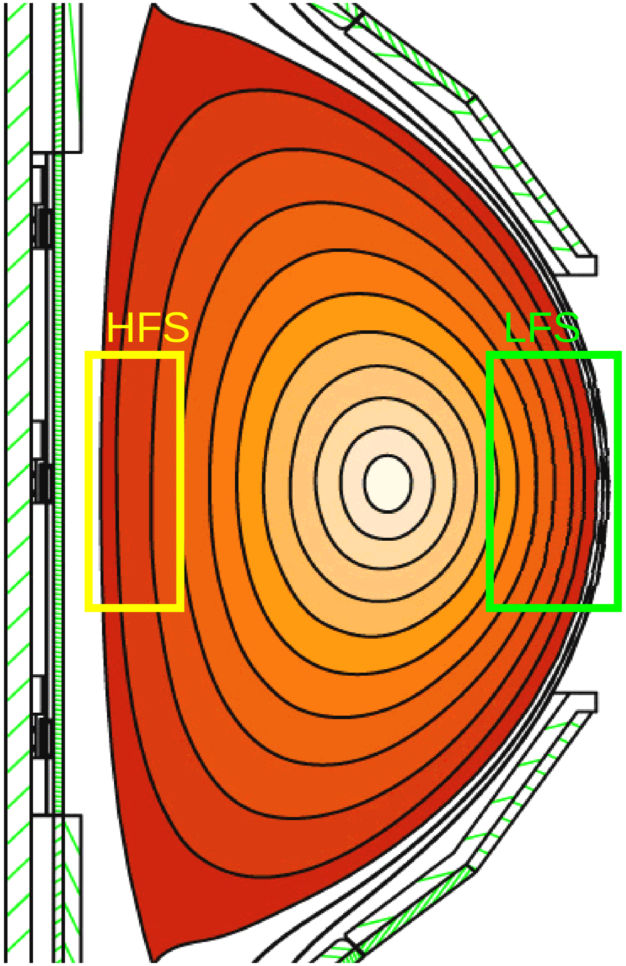


Characteristic frequencies of the electron cyclotron emission



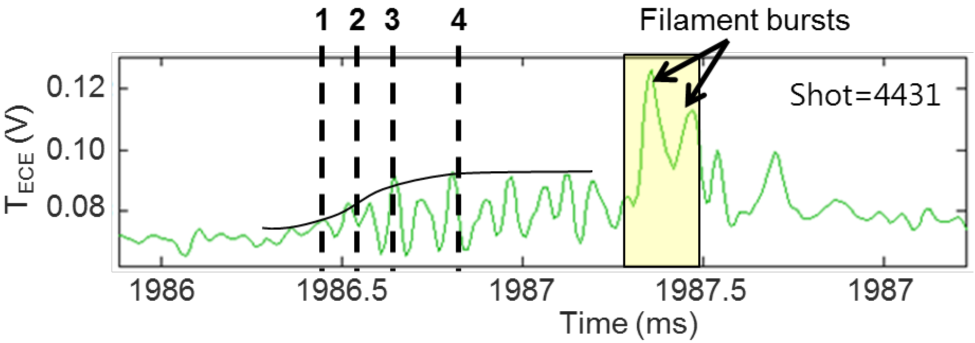
Measurement with O-mode polarization is verified for Sawtooth crash

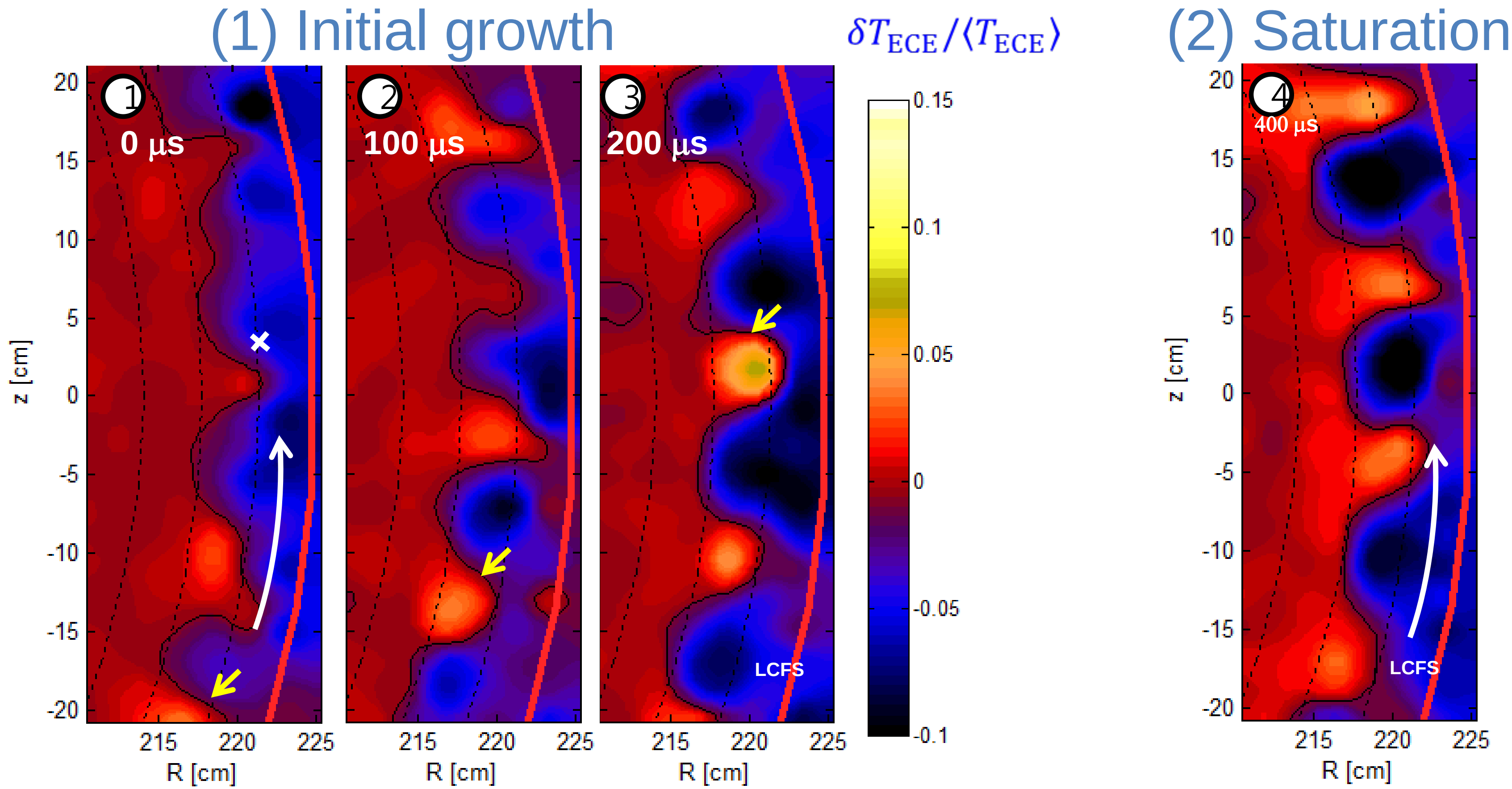
J. Lee_JINST_(2011)



Poloidal view of the KSTAR plasma

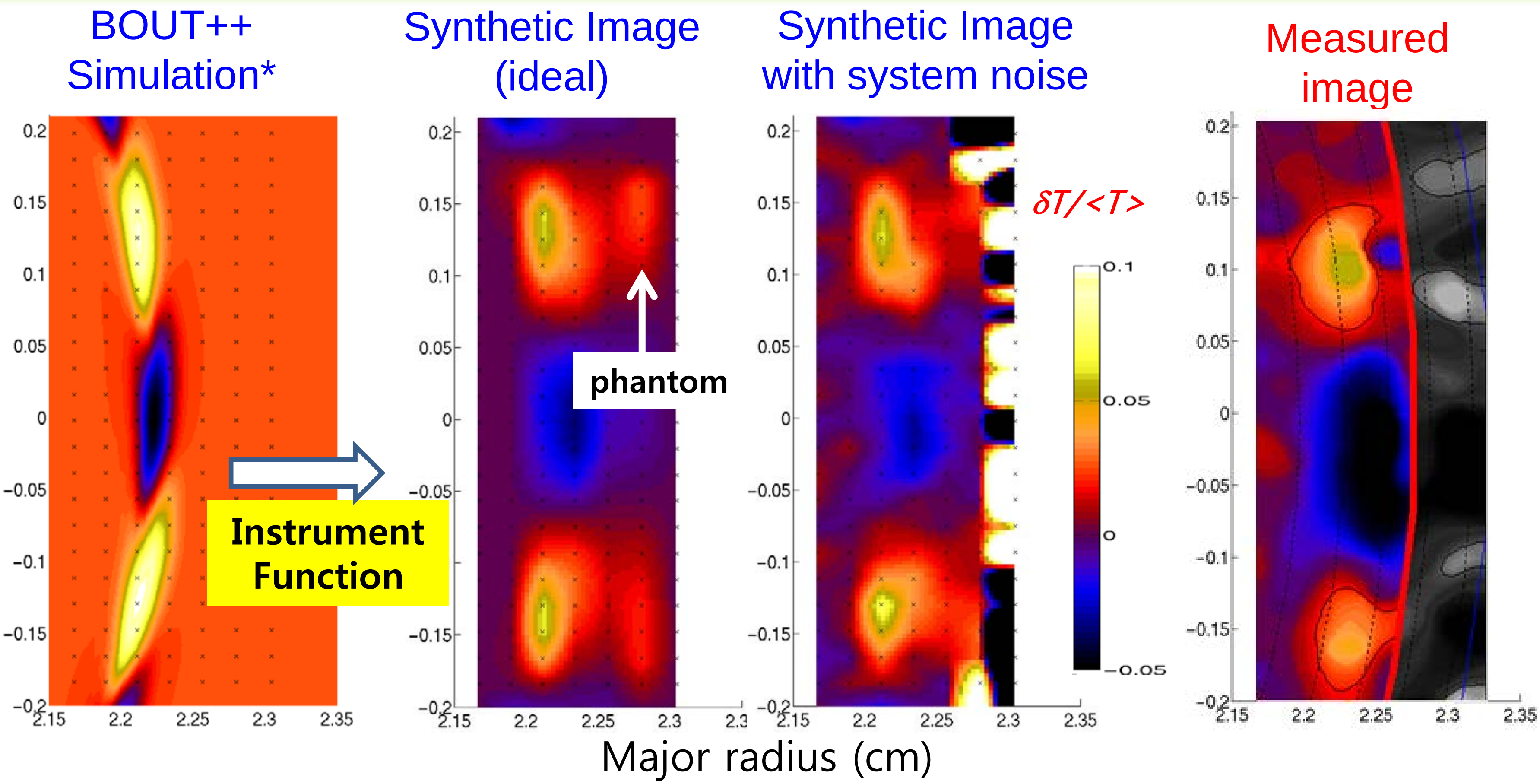
Dynamics of a single ELM in KSTAR H-mode plasmas





G.S. Yun et al., PRL 107 (2011)

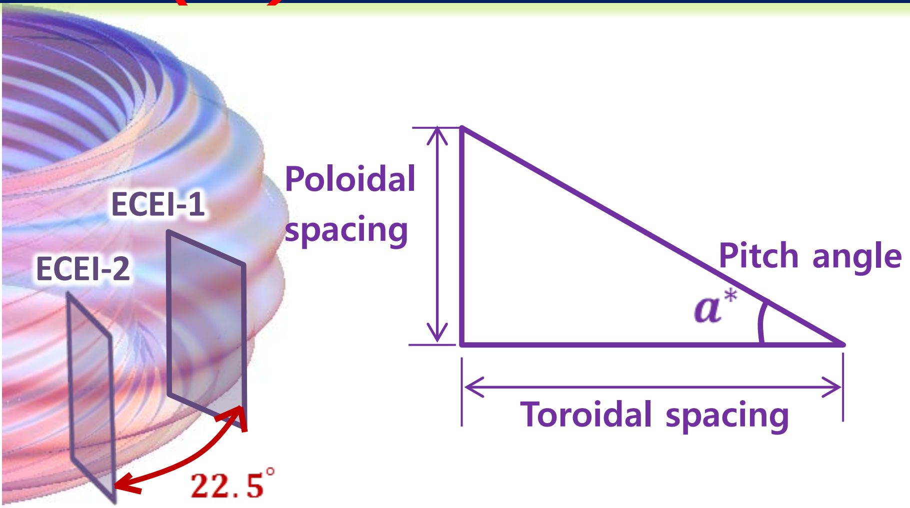
Validation of the ELM structure



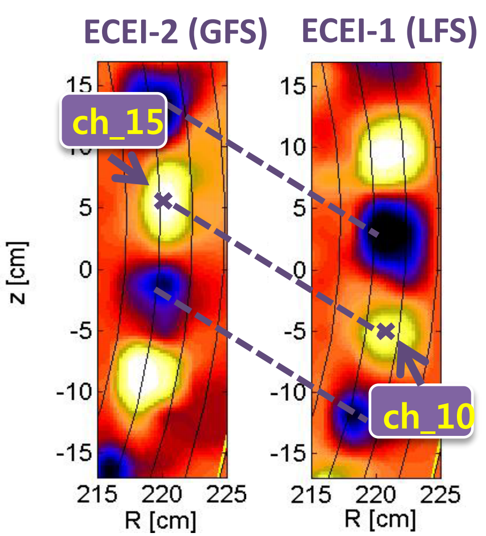
- *Observed structure = a faithful representation of ELM filaments*
  - *Phantom image outside the separatrix due to ECE downshift from inside (well known); masked by finite system noise and scattered emission*
  - *We ignore ECE signals contaminated by the downshifts*

M. Kim et al., NF 54 (2014)

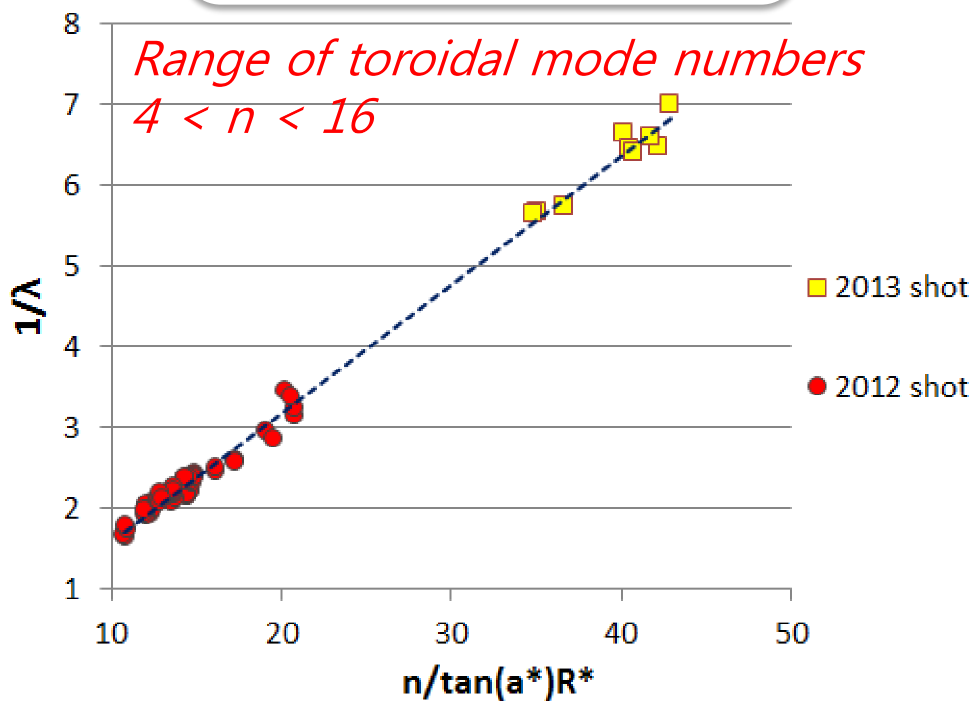
Relationship between toroidal (n), poloidal (m) mode numbers & pitch angle ($\alpha*$)



$$tan(a^*) = \frac{poloidal\ spacing}{Toroidal\ spacing}$$



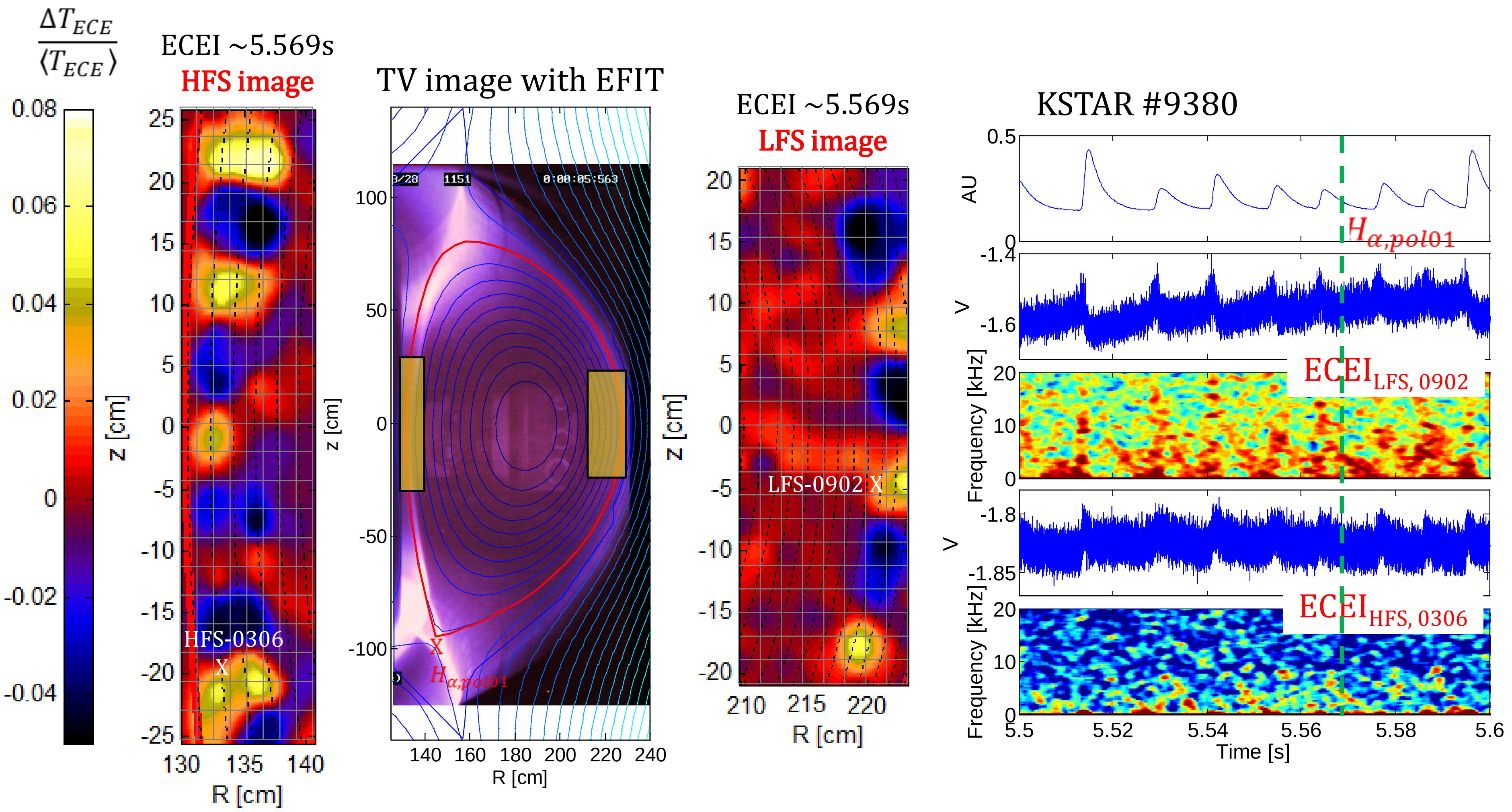
$$n = \frac{2\pi R^*}{\lambda_{pol}} tan(a^*)$$



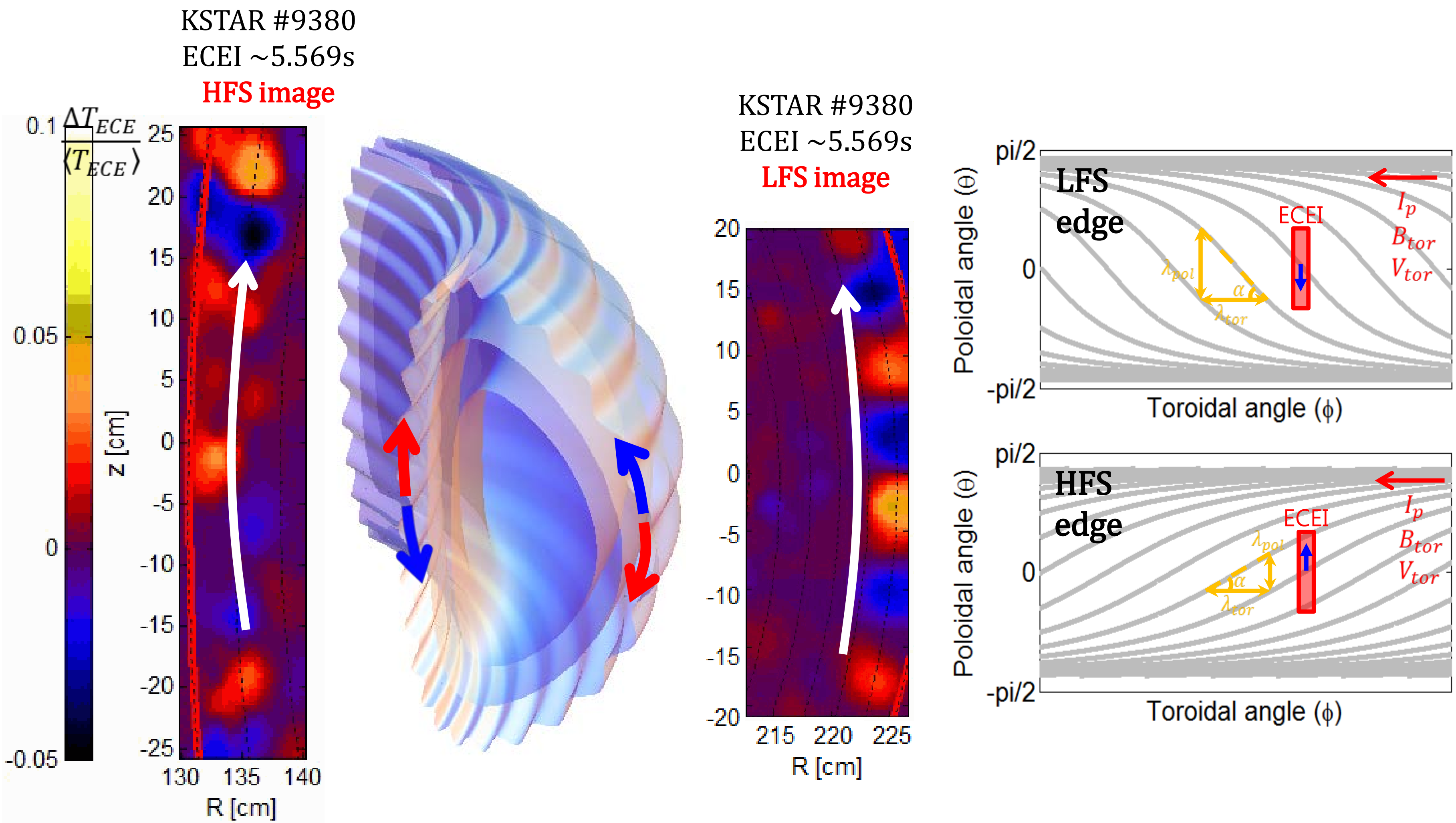
J.H. Lee, RSI, 85 (2014)

J.E. Lee, 9th APFA conference (2013)

Simultaneous measurement of the ELMs at both HFS and LFS (2013)



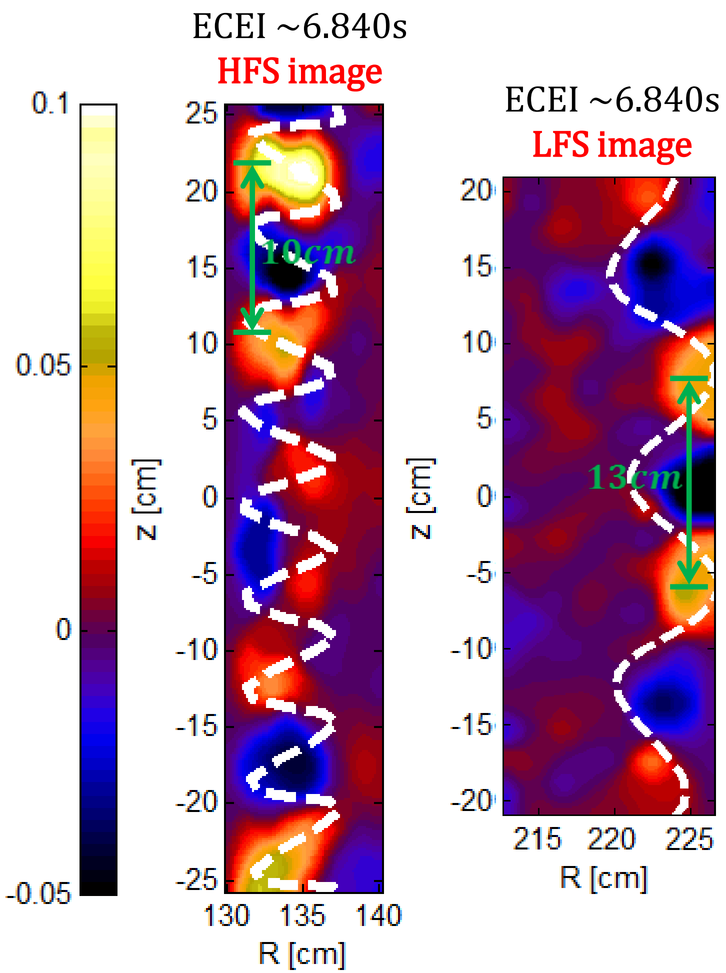
Rotation direction and mode strength



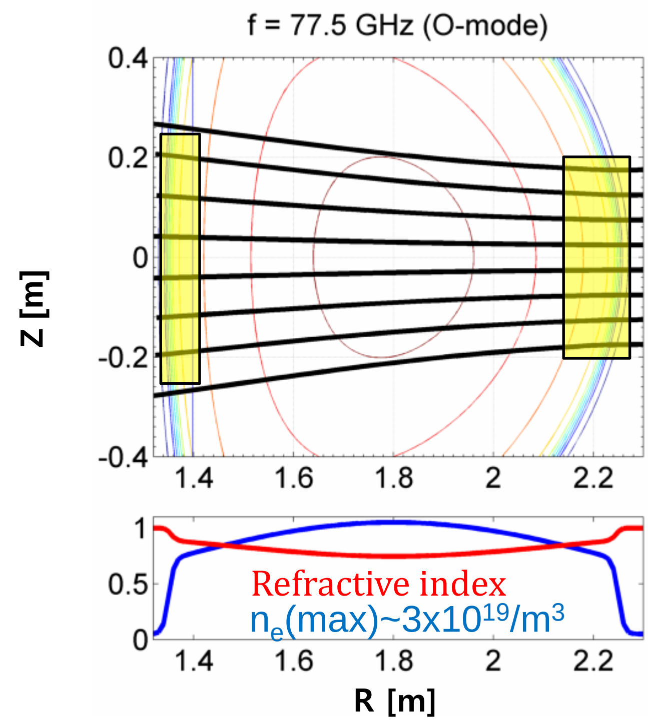
- Rotation direction – Asymmetries in toroidal and/or poloidal velocity
- Comparable mode strength at HFS and LFS – No shear flow damping at HFS ?

Mode spacing based on Ballooning mode

$B_0 = 2.15$ T $\quad W_{tot} = 270$ kJ
$I_p = 610$ kA $\quad q_{95} \approx 6$
$n_{e,avg} = 3 \times 10^{19}\ 1/\mathrm{m}^3$

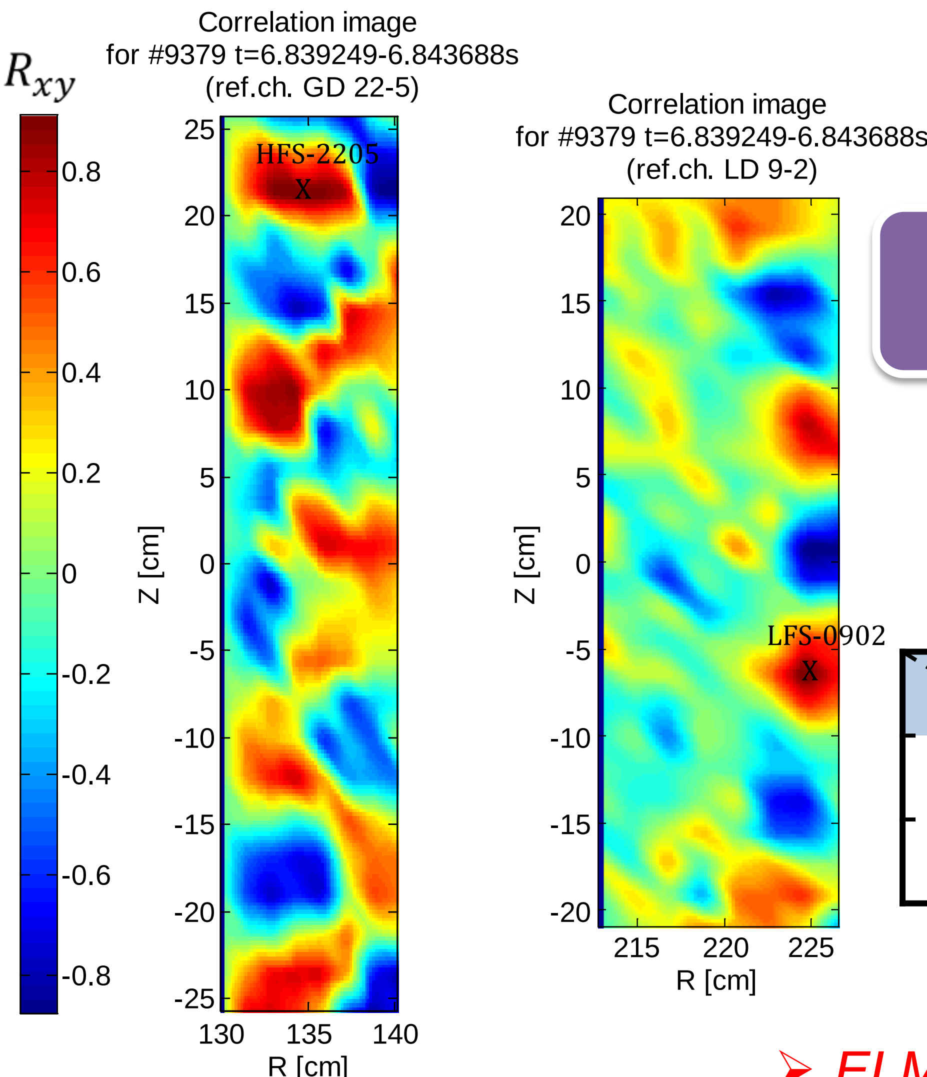


- *Refraction effect - the actual mode spacing in HFS should be larger than the observed one.*



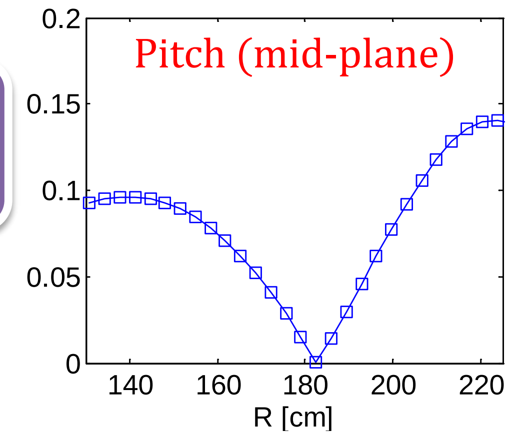
- ***In and out pressure asymmetry ? unlikely***
- ***The structure of ELM filaments at the HFS is not consistent with the ballooning mode structure.***

2-D correlation image of the HFS & LFS ELMs



- The ECEI can provide a fairly accurate toroidal mode number (n) using 2-D image and equilibrium fitting.

$$n = \frac{2\pi R^*}{\lambda_{pol}} tan(a^*)$$

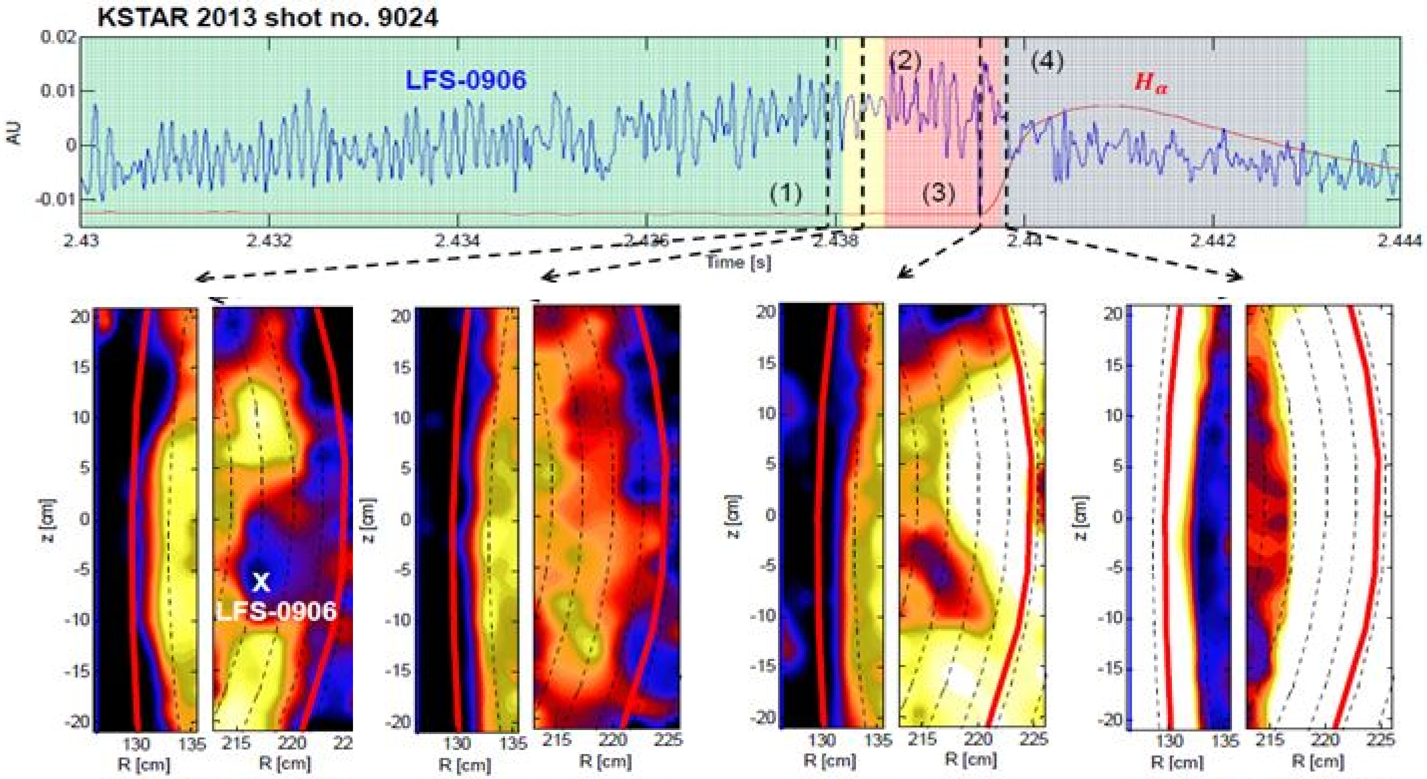


	R_* $[cm]$	λ_{pol} $[cm]$	$\tan\alpha_*$	n
LFS	225	13	0.13	14–15
HFS	132	10	0.09	7–8

➢ *ELM structure + strong shear flow in HFS edge -> streamer like role ?*

Burst process of the HFS & LFS ELMs (2013)

Time evolution of a single global ELM crash



(1) HFS LFS

(2) HFS LFS

(3) HFS LFS

(4) HFS LFS

End of the coherent mode period

Chaotic phase just before the crash – multimode interference?

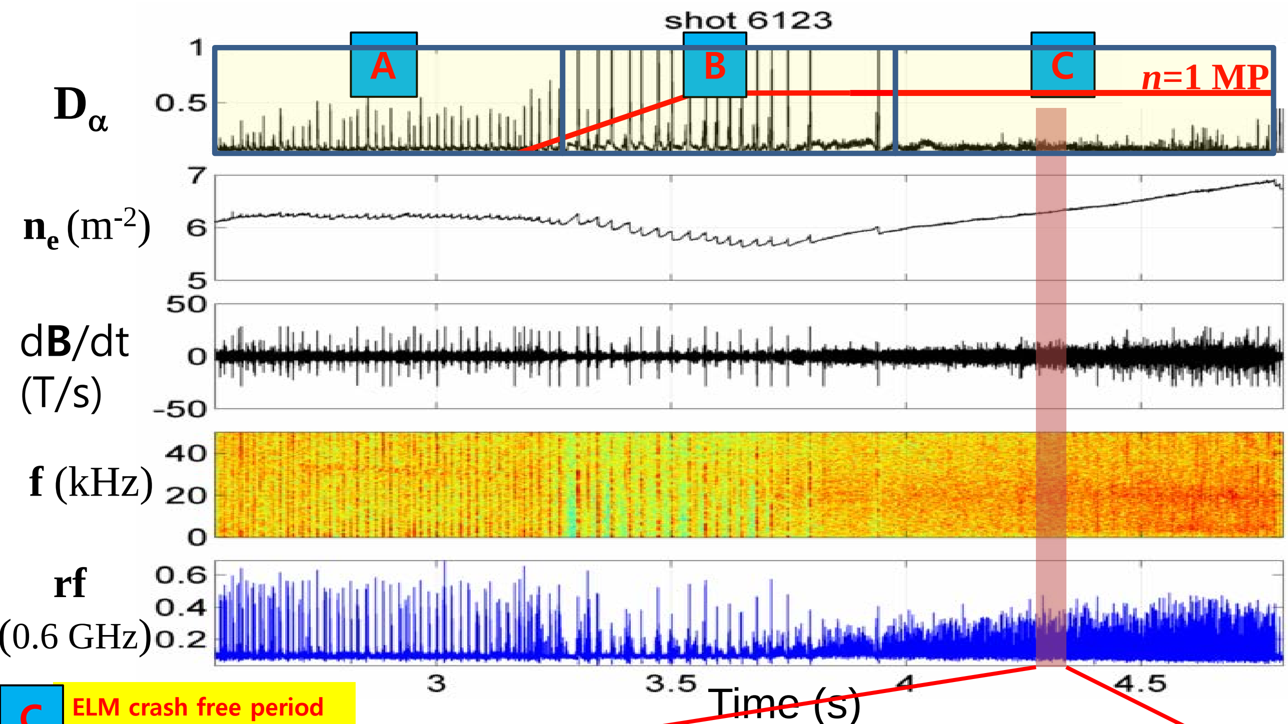
Crash phase (burst in LFS proceeds first – Ballooning character)

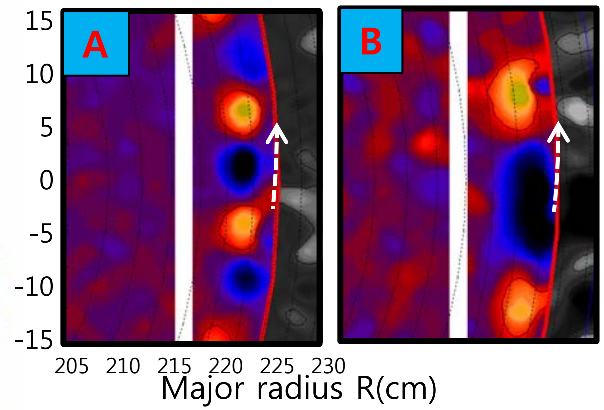
Collapse of pedestals at both sides

ELMs & crashes in crash free period (2011)

B_0=2T, I_p=600kA, $T_e(0)$~2.5 keV, $<n_e>$~3×10^{13} cm^{-3}
W_{tot}~250kJ → 240kJ

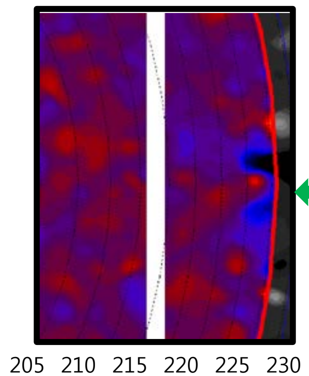
change from n=10 to n=5 mode



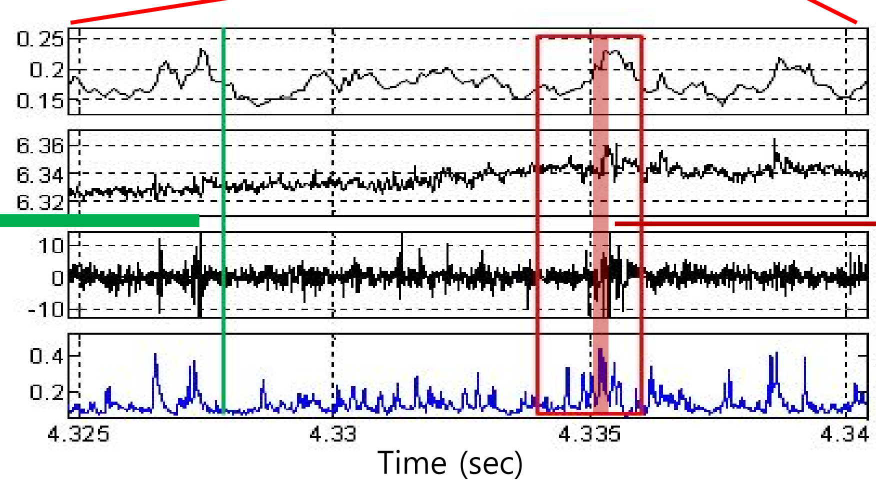


- *No steady ELMs*
- *ELMs with tiny crashes accompanied with rf bursts*

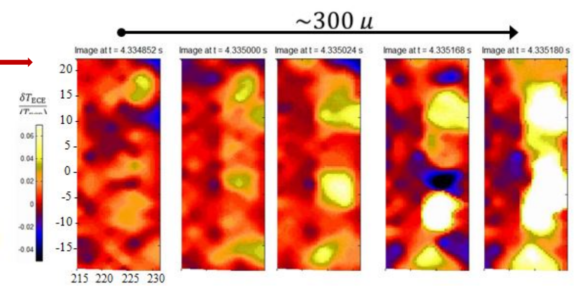
C ELM crash free period (No steady ELM)



No changes in background

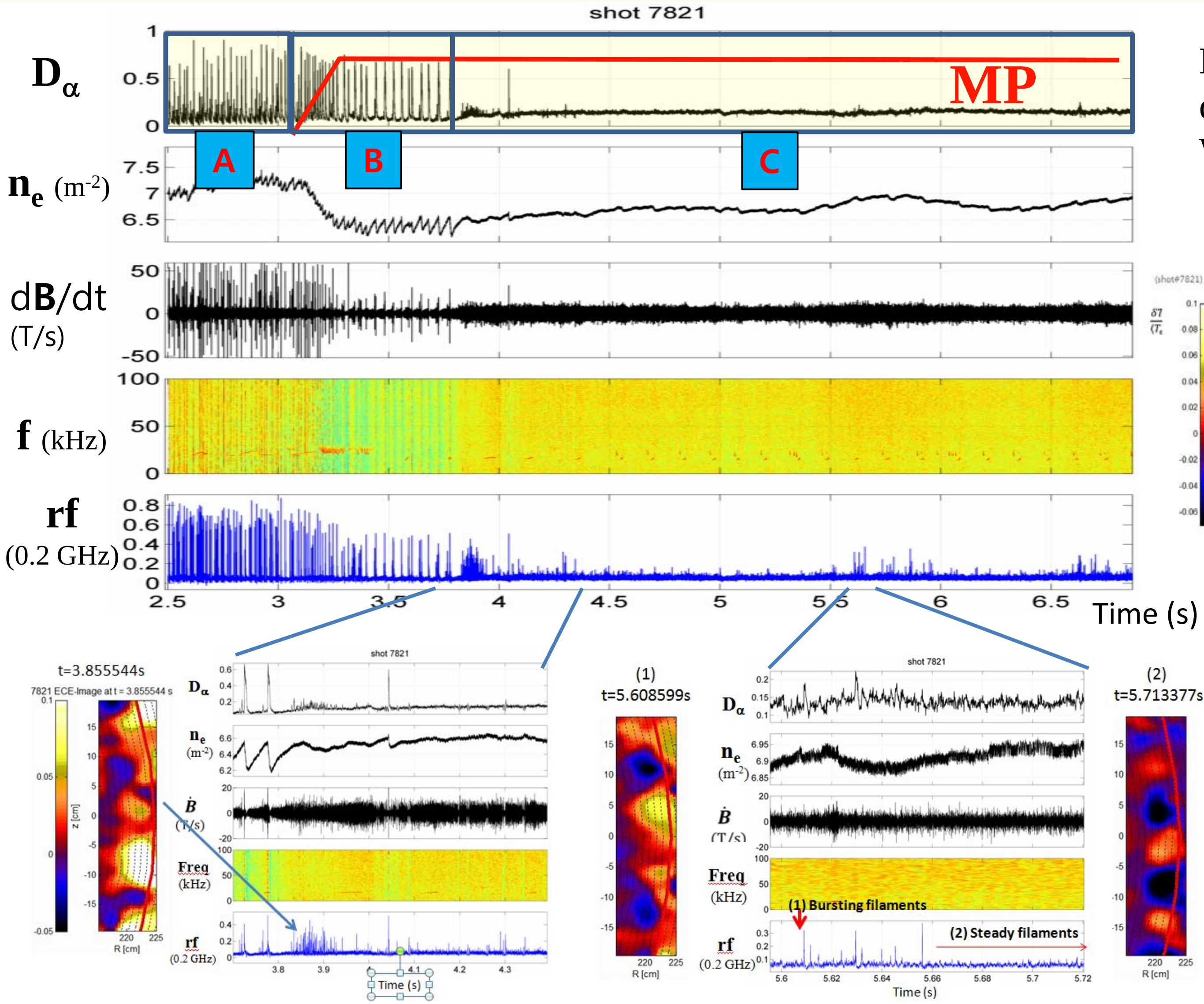


No large crash but occasional tiny crashes



G.S.Yun, PoP 19 (2012)

ELMs & crashes in crash free period (2012)

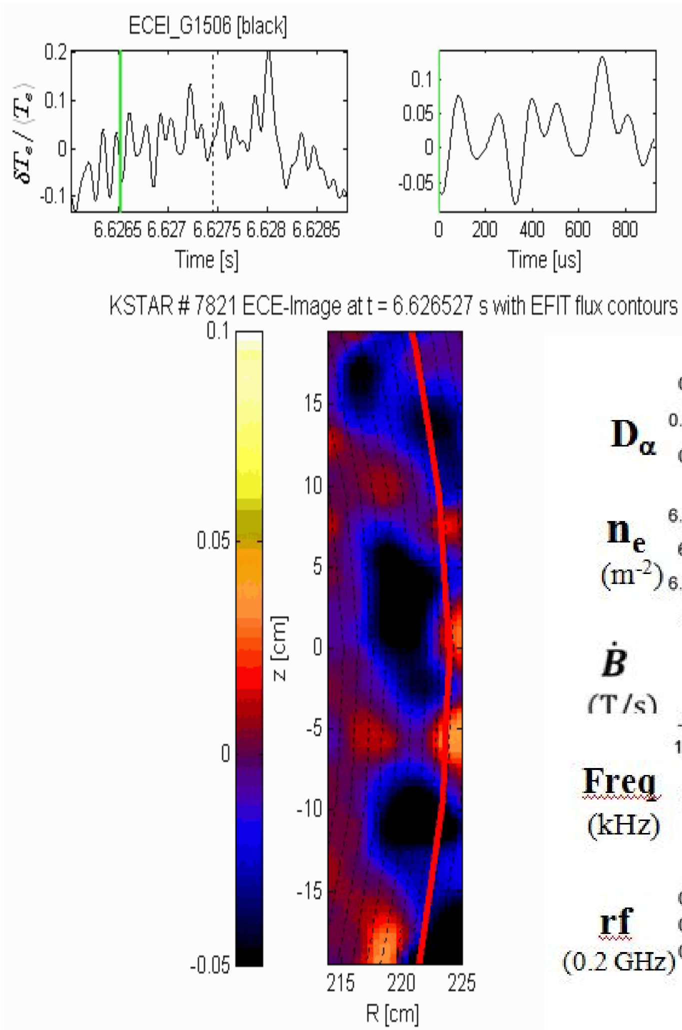


B_0 = 1.8 T, I_p = 510 kA
q_{95} ~ 4.5, P_{NBI} = 2.7 MW
W_{tot}: 220→180 kJ

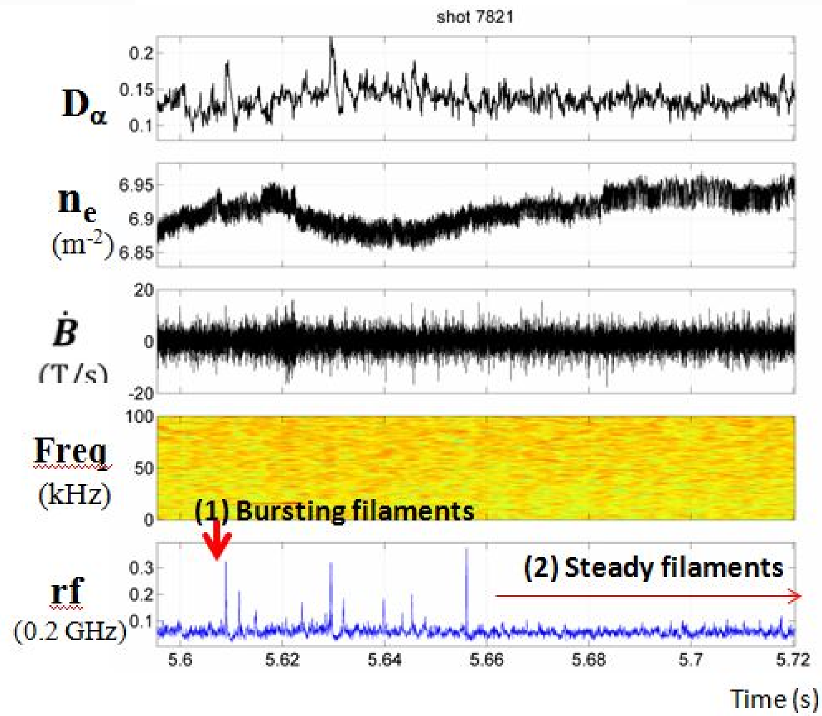
- *Observation has been consistent over 3 years*
- *High-n → suppression or High-n → low-n → suppression*
- *Suppressed time consist of* ***Smaller bursts (bunching and single), brief moment without ELM, and persistent ELM with higher n without crash***

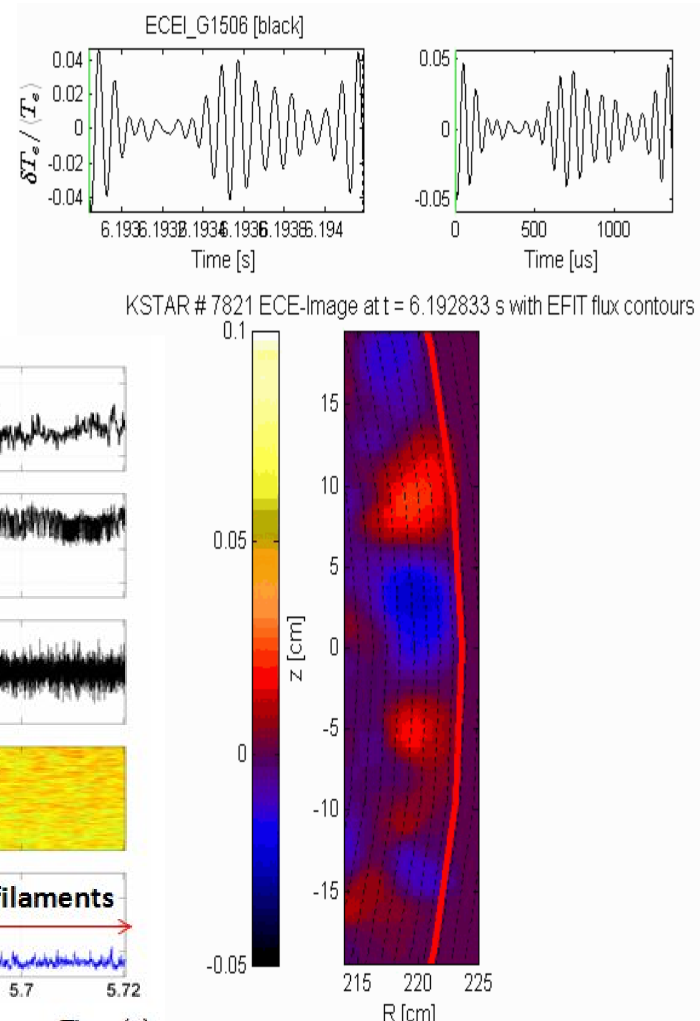
- *rf signal (<200 MHz) is a good measure of ELM crash*
- *Broad-band dB/dt signal is not from high-n mode crash (**Note:*** **EX/1-5 Y. Jun**)

Illustration of no burst and burst cases (2012)



rf signal is much better indicator of the ELM crash





Bursting ELM period

Little change in magnetic signals !!

Steady ELM period

Summary

- Findings from the HFS ELMs
  - Mode number discrepancies – ~~in/out asymmetry in pressure profile~~ or Ballooning representation incorrect??
  - Large mode amplitude – high flow shear damping at the HFS??
  - Rotation direction – asymmetries in toroidal/poloidal velocities + others (e.g., Pfirsch Schluter flow)??
  - Crash proceeds first at LFS – Ballooning characteristics??
- ELM dynamics during the "suppression" period
  - Change of the edge confinement → less free energy → higher n, higher frequency, smaller crashes (bunching and singles), persistent ELMs without crash and brief moment without ELMs :marginal free energy or intricate physics??
  - Broad spectra of dB/dt signals during ELM suppression period is not from the high-n mode burst