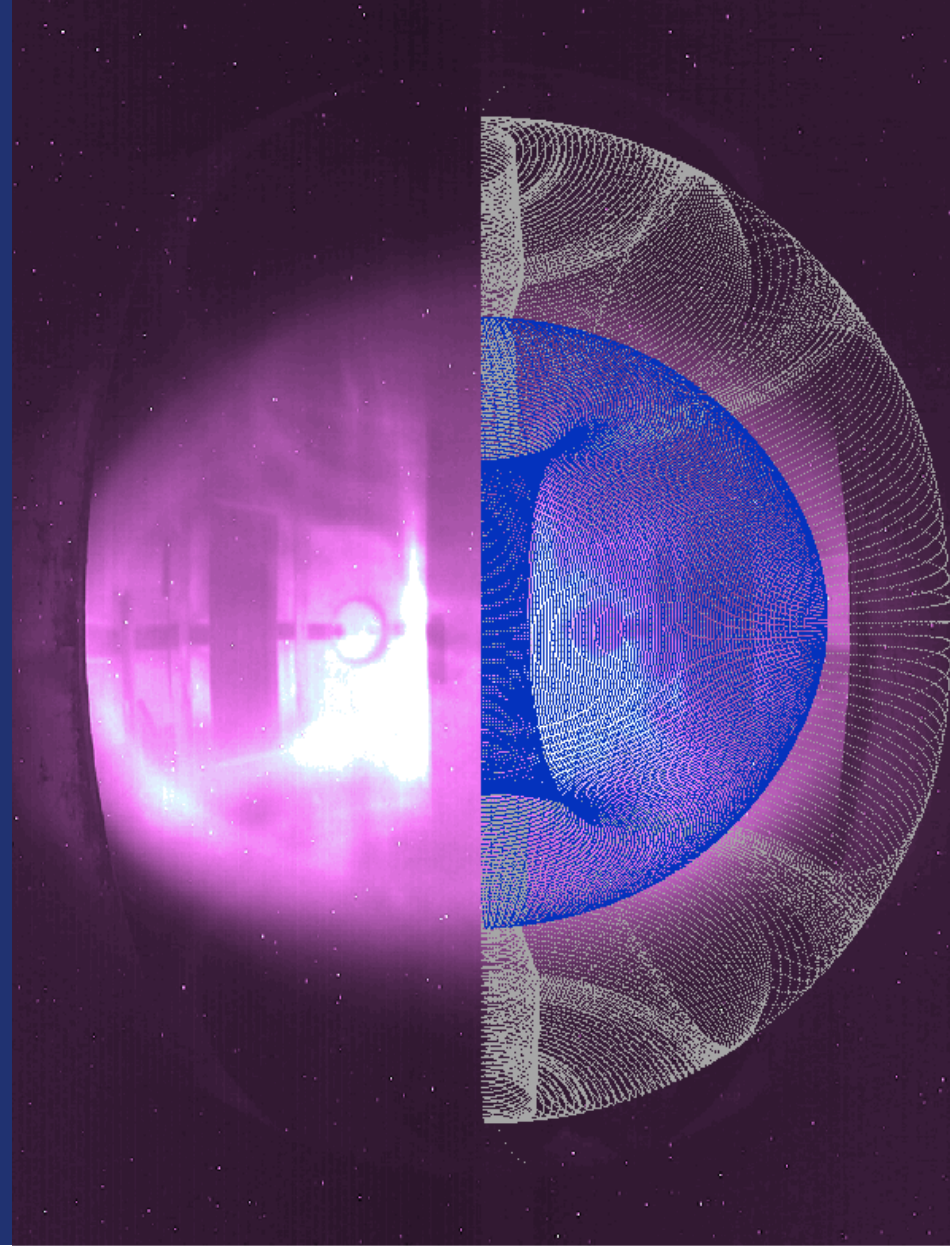
Interaction between External Blobs and Internal MHD Modes During Internal Reconnection Event in VEST

E.C. Jung[1,2], Y.S. Na[1], S. Kim[1], W.I. Jeong[1], J.-K. Park[2], T.S. Hahm[1], Y.-c. Ghim[3], and Y.S. Hwang[1*]

1 Department of Nuclear Engineering, Seoul National University, Seoul 08826, Korea, Republic Of
2 Princeton Plasma Physics Laboratory, Princeton, New Jersey 08543, USA
3 Department of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology, Daejeon 34141, Korea, Republic Of



2022.11.03
ISTW 2022

ejung@pppl.gov, yhwang@snu.ac.kr

ISTW 2022
The 21st International Spherical Torus Workshop

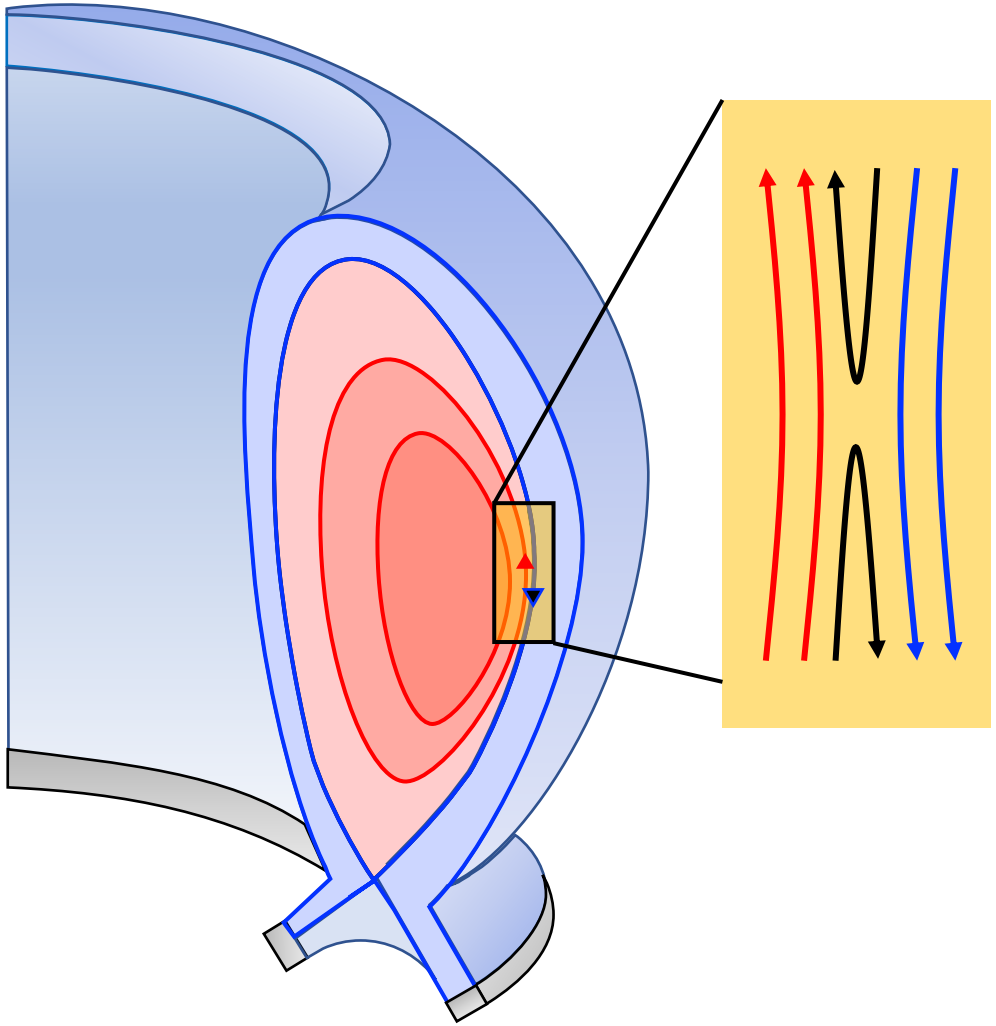
SEOUL NATIONAL UNIVERSITY

PPPL

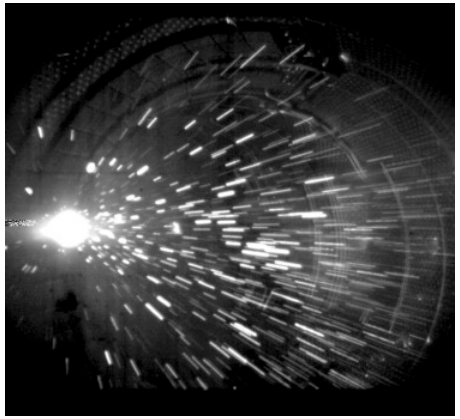
KAIST

Reconnection Events and Magnetic Confinement Fusion Devices

Magnetic reconnection in tokamak plasma



- Magnetic reconnection is one of the most universal relaxation phenomena observed in plasmas.
- One of the most threatening reconnection events in tokamaks is a disruption.
- It terminates the plasma discharge and causes a significant damage on the plasma facing component

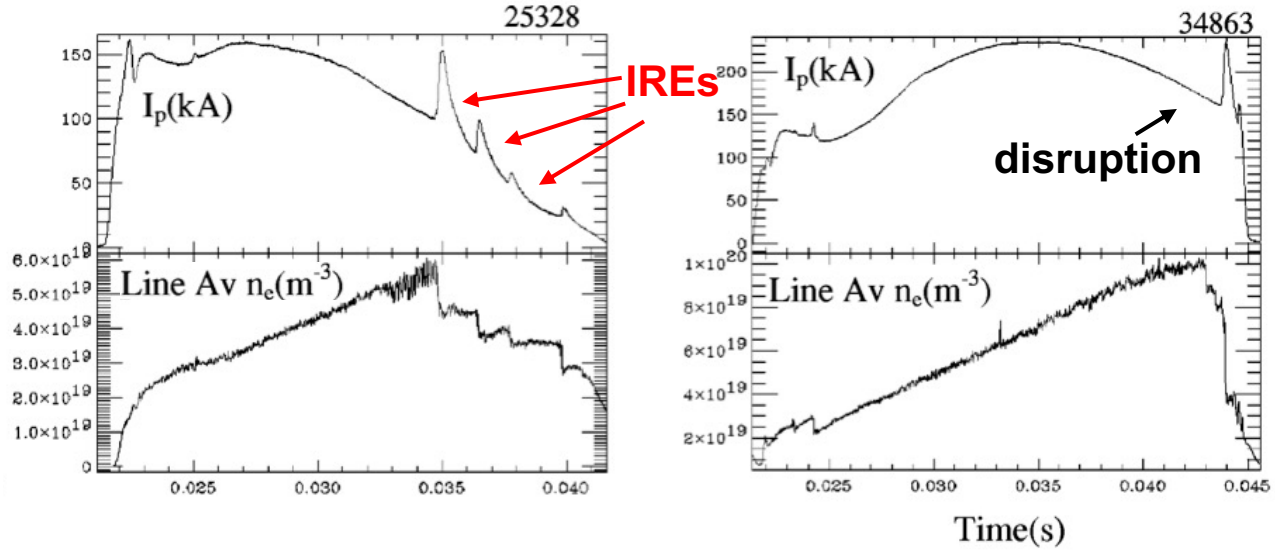


[J. Bucalossi, Magnetic Fusion Energy, 2016]

Internal Reconnection Event (IRE) and Disruption

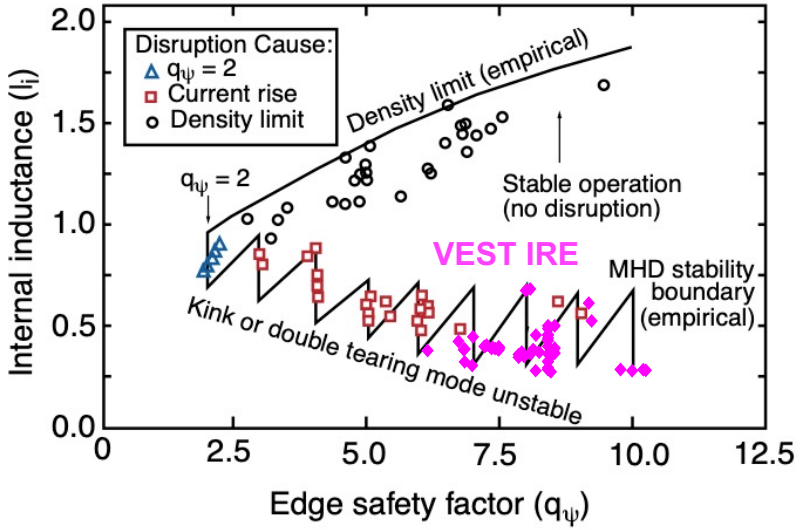
- **IRE and disruption in START**

(a) Naturally limited plasma (q_ψ=13.4) (b) Double Null plasma (q_{95}=9.1)



[Hender, T. C., *et al*. PoP 1999]

- **Inter-machine comparison of disruptions in limited JET plasmas and IREs in VEST plasmas**

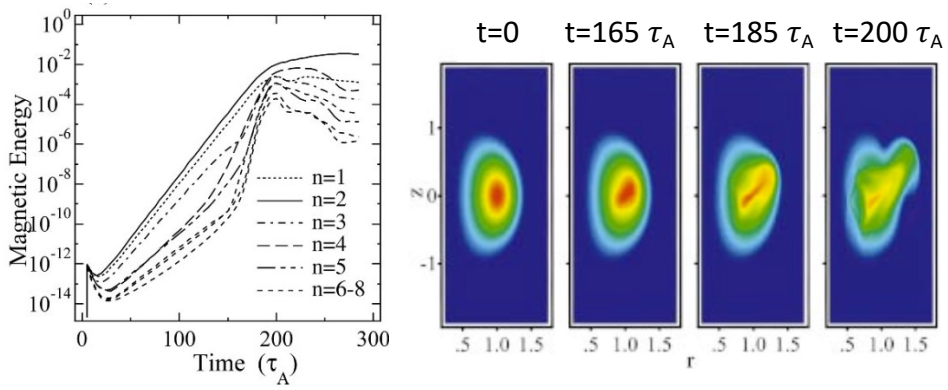


[ITER physics expert group, NF, 1999]

- Unlike the disruptions, there is another type of reconnection event called an internal reconnection event (IRE) without termination of the plasma due to the rapid recovery of the closed magnetic configuration after the event.
- The onset conditions of IREs have shown to be similar to that of disruption in conventional tokamak, implying its similar onset mechanisms with disruption. [Hender, T. C., *et al*. PoP 1999 , Semenov, I., et al, PoP, 2003]

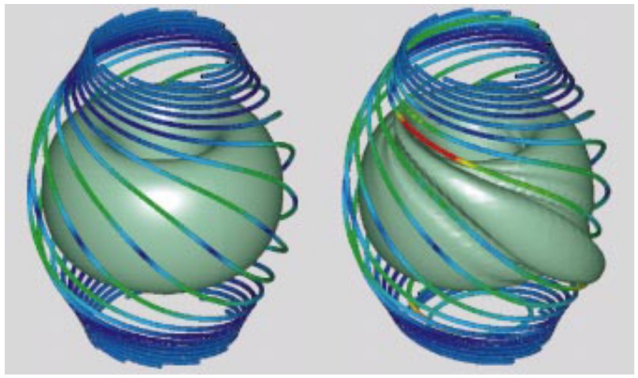
Previous Studies on IREs

➢ Time development of MHD modes in nonlinear MHD simulation on IRE



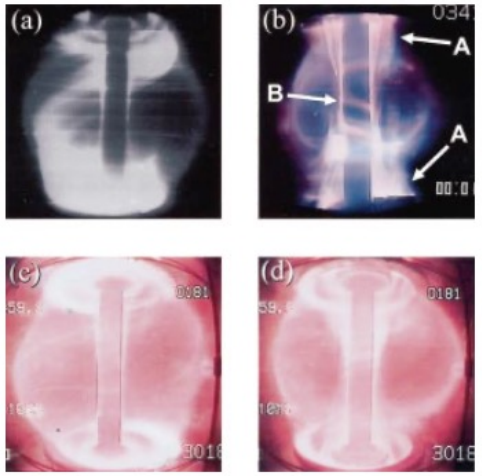
[Mizuguchi, N., et al., PoP, 2000]

➢ Temporal evolution of 3-D pressure profiles and magnetic field lines in the nonlinear MHD simulation



[Hayashi, T. *et al.* NF, 2002]

➢ IREs in START

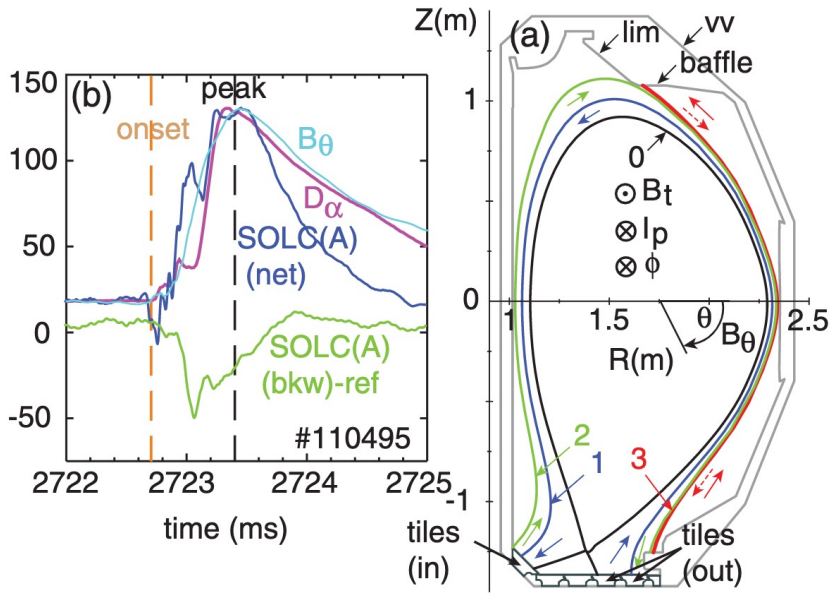


[Mizuguchi, N., et al., PoP, 2000]

- IREs are caused by the nonlinear growth of internal magnetohydrodynamic (MHD) modes as in the disruption
- Numerical studies using nonlinear MHD codes successfully reproduced major phenomenological features such as a largely elongated plasma shape observed in IREs [Mizuguchi, N., et al., PoP, 2000, Hayashi, T. et al. NF, 2002],
- However, the analysis of the onset mechanism of the IREs has been solely numerical, and little experimental study on the mechanism of IREs has been conducted.

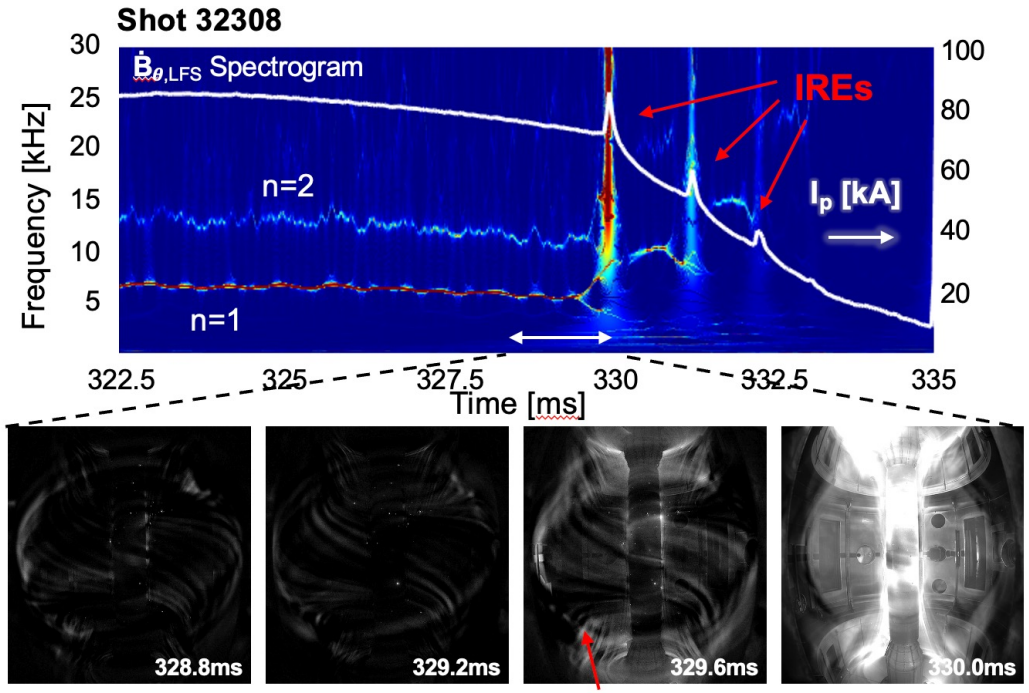
New potential factor to influence the onset of IREs

➢ **Increase in SOL current before ELMs in DIII-D**



[Takahashi, H., Fredrickson, E. D., Schaffer, M. J., PRL, 2008]

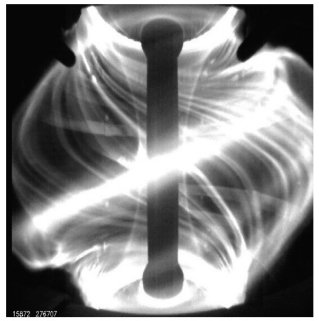
➢ **Enhanced external filament structures before IREs in VEST**



*** Wider view with 2.5 kFrame·s^{-1} in Shot 32302 (identical shot)**

Enhanced external filaments before the event

ELMs in MAST



IREs in VEST

- In edge localized modes(ELMs), the contribution from the SOL region on the crash was found [Takahashi, H. PRL 2008 , A. Wingen, PRL 2010]
- Although IRE is fundamentally different from ELMs in terms of global impacts and the distance of MHD modes to the SOL, IREs also show a phenomenologically similar filamentary blob during the process

[Kirk A., *et al.,* PRL, 2006]

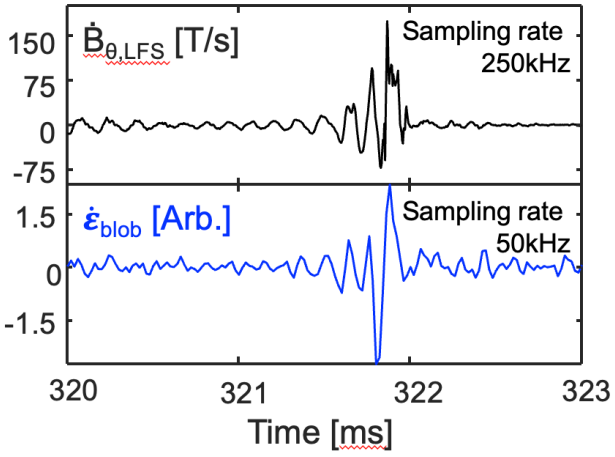
Motivation and Highlights

MHD modes → **Internal reconnection events (IREs)**

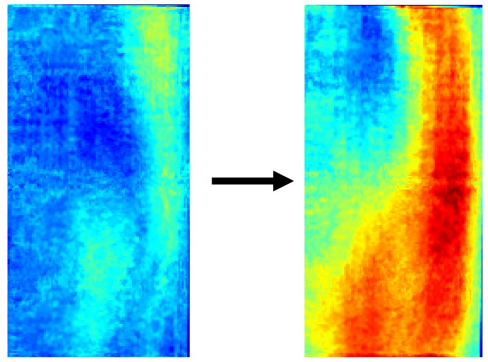
External filaments/blobs

- Here, we present an experimental study to systematically investigate the external filaments/blobs during IREs
- We observe that the external blobs play a significant role in the onset and the strength of IREs.

- Correlation between MHD modes and blobs

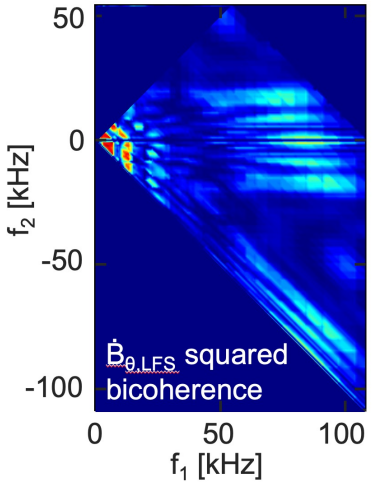


- Dynamic between internal MHD and external blobs changes before IREs



*MHD-frequency-filtered visible camera images

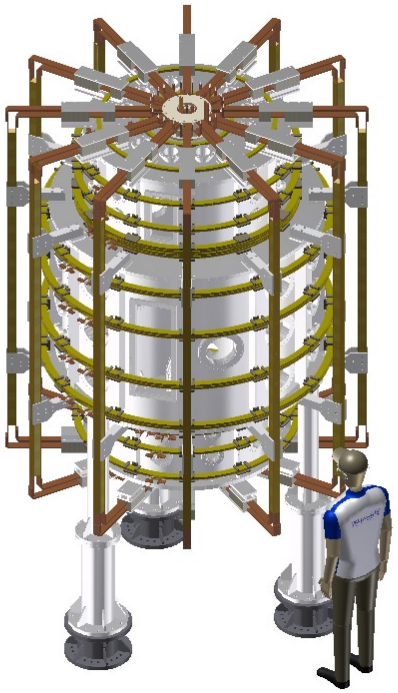
- Nonlinear interaction with edge turbulence together with MHD-correlated blobs



Experimental Setup

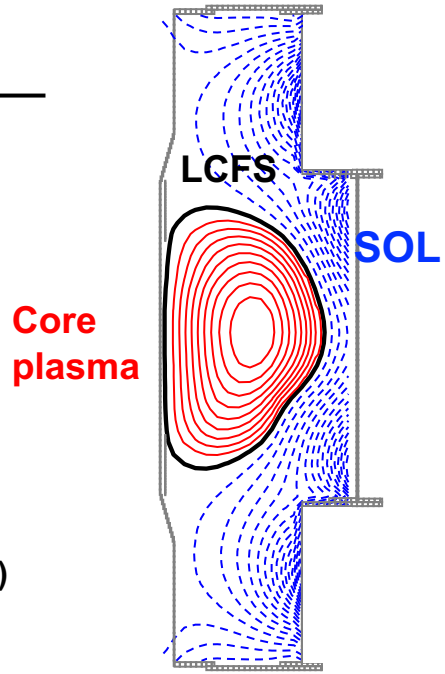
Versatile Experiment Spherical Torus (VEST)

➢ VEST specifications

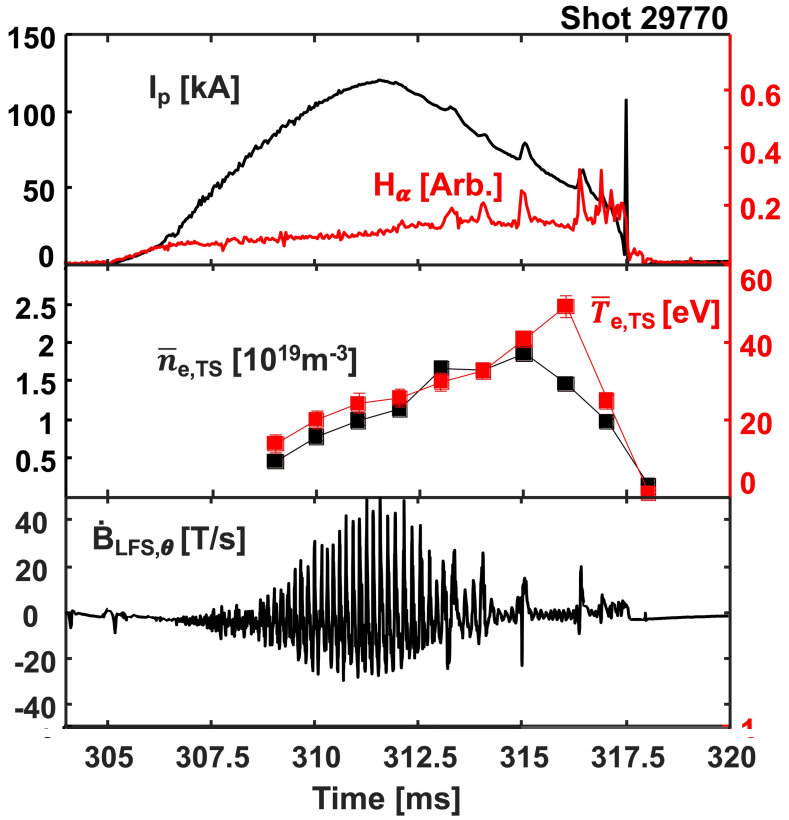


	Present
Toroidal B Field	**0.05 – 0.19 T**
Major Radius	**0.45 m**
Minor Radius	**0.33 m**
Aspect Ratio	**>1.36**
Plasma Current	**<170 kA**
H & CD (ECH, NBI, LHFW)	**ECH (7.9GHz, 3kW)** **ECH (2.45GHz, 15kW)** **NBI (15keV, 600kW)** **LHFW (500MHz, 10kW)**

➢ VEST magnetic configuration (ST and limited plasma)

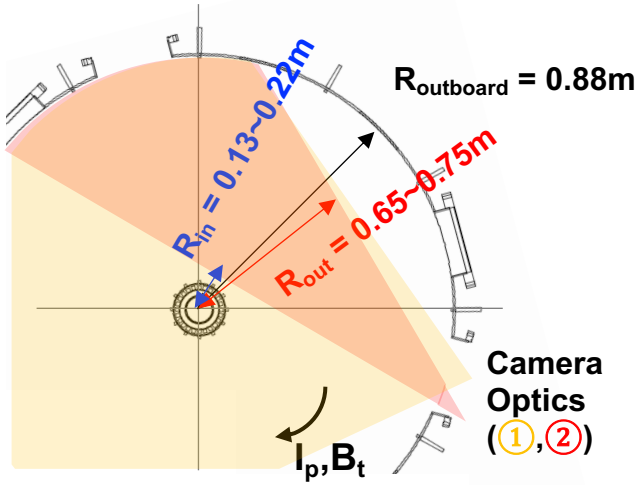


➢ Typical ohmic discharge in VEST

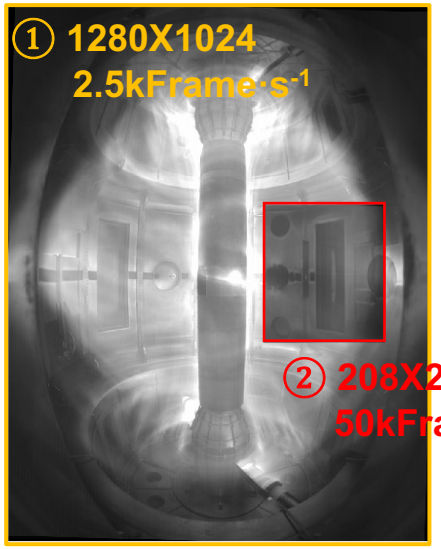


- The first and only ST device in South Korea
- VEST has an Inboard limited configuration and 10 – 30 ms discharge length with 100 – 150 kA plasma current
- Plasmas often have strong MHD activities, leading to the IREs in the ramp-down.

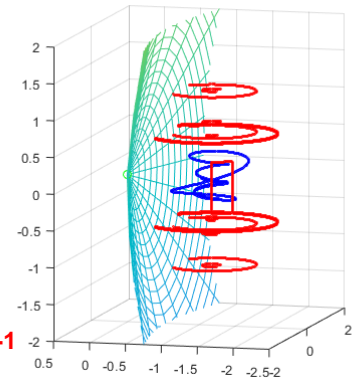
Visible Fast Camera in VEST



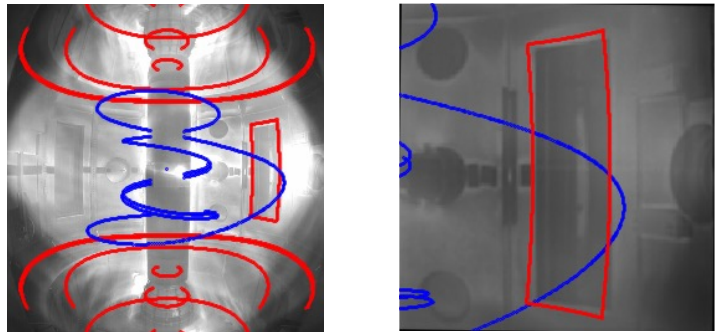
↑ **Top view of VEST showing the camera viewing region**



3D geometry and optics of camera

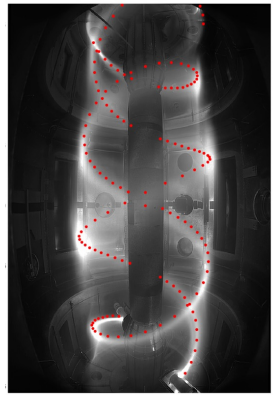


Calibrated results of the 3D geometry projection for view ① and ②

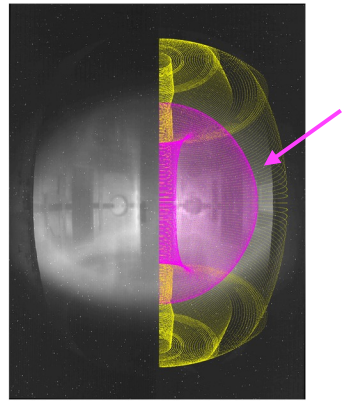


- Visible fast camera is mainly used to observe the dynamics of the external blobs during IREs
- Temporal resolution : 50kFrame·s^{-1} with 208×208 pixels, which covers most LFS of the plasmas
- The images is analyzed with the calibrated camera projection matrix to interpret the position and the 3D structure of the object. [Hommen, G. et al. RSI 2010]

Projection of magnetic field line with the helicity injection images

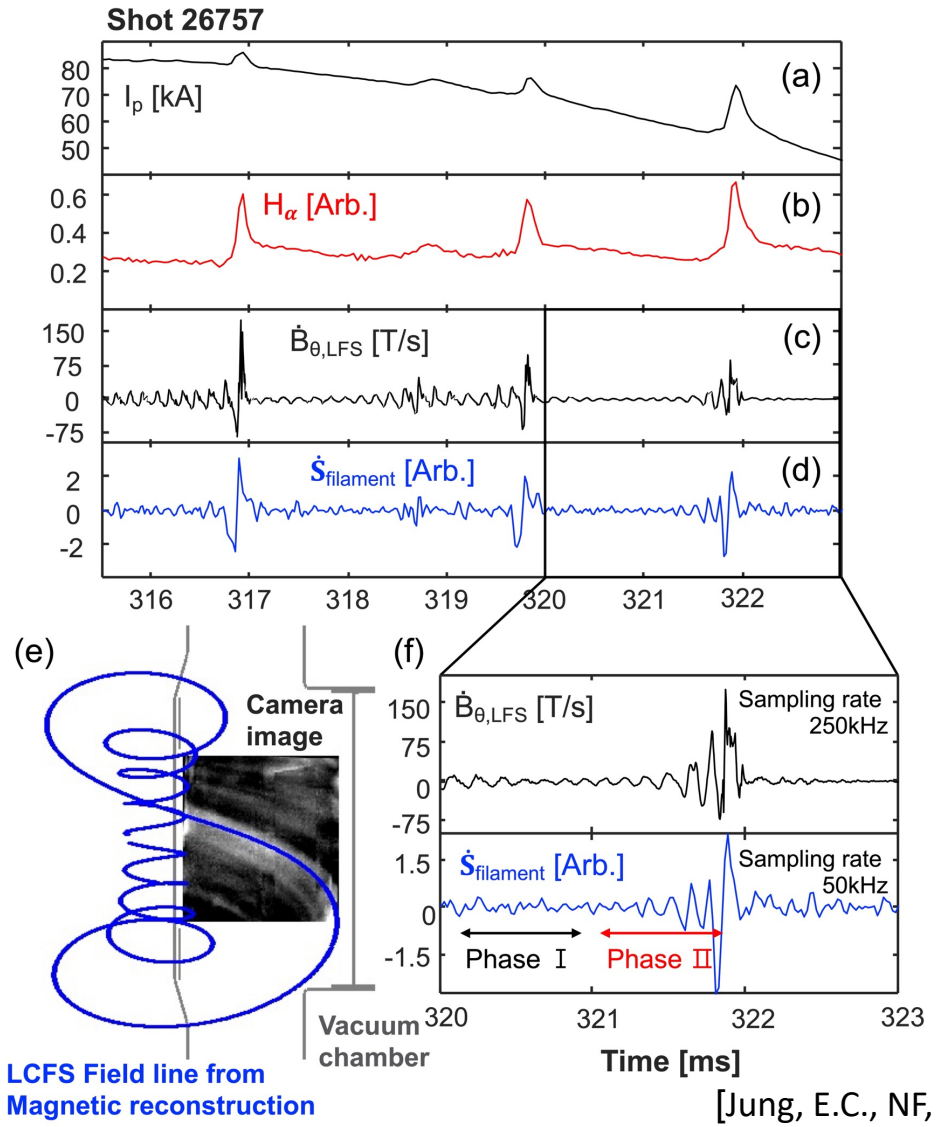


Projection of magnetic reconstruction results

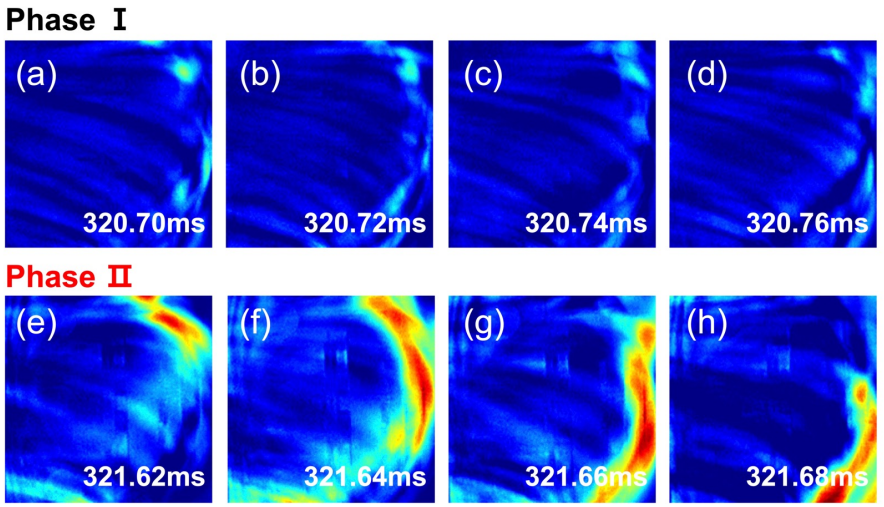


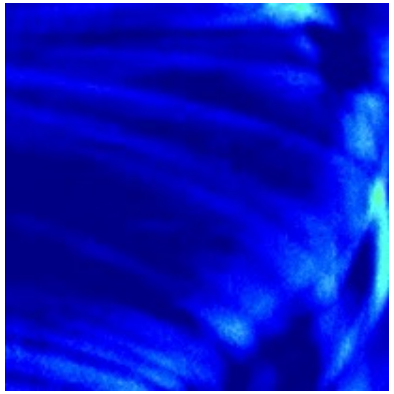
MHD-corelated blobs before IRE

MHD-corelated blobs before IRE



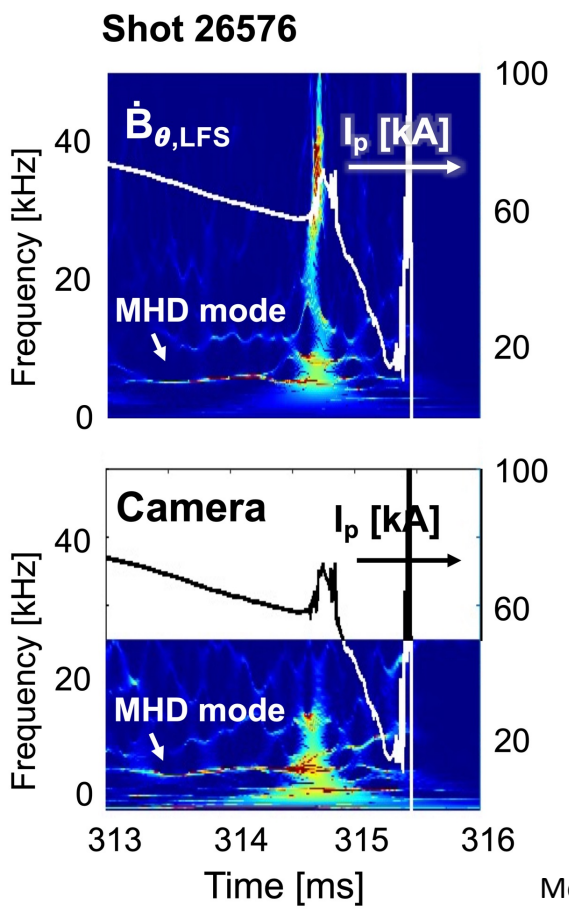
[Jung, E.C., NF, 2022]

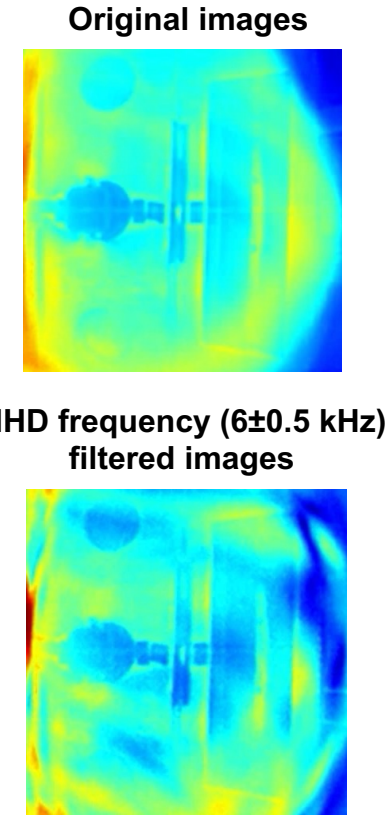




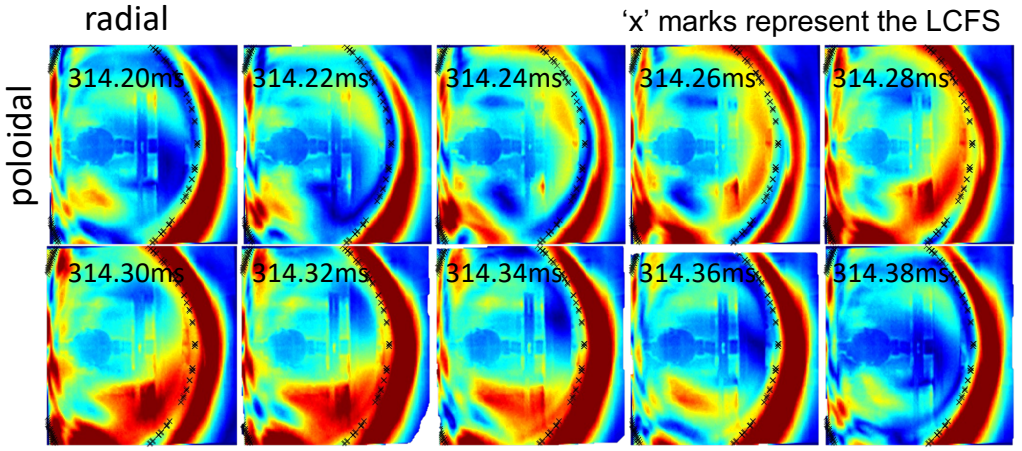
- Blob's fluctuation is measured from the time evolution of the intensity summation along the field line on the last closed flux surface (LCFS) to directly compare with the Ḃ coil signal.
- Blob's fluctuation becomes correlated with Ḃ coil signal near the IREs
- The results shows that MHD-corelated blobs are formed before the onset of IREs

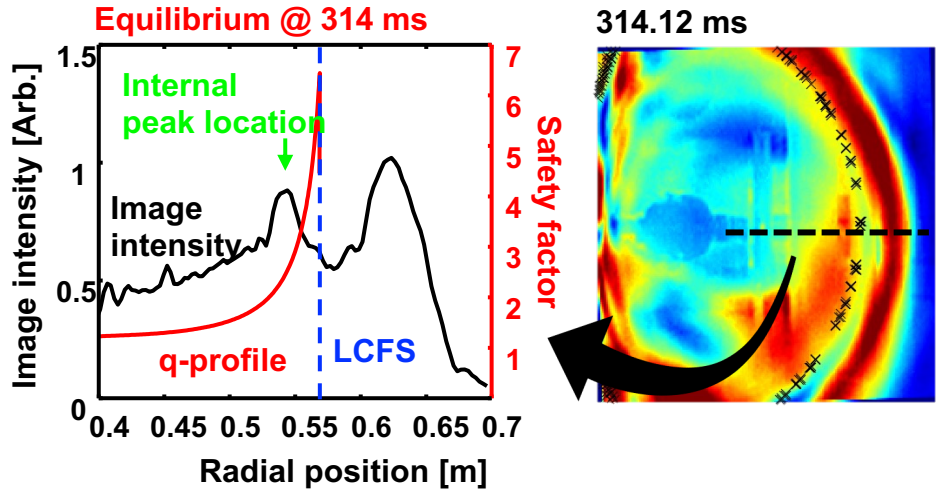
Visualization of MHD-correlated blobs and MHD modes





Method from [Van Zeeland, M., et al., NF, 2008]

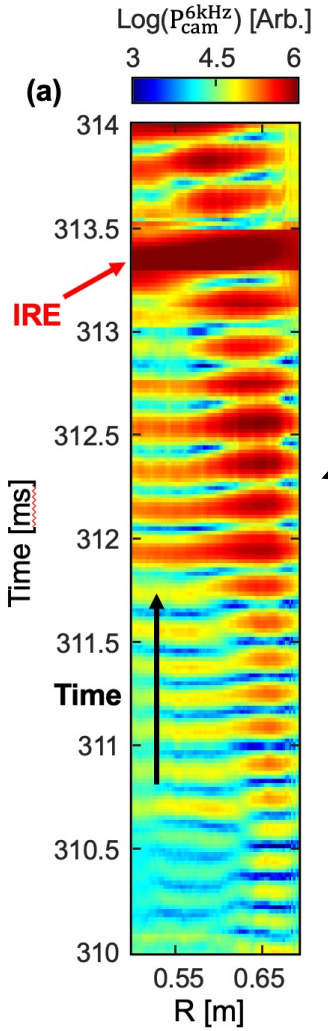


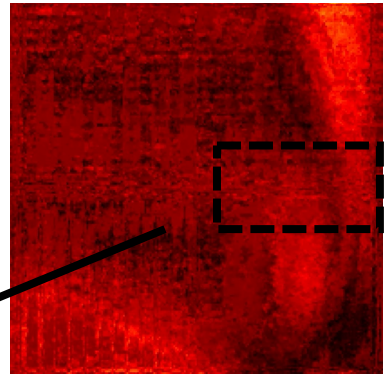


- MHD-correlated blobs and MHD modes are visualized by filtering camera images with the MHD-frequency
- MHD-frequency-filtered images show the internal MHD mode structures and correlated blobs outside the LCFS

Phase alignment between MHD modes and MHD-correlated blobs

➢ Dynamic of MHD modes and MHD-correlated blobs during IREs

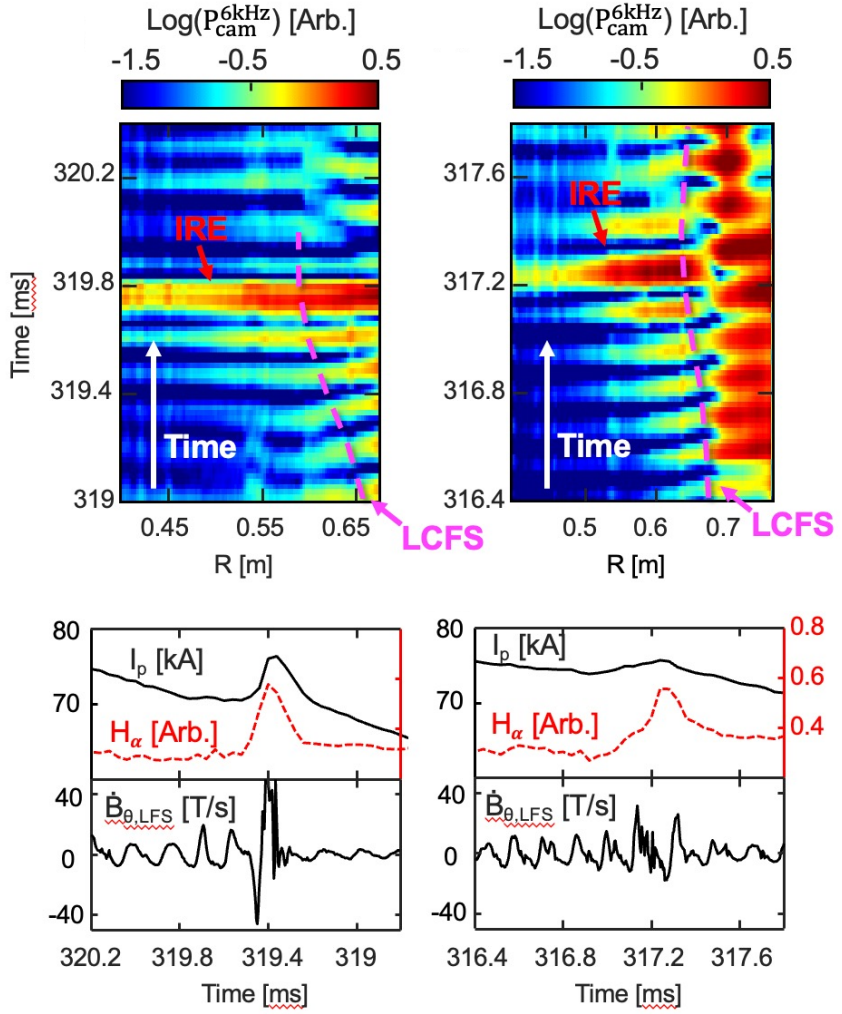




*** Frequency filtered images (5kHz ± 0.5) with 50kFrame·s^{-1} and CIII464 optical filter**

- Correlated behavior between MHD modes and MHD-correlated blobs changes before the IRE onset
  → Phase drag between two structures disappear
- The existence of phase alignment also affects the strength of IREs
- These results imply that the external blobs play a significant role in the onset of IREs.

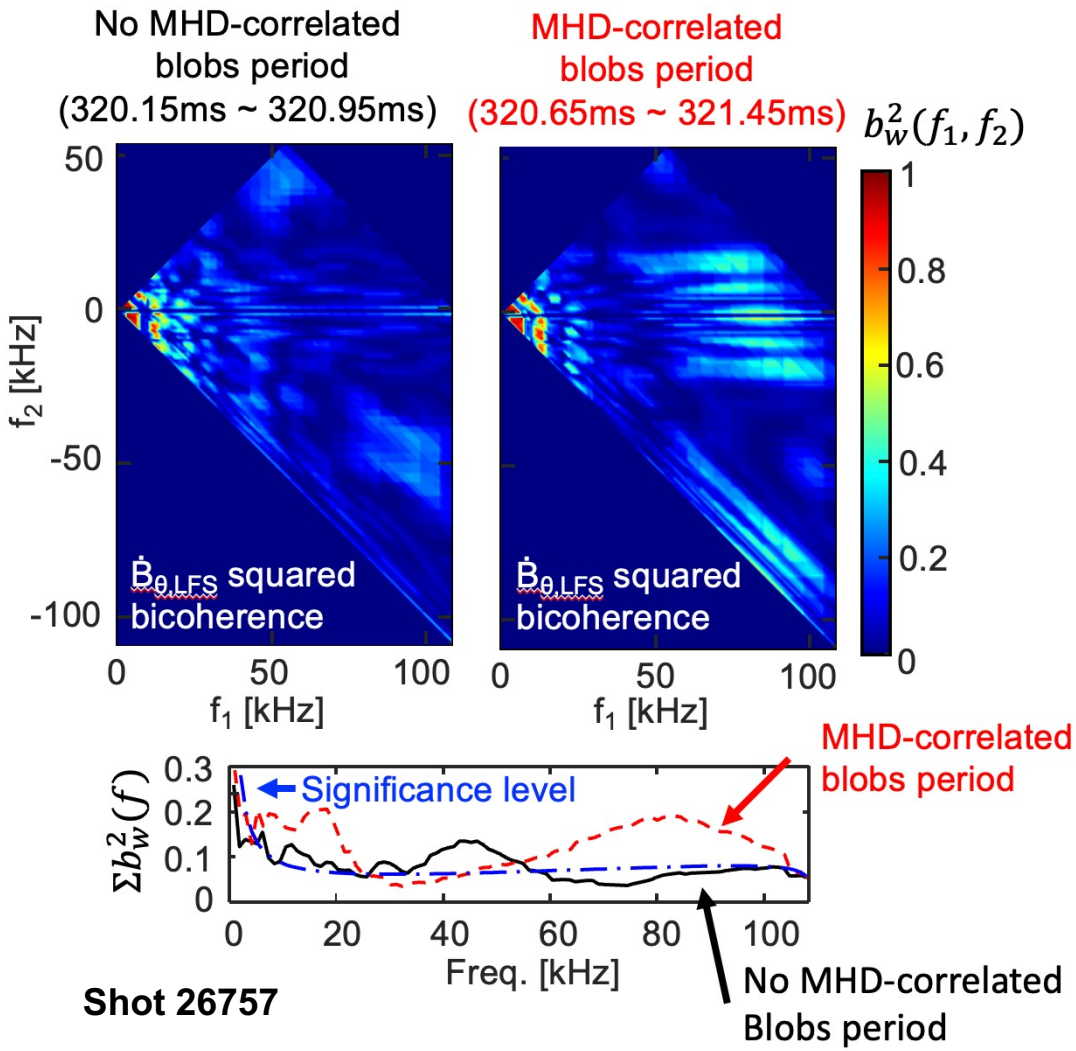
➢ Comparison between IREs with and without phase alignment



[Jung, E.C., NF, 2022]

Increasing nonlinear coupling between internal MHD modes and edge turbulence

➢ Bicoherence analysis on Ḃ coil signal



- Squared wavelet bicoherence :

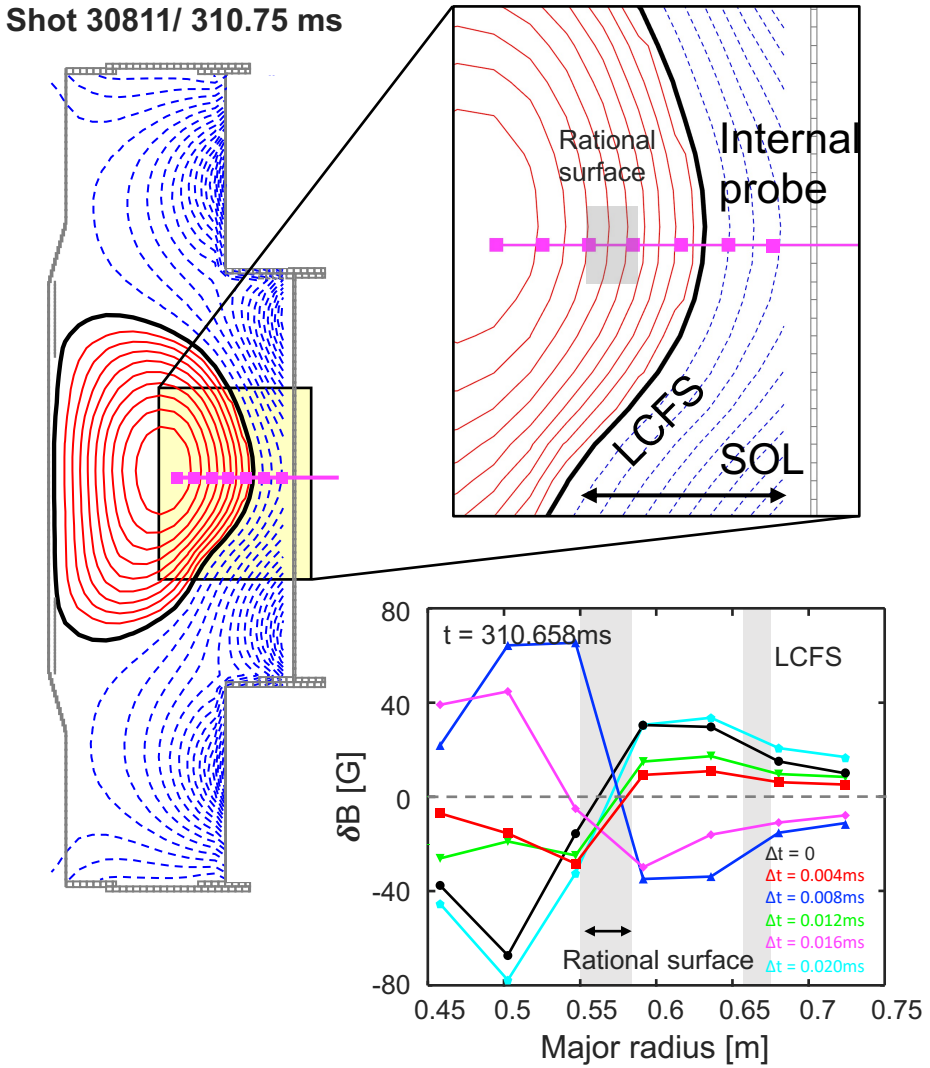
$$b_w^2(f_1, f_2) = \frac{\left|\langle W_f(f_1) W_f(f_2) W_f^*(f_1 + f_2)\rangle\right|^2}{\left\langle\left|W_f(f_1) W_f(f_2)\right|^2\right\rangle \left\langle\left|W_f^*(f_1 + f_2)\right|^2\right\rangle}$$

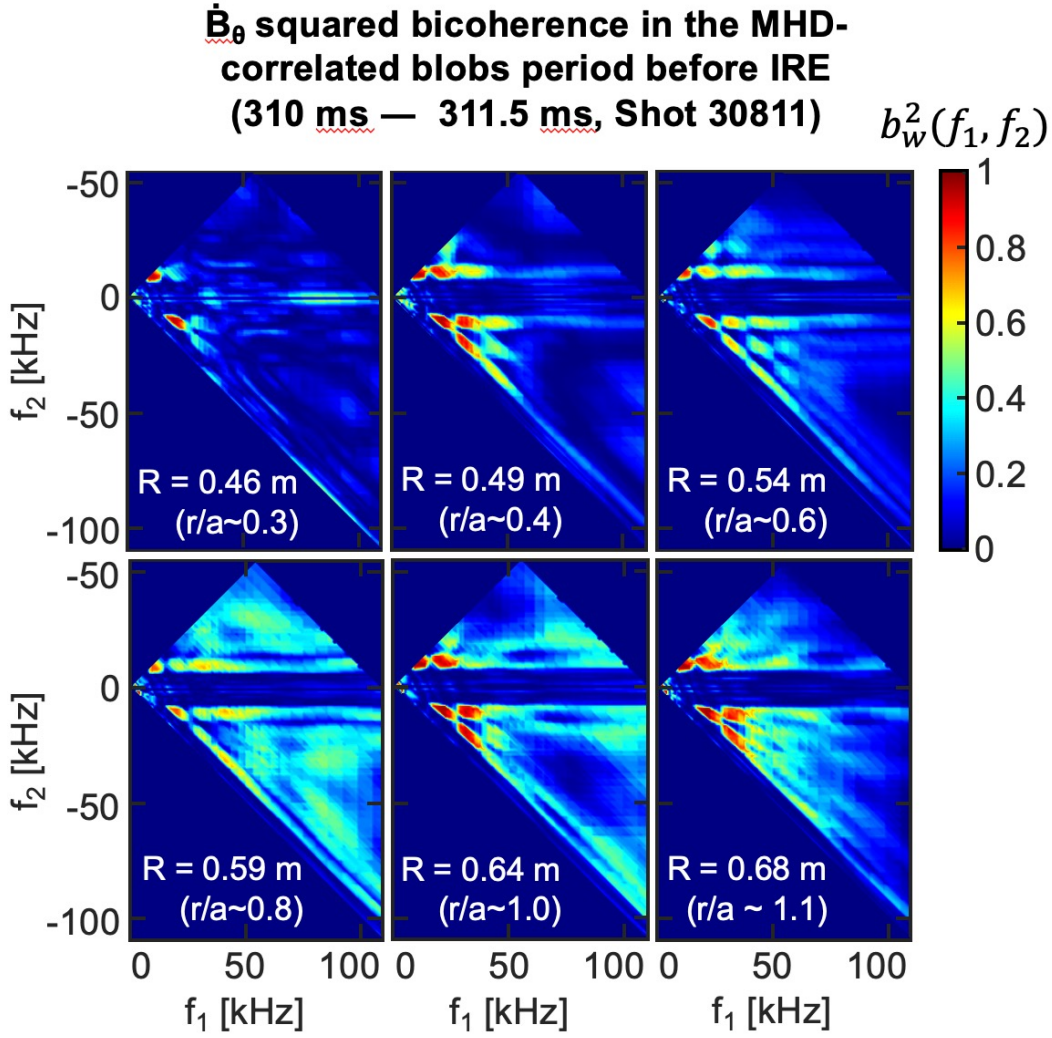
$$\Sigma b_w^2(f) = \Sigma_{f=f_1+f_2} b_w^2(f_1, f_2) / N_{f1,f2}$$

[Milligen, B. P. van, *et al.*, PoP, 1995]

- Bicoherence level above the significance level shows that phases are coupled in two different frequencies.
- The result shows that nonlinear interaction between MHD modes and high frequency broadband appears together with MHD-correlated blobs

Increasing nonlinear coupling between internal MHD modes and edge turbulence



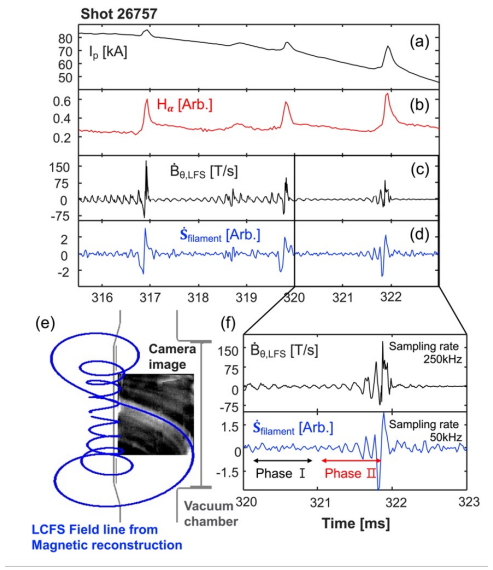


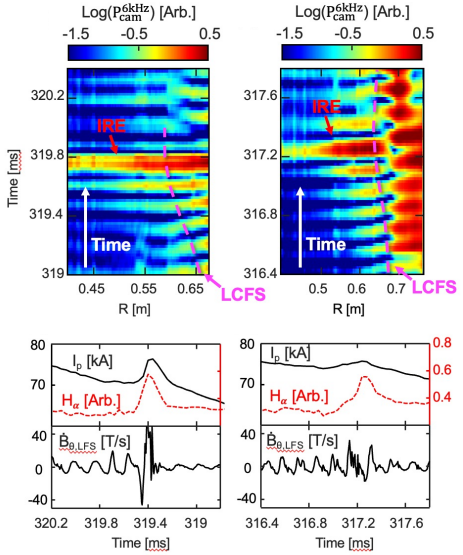
- Internal probe data shows that such nonlinear interaction mainly occurs near the LCFS.
- This implies that the edge turbulence might be related to the formation of blobs.
- However, more precise investigations are needed to examine the mechanism of MHD-correlation blobs

Conclusion

Conclusion

We investigate the correlated behavior between external blobs and internal MHD modes during IRE, and we found that the external blobs play a significant role in the onset and the strength of IREs

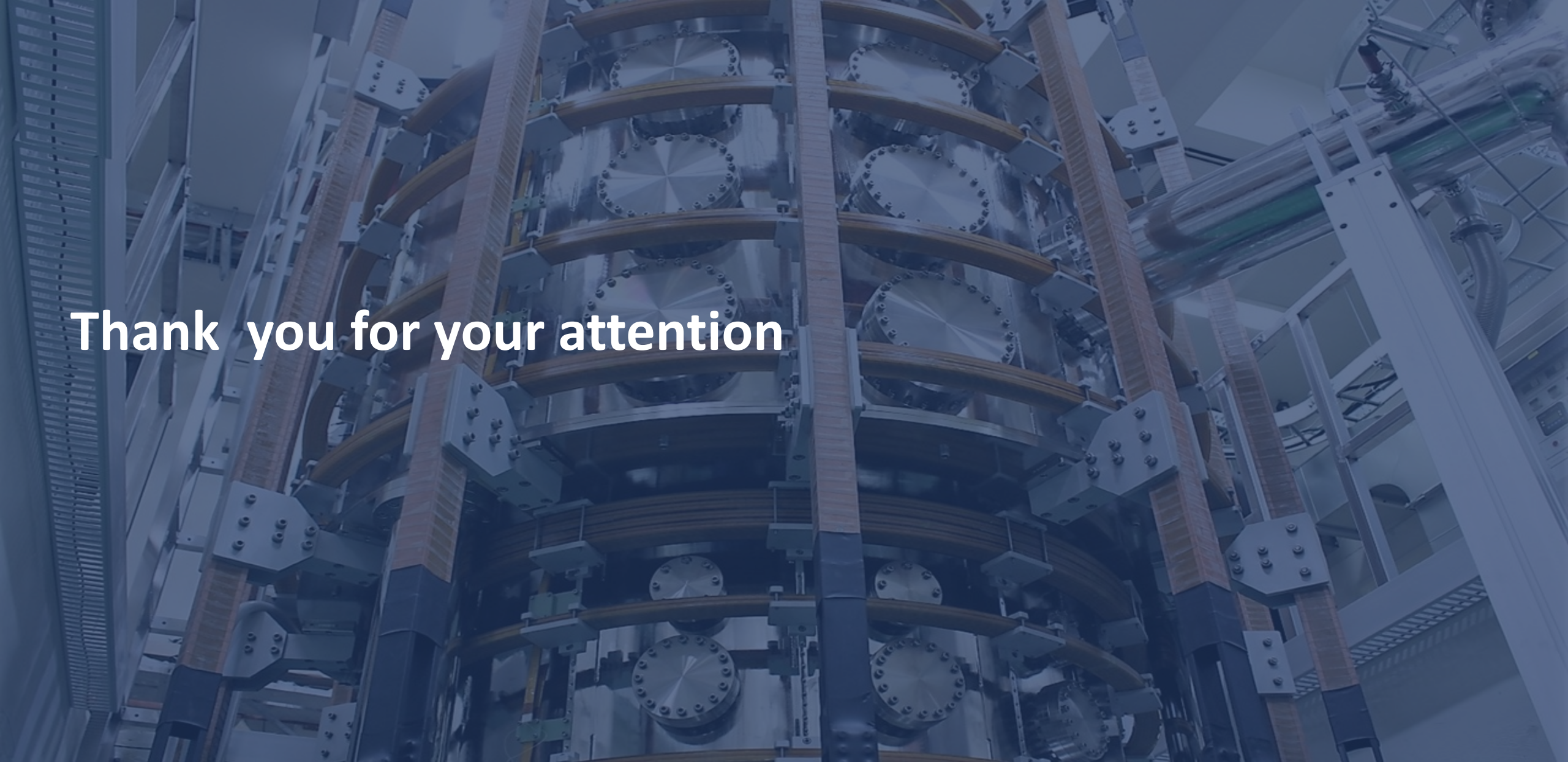




We observe :

1. the correlation between the external blob's fluctuation and the magnetic perturbations near IREs
2. Phase alignment between MHD modes and MHD-correlated blobs on the verge of IREs, and its absence can prevent a violent IRE
3. Nonlinear interaction between the internal MHD modes (<20 kHz) and a broadband high-frequency turbulence at the edge (>60 kHz) together with MHD-correlated blobs

These results suggest that boundary plasmas can impact internally driven relaxation events via MHD-correlated edge phenomena.



Thank you for your attention

NUPLEX
서울대학교 플라즈마 및 양자빔 공학 연구실
Seoul National University Plasma & Ion Beam Laboratory

SEOUL NATIONAL UNIVERSITY