Studies of Energetic-ion-driven MHD Instabilities in Helical Plasmas with Low Magnetic Shear

S. Yamamoto[1)], E. Ascasíbar[2)], R. Jiménez-Gómez[2)], S. Kobayashi[1)], S. Ohshima[2)], K. Nagaoka[3)], D. Spong[4)], B. Blackwell[5)], D. Pretty[5)], K. Nagasaki[1)], T. Mizuuchi[1)], H. Okada[1)], T. Minami[1)], Y. Nakamura[6)], S. Konoshima[1)], N. Shi[1)], T. Estrada[2)], M. Ochando[2)], D. López-Bruna[2)], K. Mukai[3)], H.Y. Lee[6)], L. Zang[6)], and F. Sano[1)]

1) *Institute of Advanced Energy, Kyoto University, Uji, Japan*
2) *National Laboratory for Magnetic Fusion, CIEMAT, Madrid, Spain*
3) *National Institute for Fusion Science, Toki, Japan*
4) *Oak Ridge National Laboratory, Oak Ridge, U.S.A.*
5) *Plasma Research Laboratory, The Australian National University, Canberra, Australia*
6) *Graduate School of Energy Science, Kyoto University, Uji, Japan*

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Heliotron J

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Outline

1. Introduction
2. Heliotron J and TJ-II plasmas
3. Shear Alfvén spectra in helical plasmas
4. Observation of AEs in Heliotron J and TJ-II plasmas
5. Iota dependence of AE - iota scan exp. -
6. Conclusion

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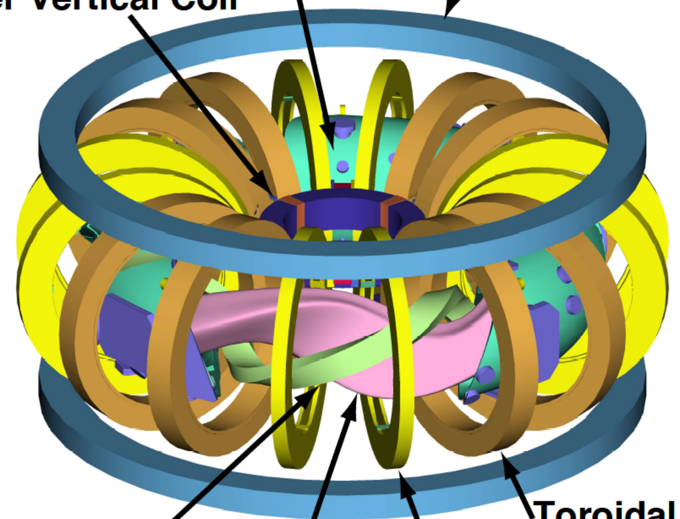
Introduction

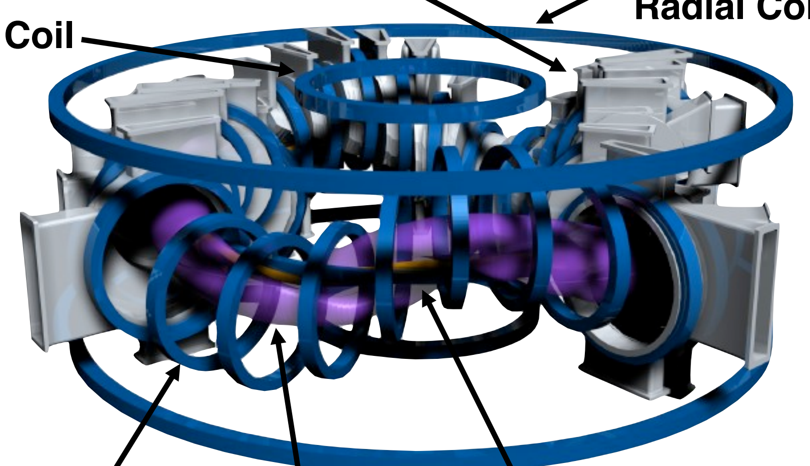
- ✓ In Heliotron J and TJ-II, magnetic configuration has a low magnetic shear in combination with magnetic well in order to avoid and stabilize the pressure-driven MHD instabilities. In addition, both have a low toroidal field period.
- ✓ In order to clarify the energetic-ion-driven MHD instabilities in advanced helical plasmas, we have studied them by using similarities and differences between two devices.
- ✓ Global AEs (GAEs) which can lie just below and above the shear Alfvén continuum, and helicity induced AEs (HAEs) which can exist in HAE gap formed by both poloidal and toroidal mode coupling are important in helical plasmas with low magnetic shear and low toroidal field period.

Heliotron J and TJ-II

Heliotron J



TJ-II



	Heliotron J	TJ-II
	Helical axis Heliotron	Flexible Heliac
Major radius R (m)	1.2	1.5
Minor radius a (m)	< 0.25	< 0.22
Magnetic field B (T)	1.25	0.95
Toroidal period N_p	4	4
ECH Power P_{ECH} (kW)	< 300	< 300 x 2
NBI Power P_{NBI} (kW)	< 700 x 2	< 700 x 2
NBI Energy E_{NBI} (keV)	< 30 [H]	< 40 [H]
Working gas	D	H
Rotational transform	0.4 ~ 0.7	0.9 ~ 2.2

Shear Alfvén Continua in Three-dimensional Magnetic Configuration

- ✓ **In Boozer coordinate, magnetic field strength is expressed as**

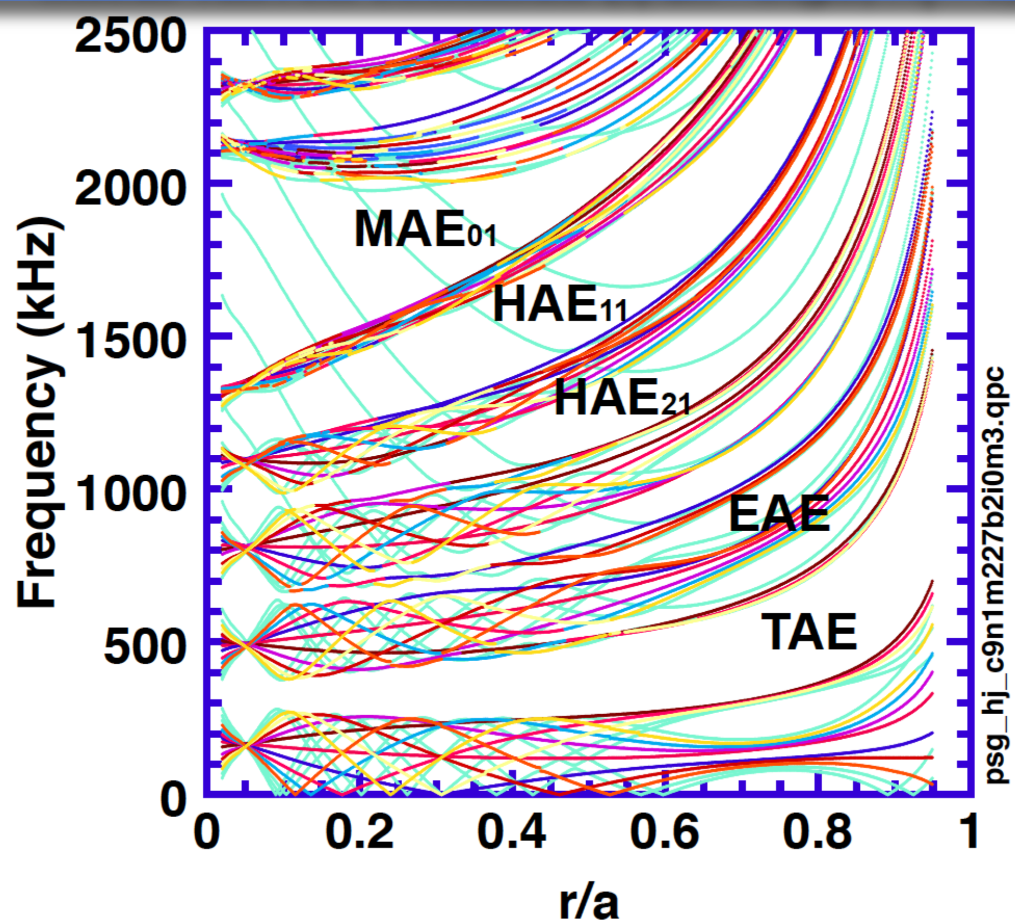
$$|\mathbf{B}| = B_0 \left[1 + 0.5 \sum_{\mu\nu} \varepsilon_B^{\mu\nu}(\psi) \cos\left(\mu\theta - \nu N_p \phi\right) \right]$$

mode coupling occurs between (*m*, *n*) ⇔ (*m*±*μ*, *n*±*νN*$_p$)

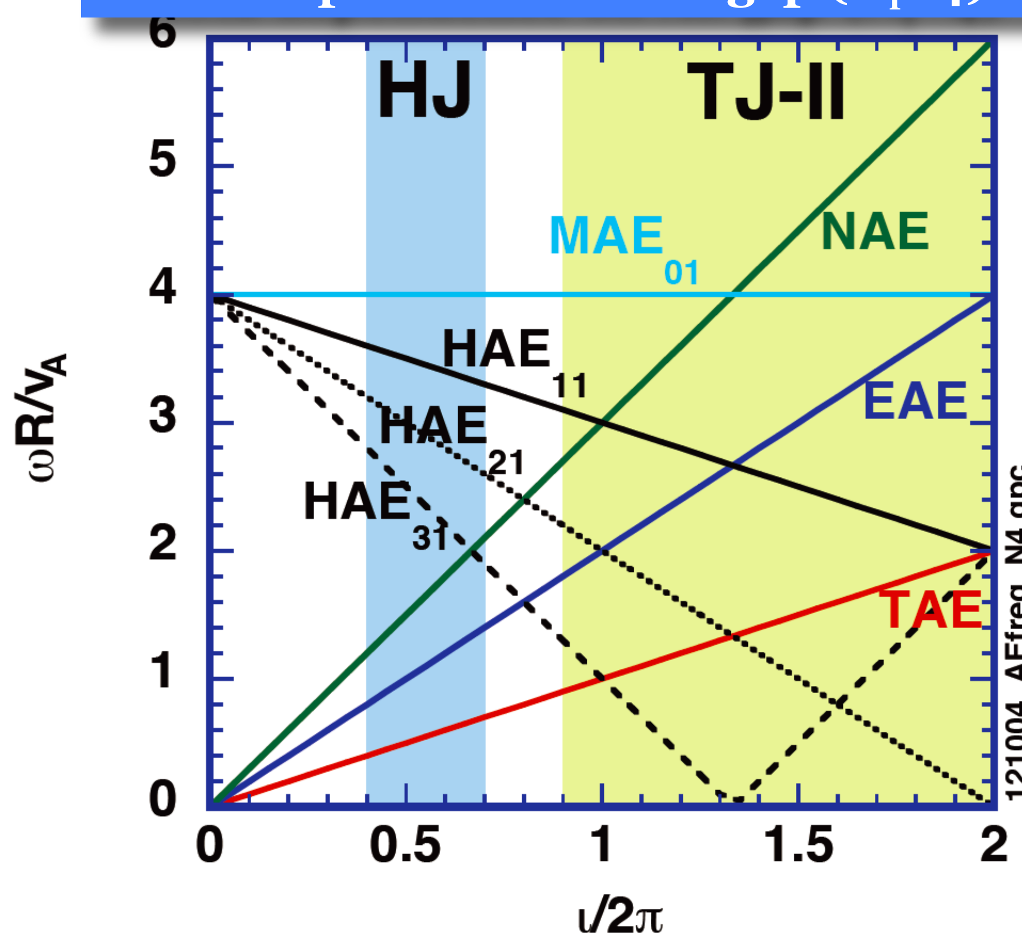
$$\omega_* = \left|k_{\parallel *}^{\mu\nu}\right| v_{A*} \equiv \left|\mu \iota_* - \nu N_p\right| \frac{v_{A*}}{2R} \qquad \iota_* = \frac{2n + \nu N_p}{2m + \mu} \qquad (\iota = 1/q)$$

(*μ*, *ν*) = (1,0): TAE / (2,0): EAE / (1,1): HAE$_{11}$ / (0,1): MAE$_{01}$

Shear Alfvén continua ($\iota/2\pi$=0.56, N_f= 1)



Iota dependence on AE gap (N_f=4)



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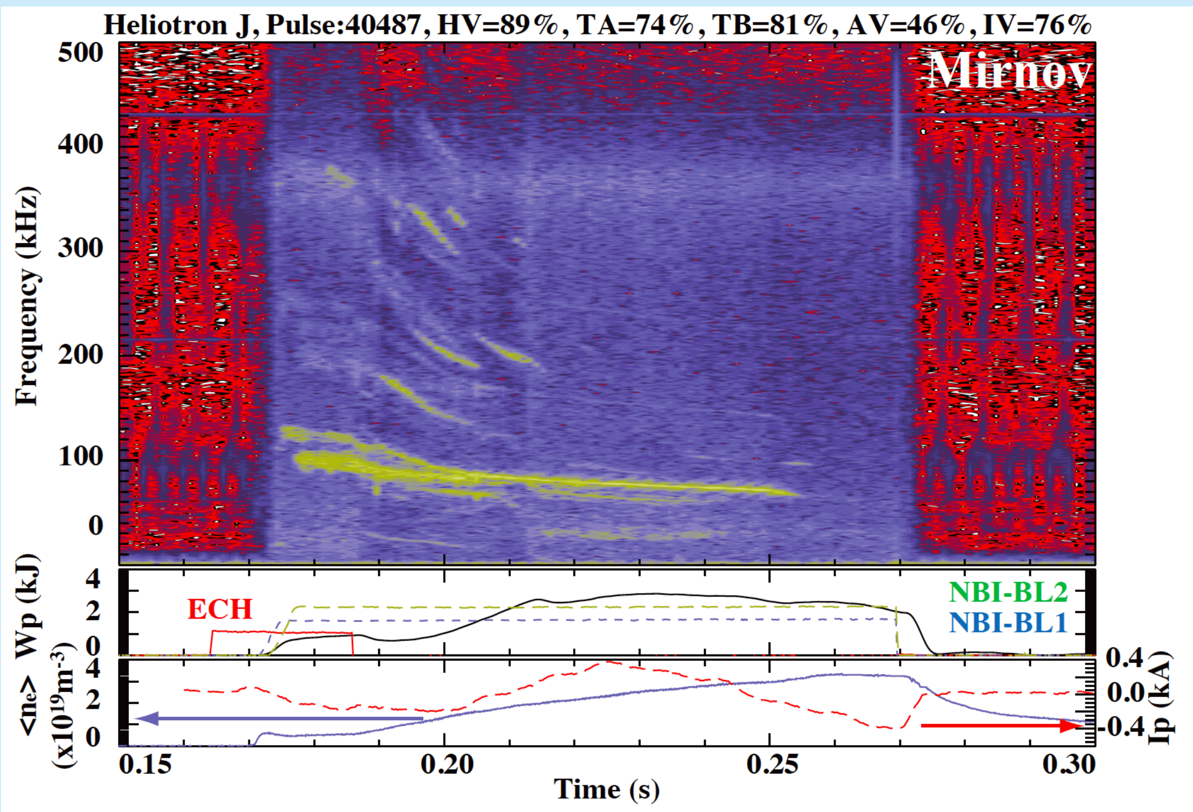
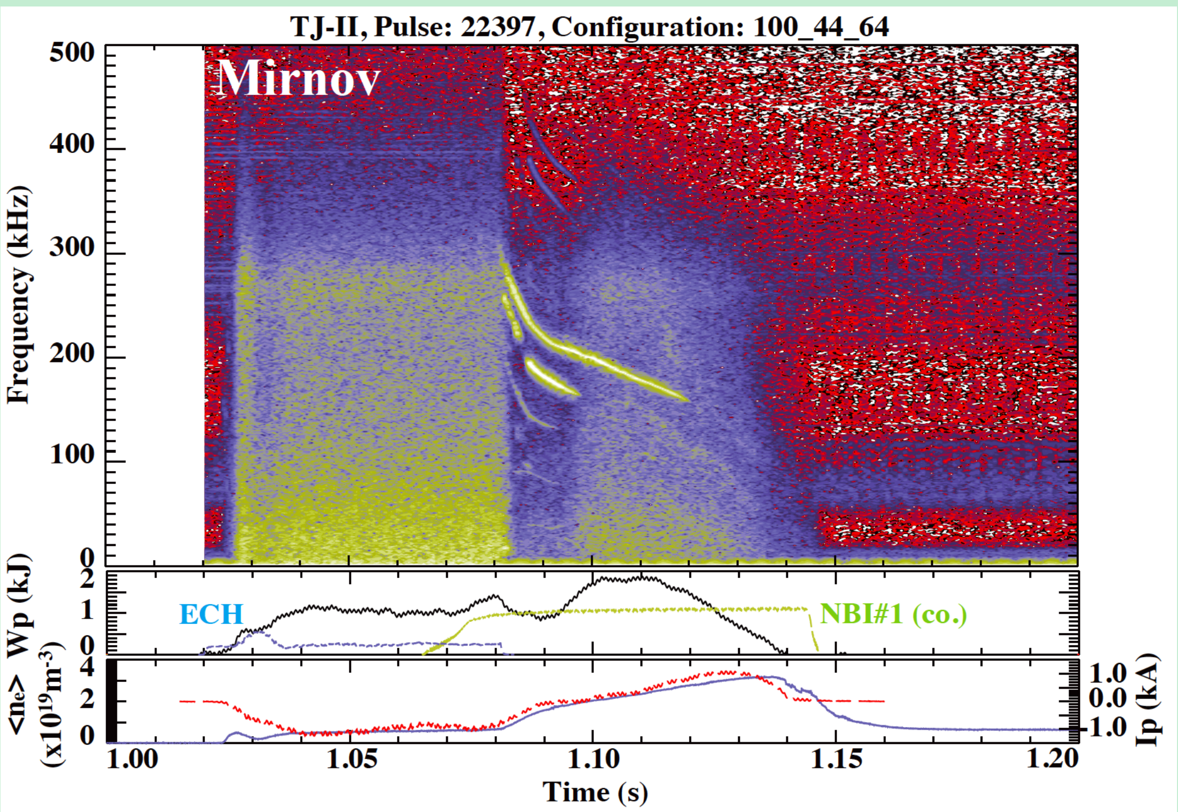
Observation of AE in NBI-heated Plasma on Heliotron J and TJ-II

Heliotron J



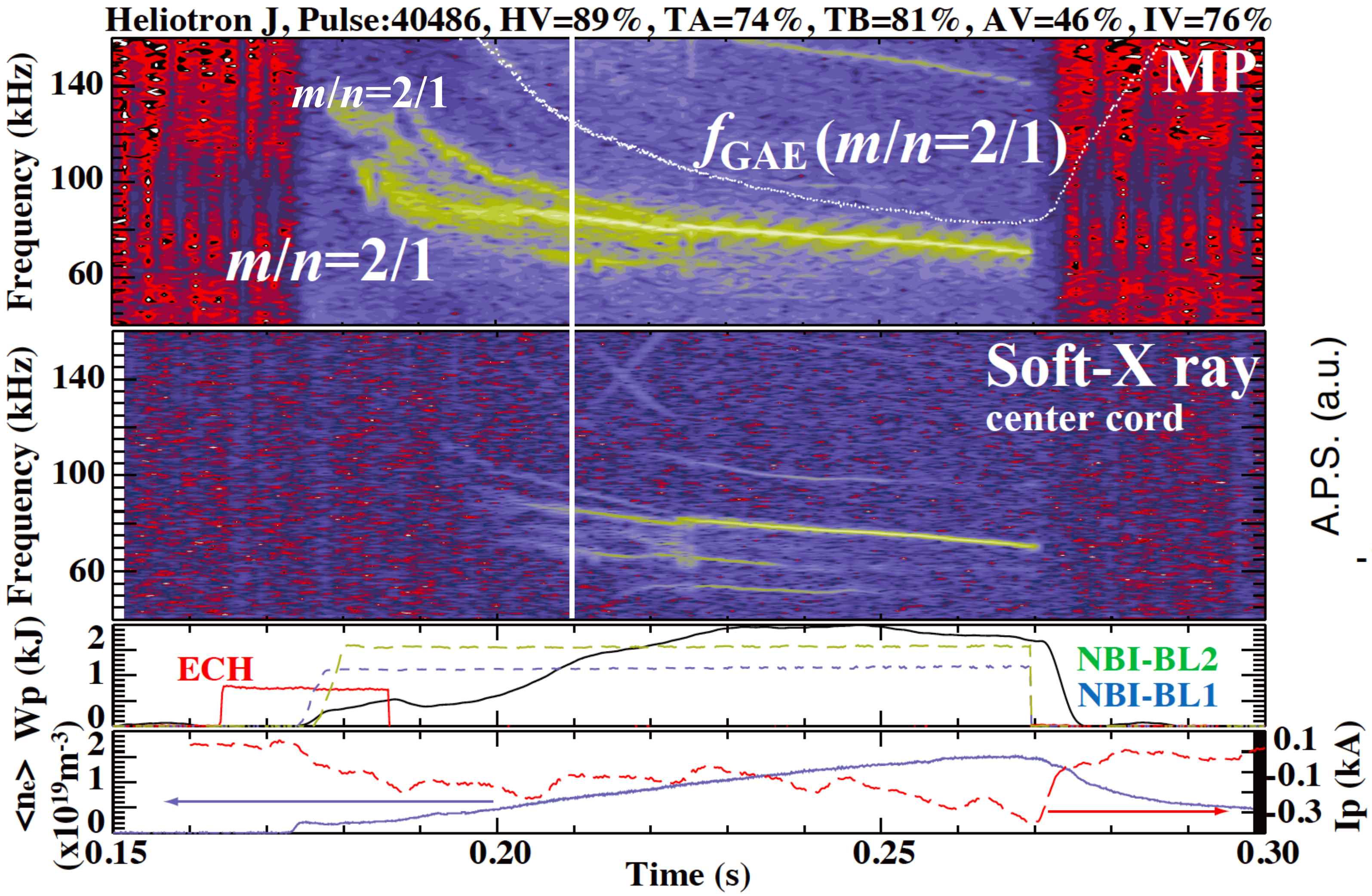
TJ-II

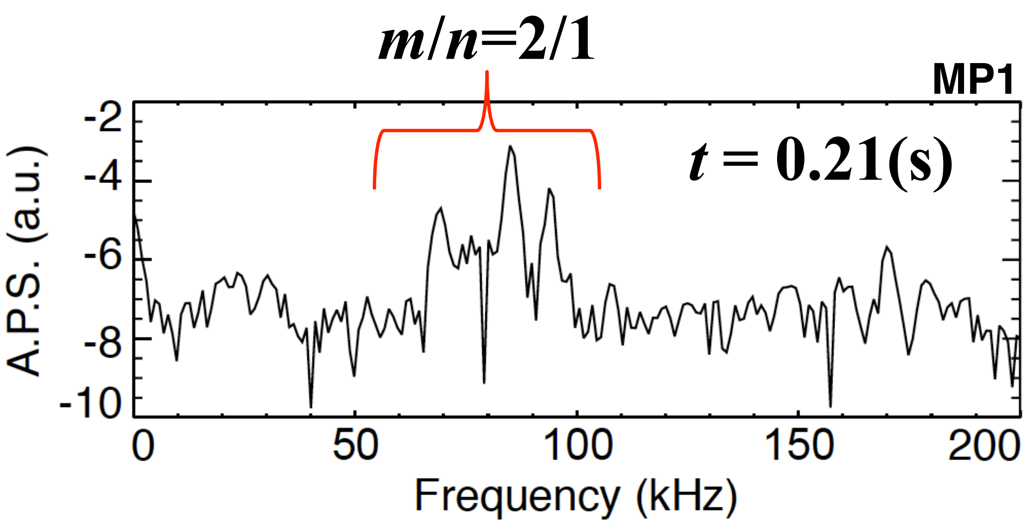


- ✓ In NBI heated plasmas, **coherent MHD instabilities** are observed in the range of Alfvén frequency in both Heliotron J and TJ-II.
- ✓ The frequency of observed modes is proportional to **Alfvén velocity** v_A.

Observation of AE in NBI-heated plasma on Heliotron J

Typical observation of AE

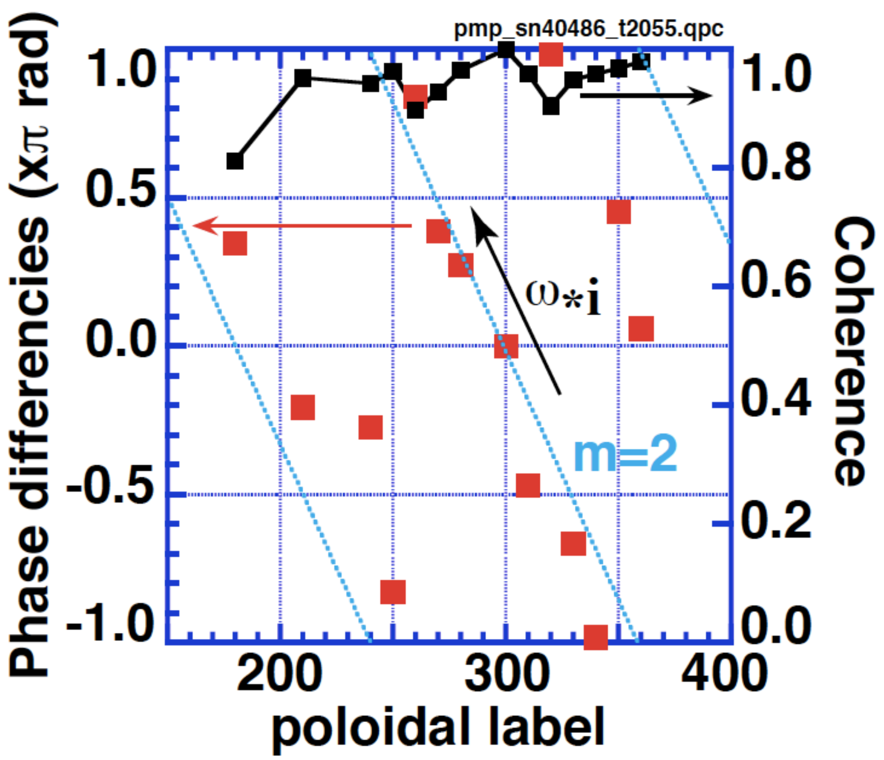




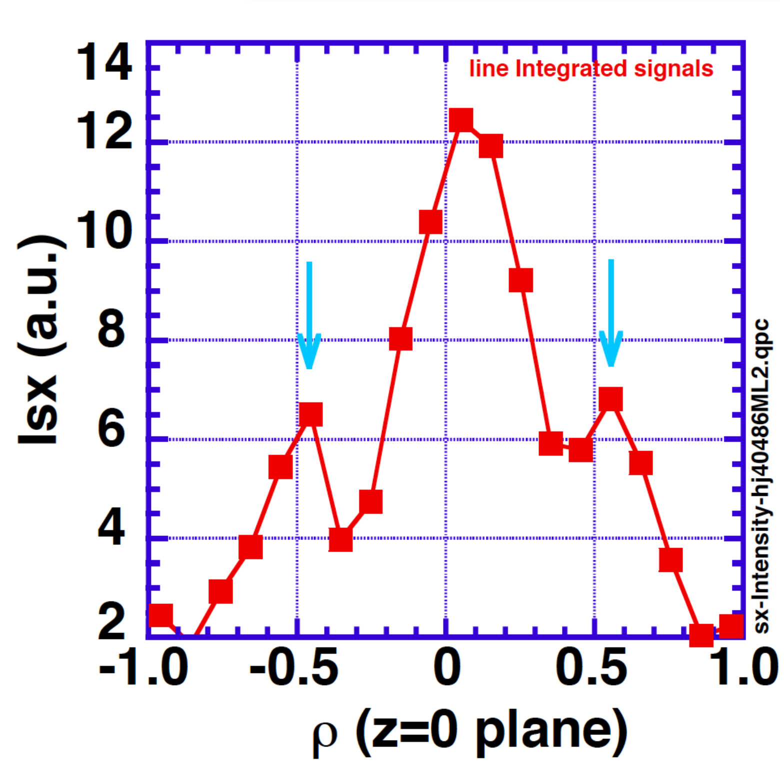
- ✓ In NBI heated plasmas, a few coherent MHD instabilities are observed in the range of Alfvén frequency.
- ✓ The time evolution of the frequency of the observed mode is similar to that of the GAE frequency with m=2/n=1. (without impurity effect)

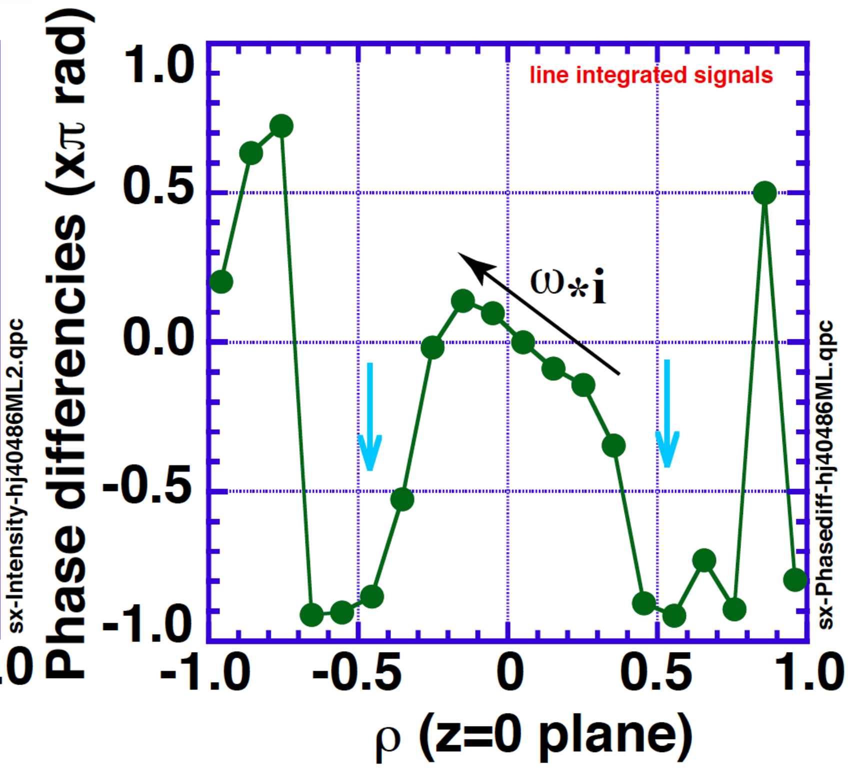
Spatial Structure of Observed AE in Heliotron J

Mirnov coil analysis



Spatial information obtained from soft-X ray



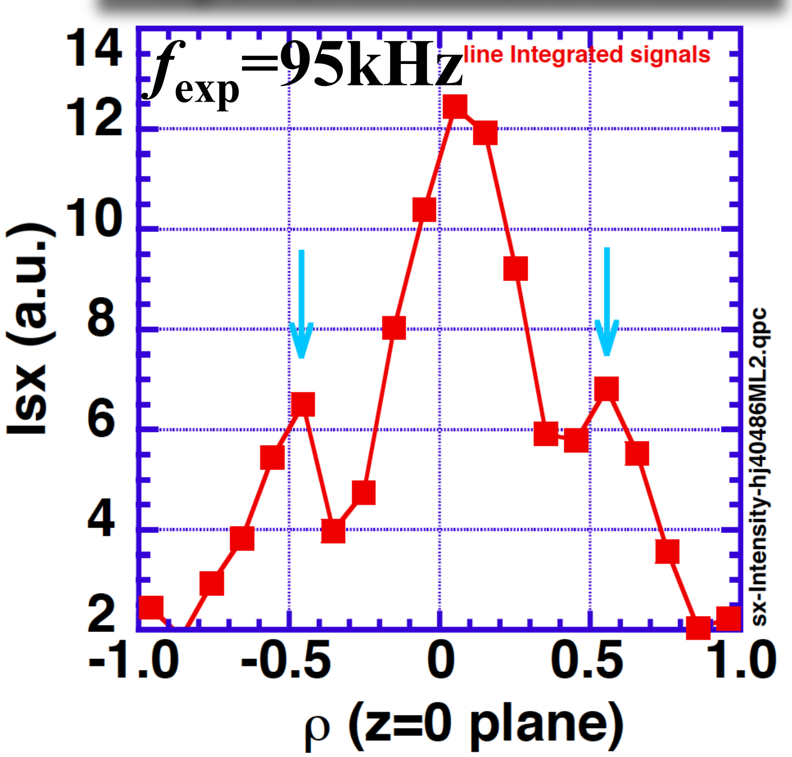


- ✓ The observed modes have m=2/n=1 mode number and propagate in the ω_{*i}.
- ✓ The mode (f_{exp} = 95 kHz) has a peak at ρ ~ 0.5 and even poloidal mode number which is coincident with magnetic probe analysis (m=2).
- ✓ MHD instabilities including GAE are also observed in BES and Reflectometer.

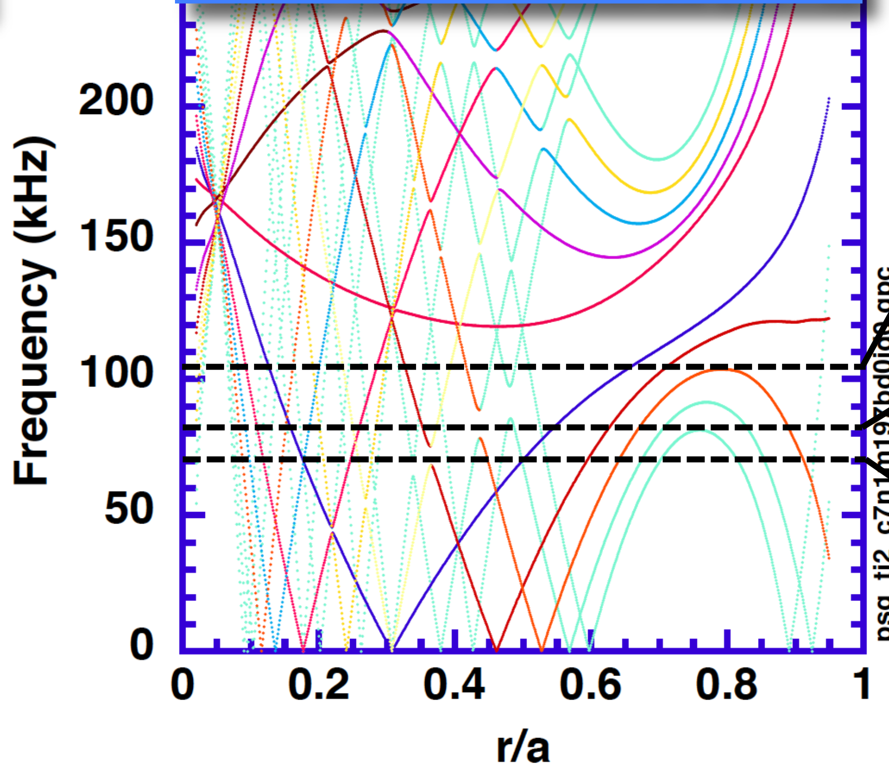
Identification of the mode as GAE in Heliotron J

☆ Continua and eignmode are calculated by STELLGAP and AE3D coded by D. Spong

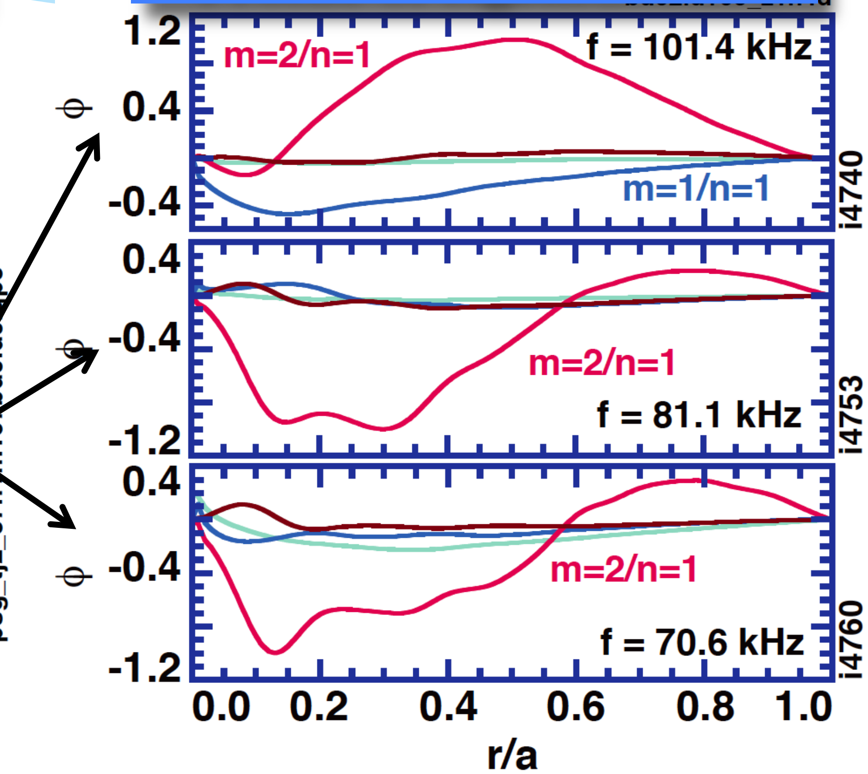
Spatial structure of SX



Shear Alfven Continua (Nf=1)



Profile of eigenfunction



- ✓ We found three discrete modes. The spatial structure of eigenmode with f_{cal} = 101kHz agree with that of the observed mode with f_{exp} = 95kHz .
- ✓ Comparison of experimental result with shear Alfvén spectra indicates that the observed modes are GAEs in Heliotron J.
- ✓ Effect of toroidal mode coupling on low-n GAE is weak in Heliotron J with N_f = 4.

Observation of AEs in NBI-heated Plasmas

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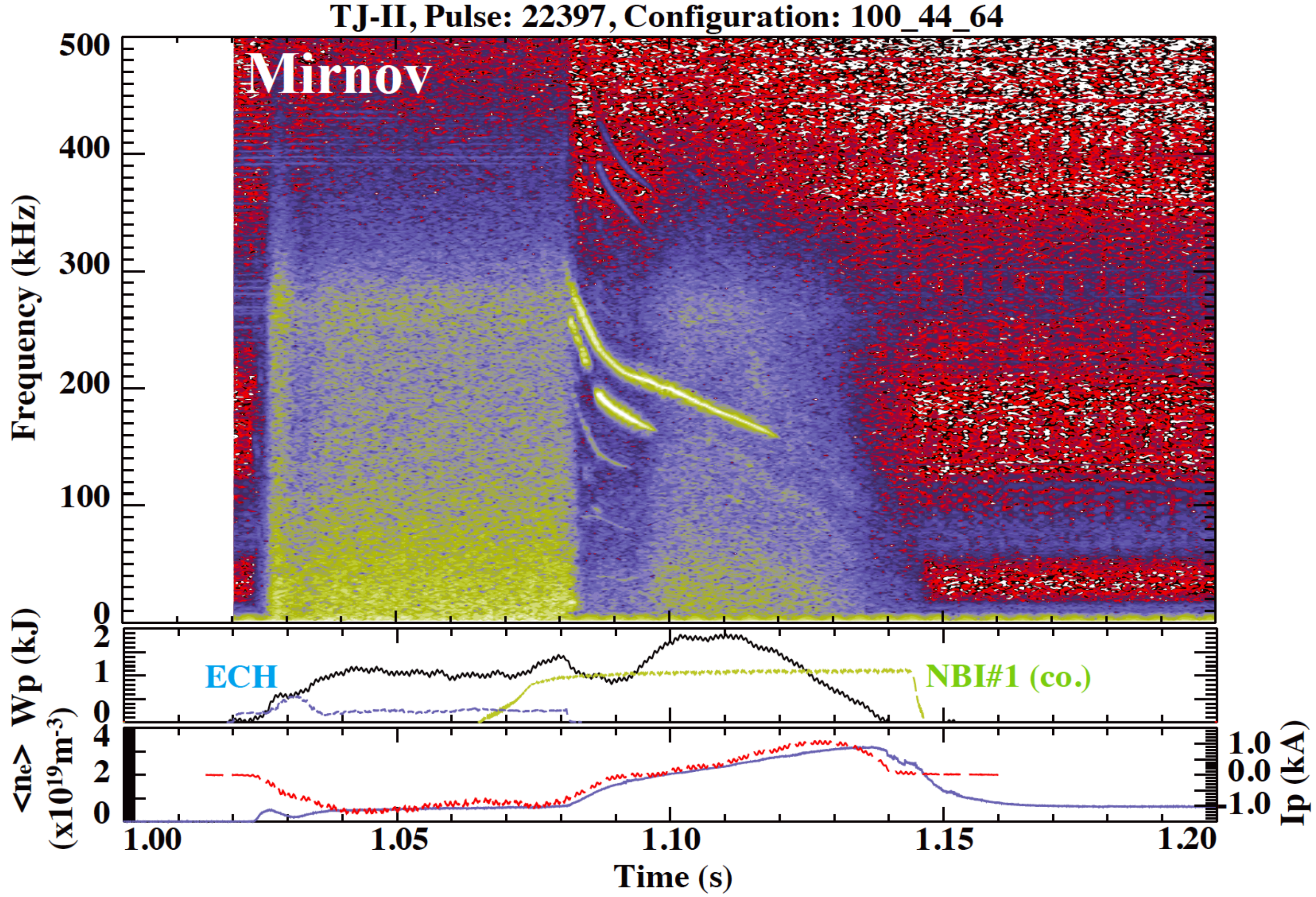
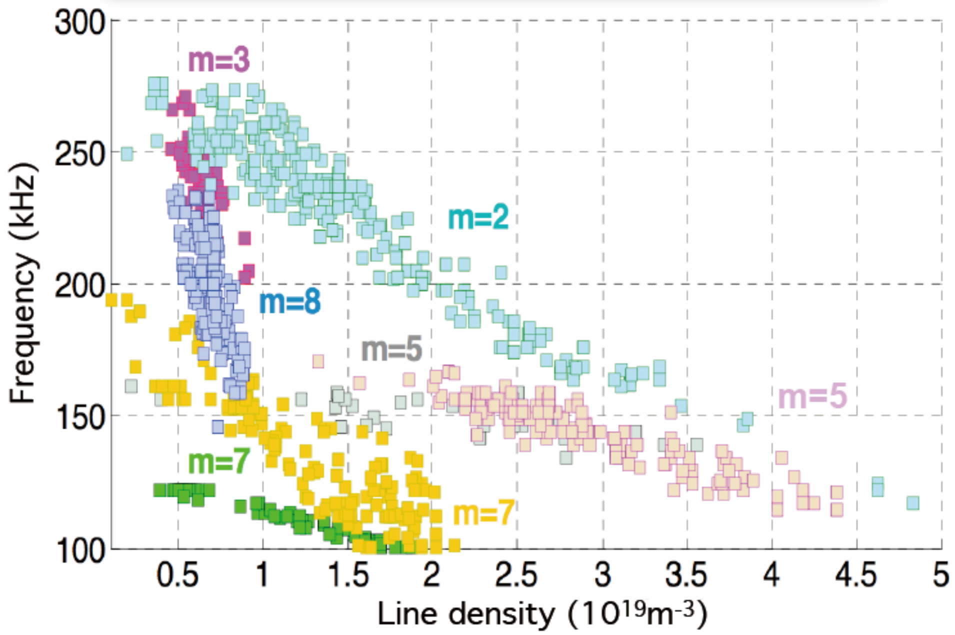
Typical observation of AEs



Seven Alfvénic cluster *



* R. Jimenez-Gomez, *et al.*, NF 51, 033001 (2011)

- ✓ In NBI heated plasmas of TJ-II, coherent MHD instabilities are observed in the range of Alfvén frequency.
- ✓ Seven Alfvénic clusters whose frequency is depended on $n_e^{-1/2}$, are mainly obtained with m = 2,3,5,7 and 8 in standard configuration in TJ-II.

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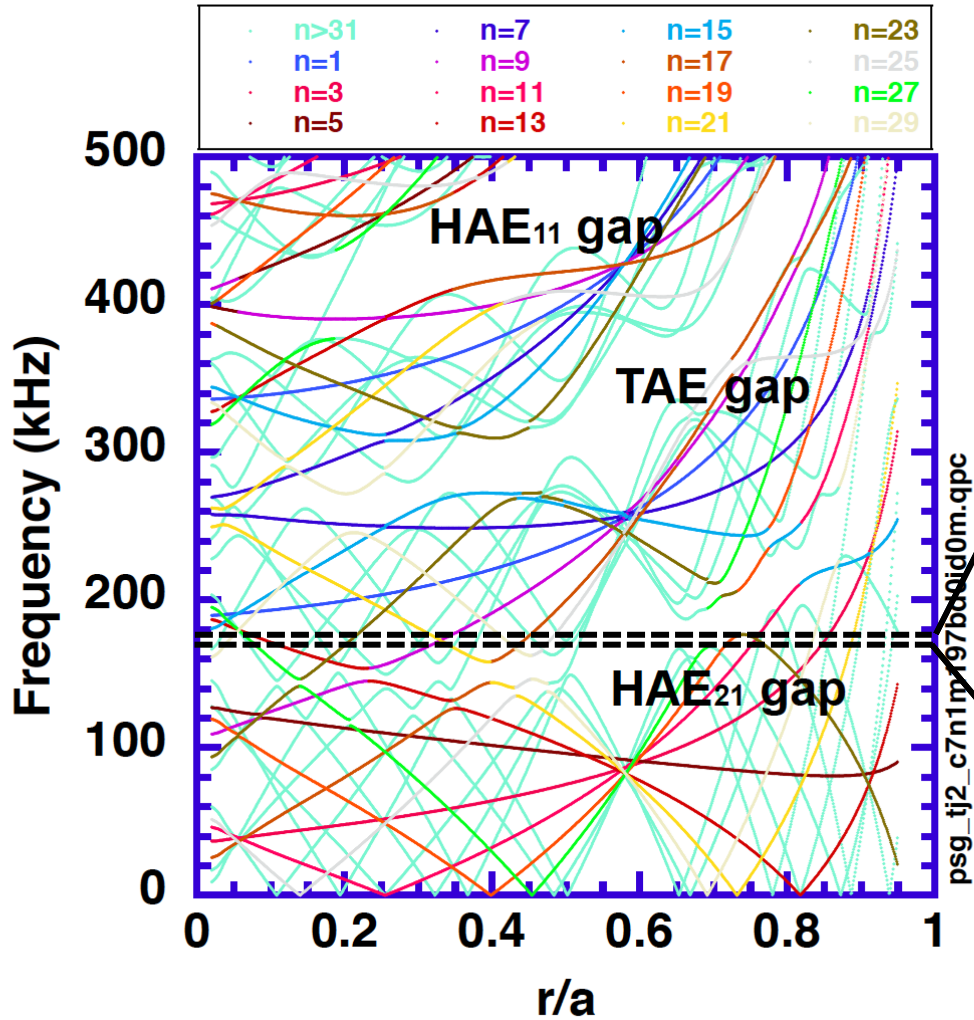
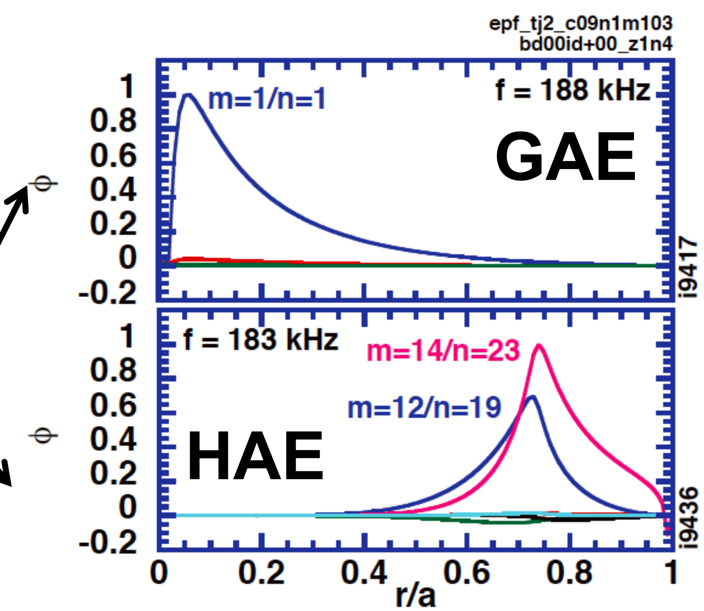
Identification of the mode in TJ-II

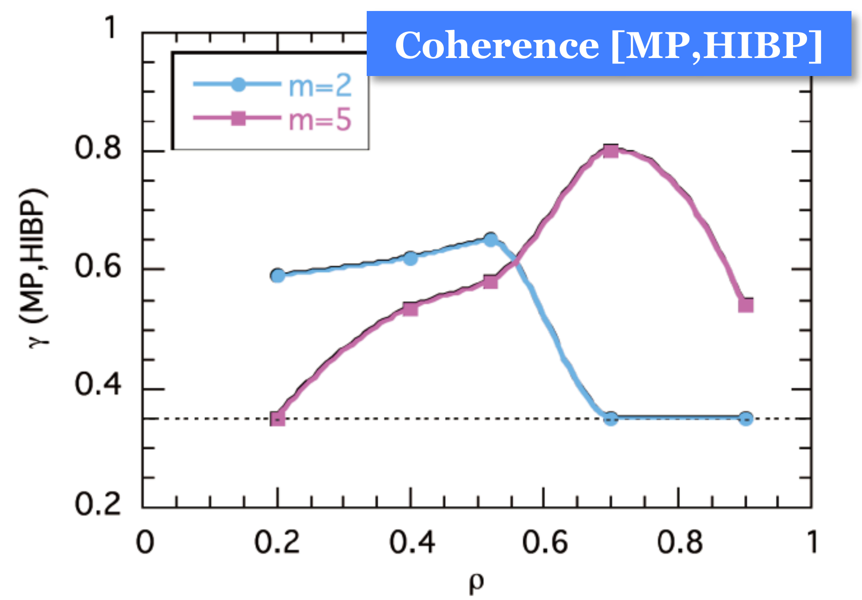
Shear Alfvén continua (N_f=1)



Spatial structure of AE



Spatial structure of observed AE *



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- ✓ Numerical simulation indicates there are **low-*n* GAEs and high-*n* HAEs.**
- ✓ The difficulty in estimating the mode number of the observed modes prevents the mode identification in our study.
- ✓ The *m*-numbers identified in the seven clusters appear **to be consistent with the numerical simulations**.

Identification of the mode in TJ-II

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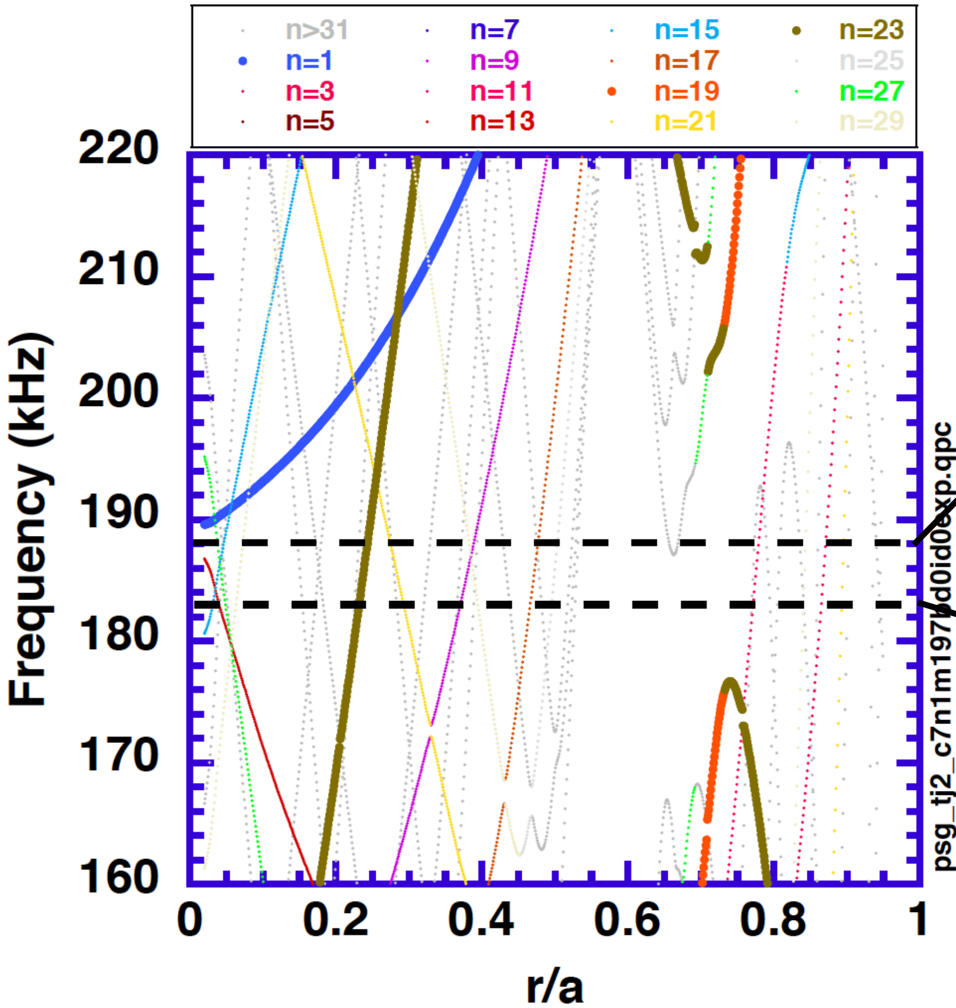
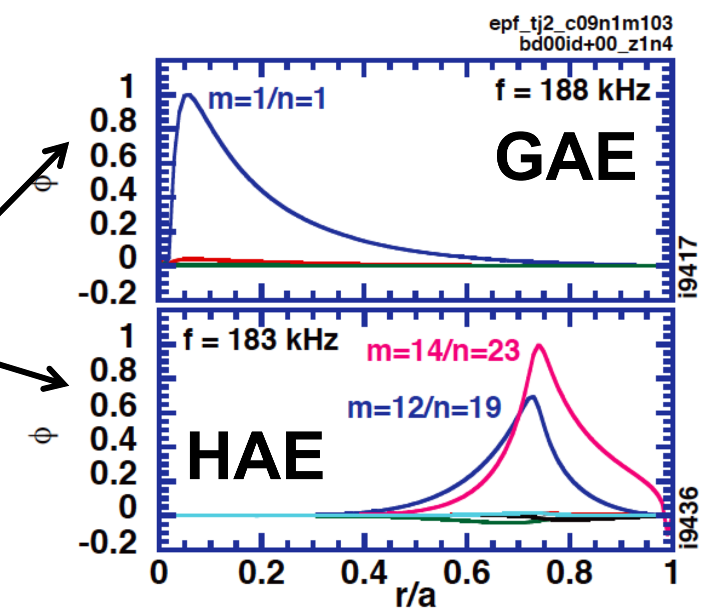
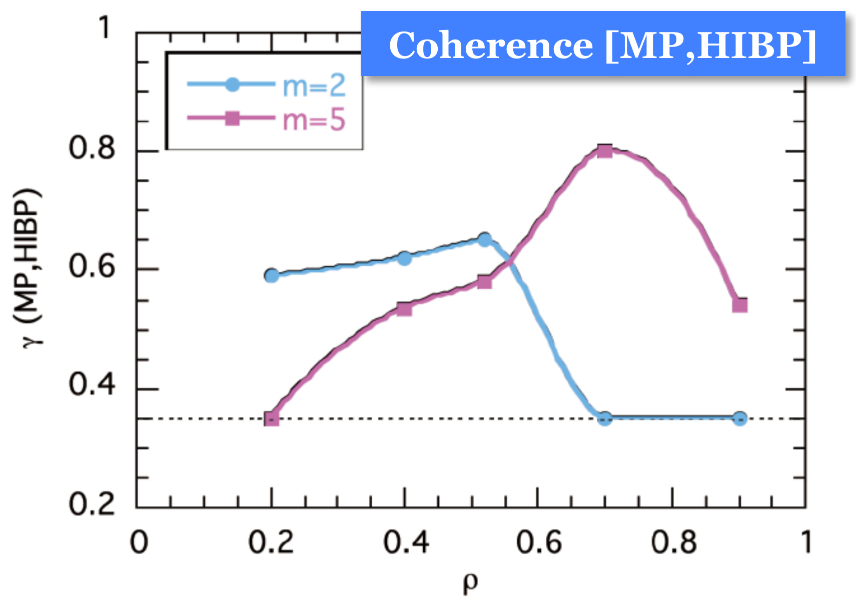
Shear Alfvén continua (N_f=1)



Spatial structure of AE



Spatial structure of observed AE *



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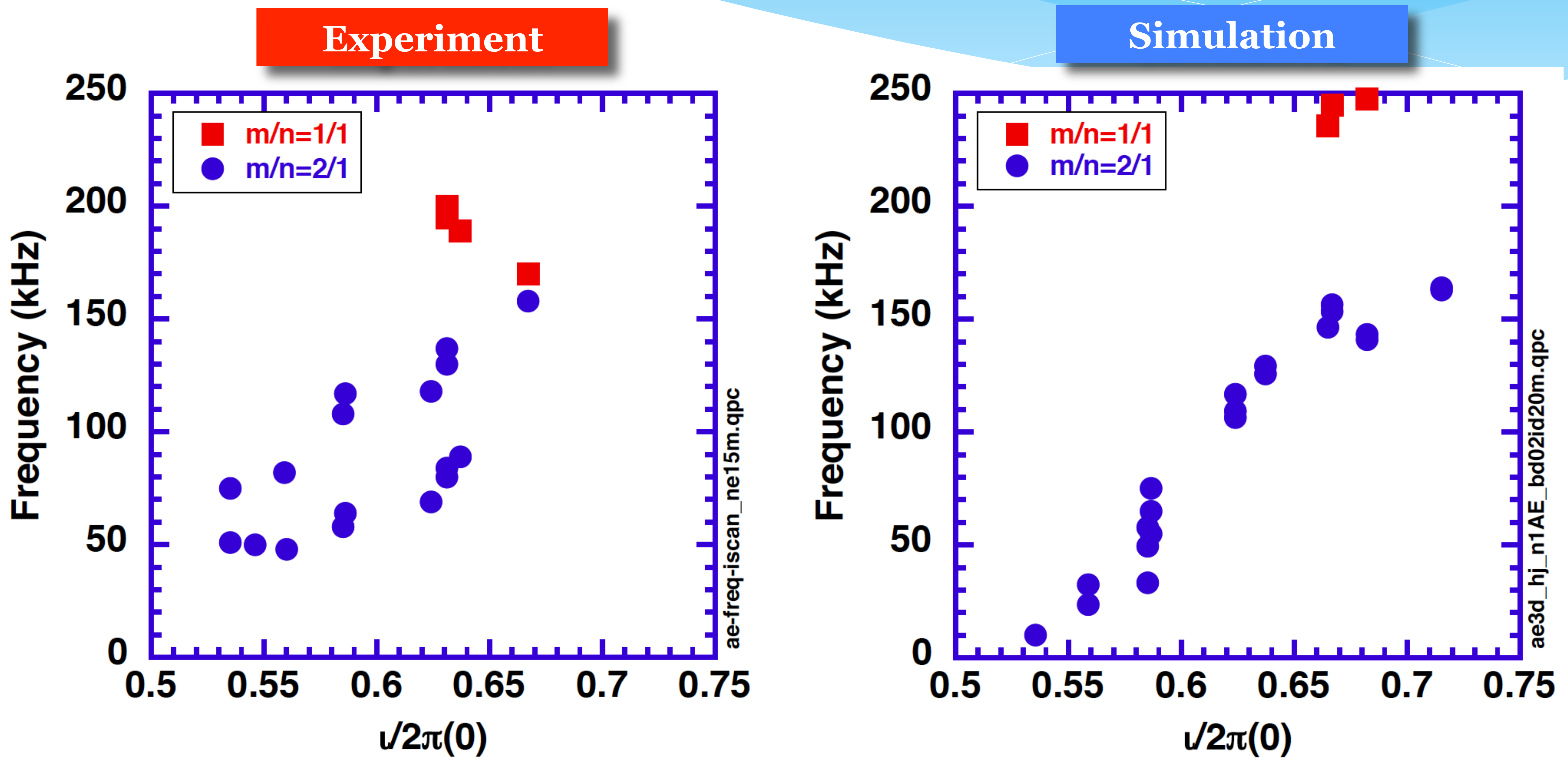
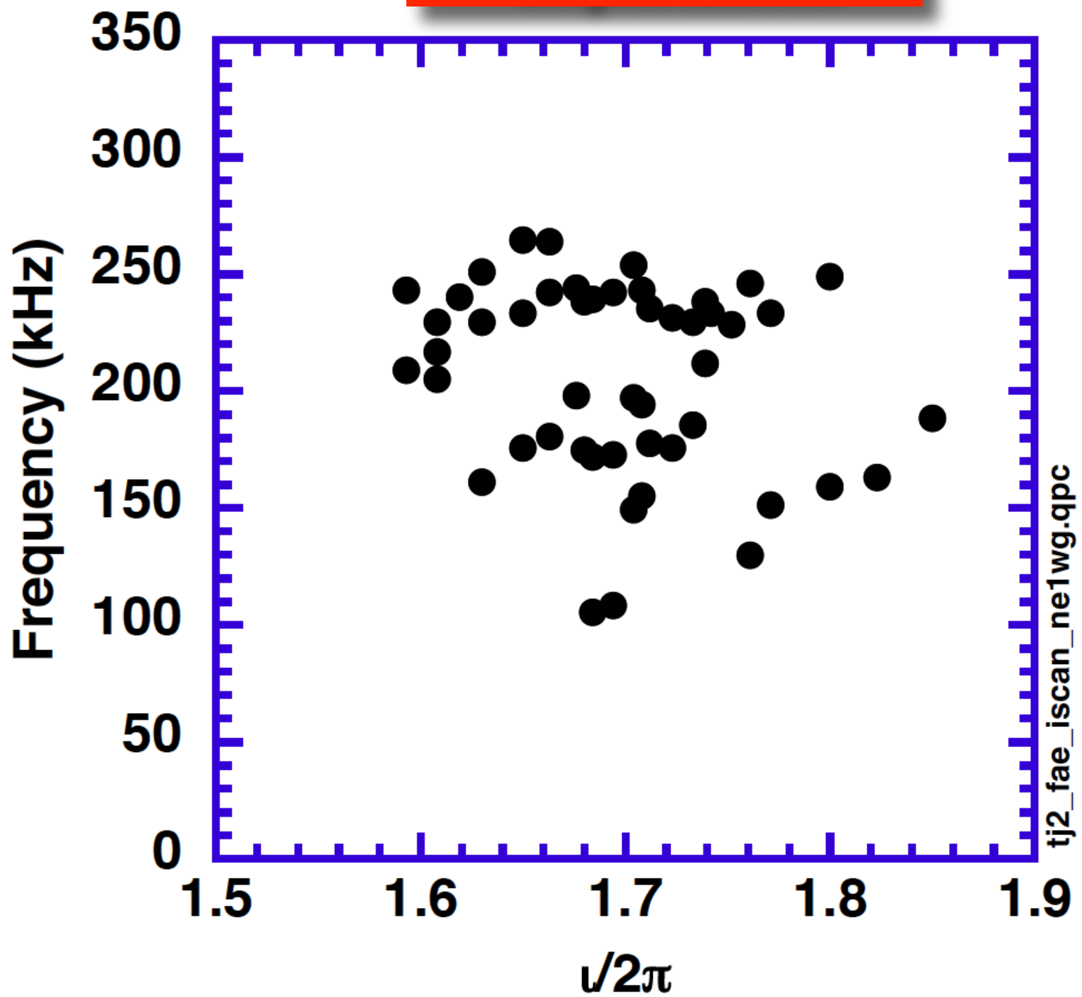
Iota Scan Experiment in Heliotron J
- simulation and experiment -



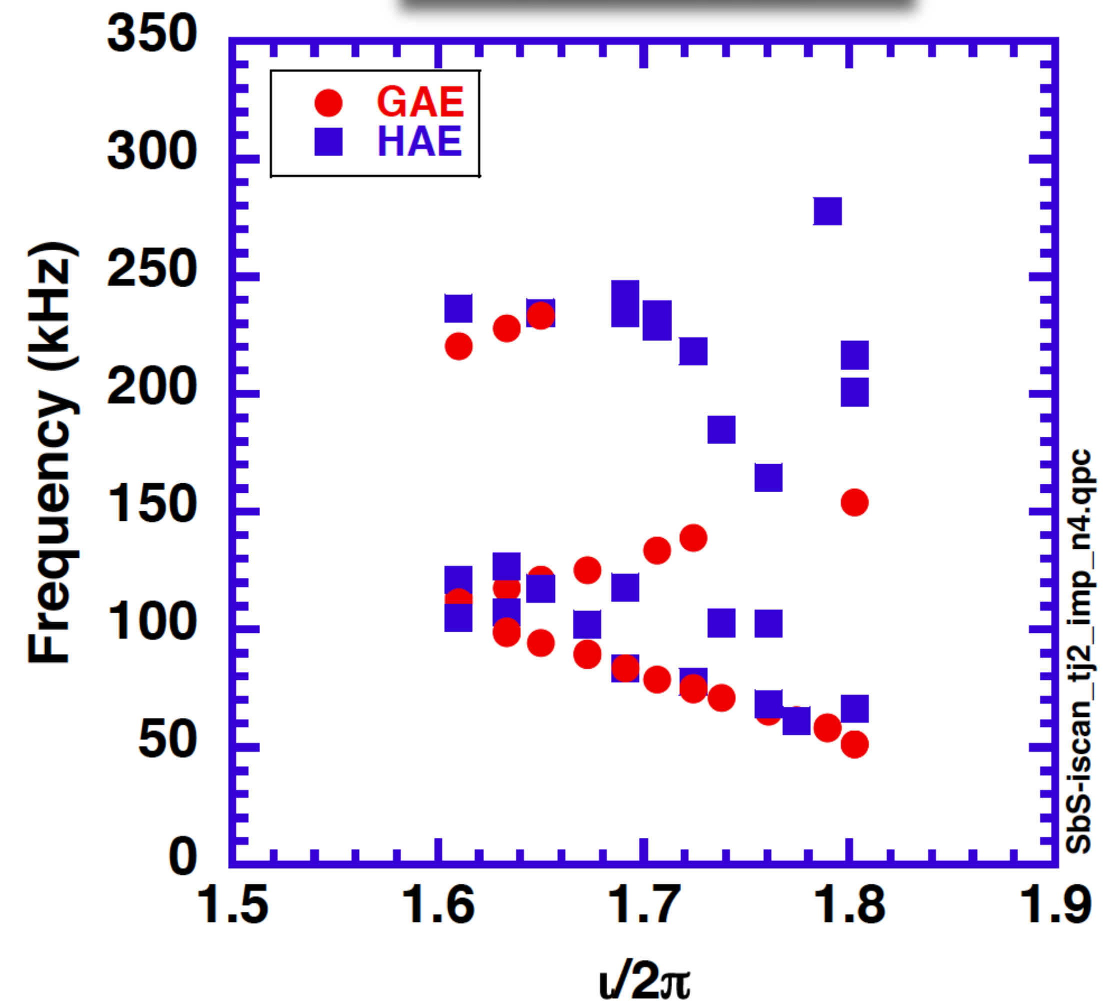
- ✓ The frequency of the observed mode with *m/n*=1/1 and *m/n*=2/1 decreased and increased with the rotational transform in experiment, respectively.
- ✓ Experimental result shows the same tendency as simulation.
- ✓ Low frequency mode (f < 50kHz) is not observed although discrete mode with low frequency is found in simulation. ➡ coupling with sound wave?

Iota Scan Experiment in TJ-II
- simulation and experiment -

Experiment



Simulation



- ✓ The behavior of the observed mode frequency has complex nature in TJ-II.
- ✓ It seems that the frequency range of the observed mode is consistent with numerical simulation. This means the observed modes are thought to be GAEs and HAEs in TJ-II.

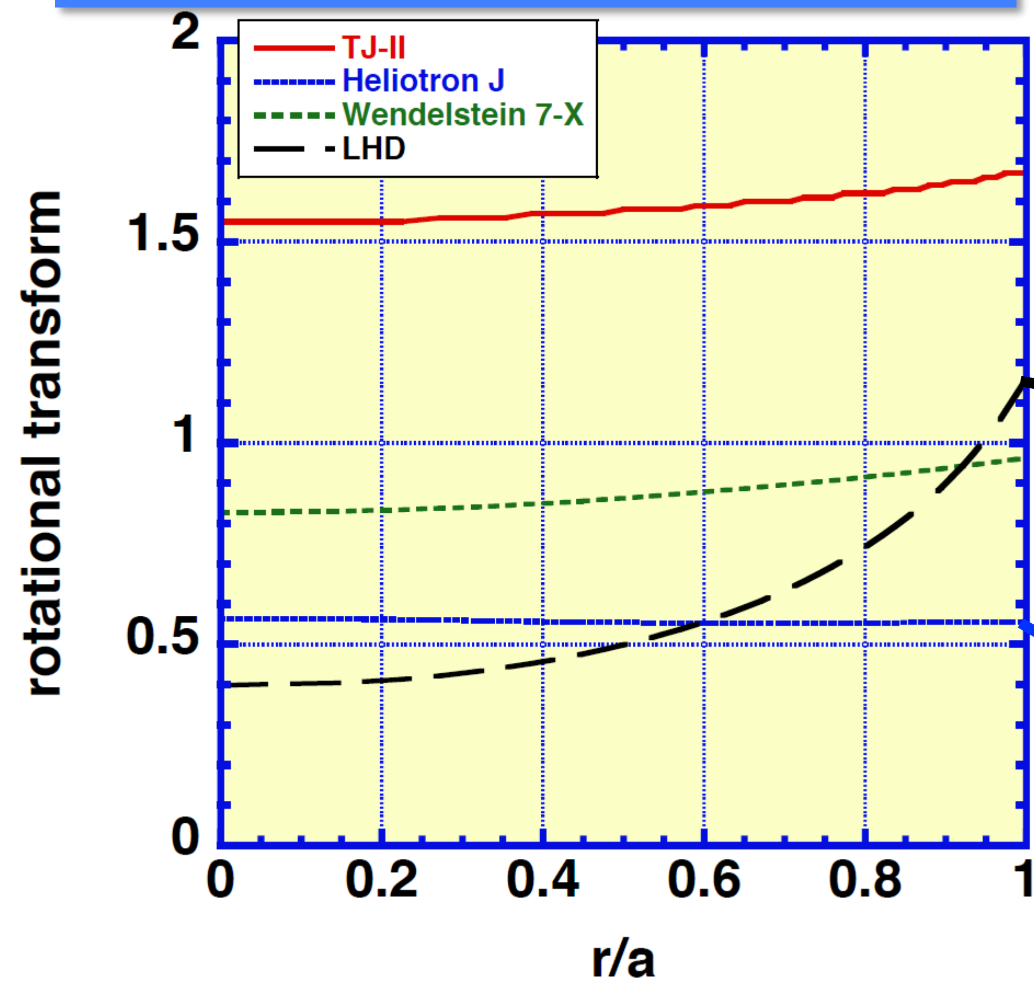
Conclusion

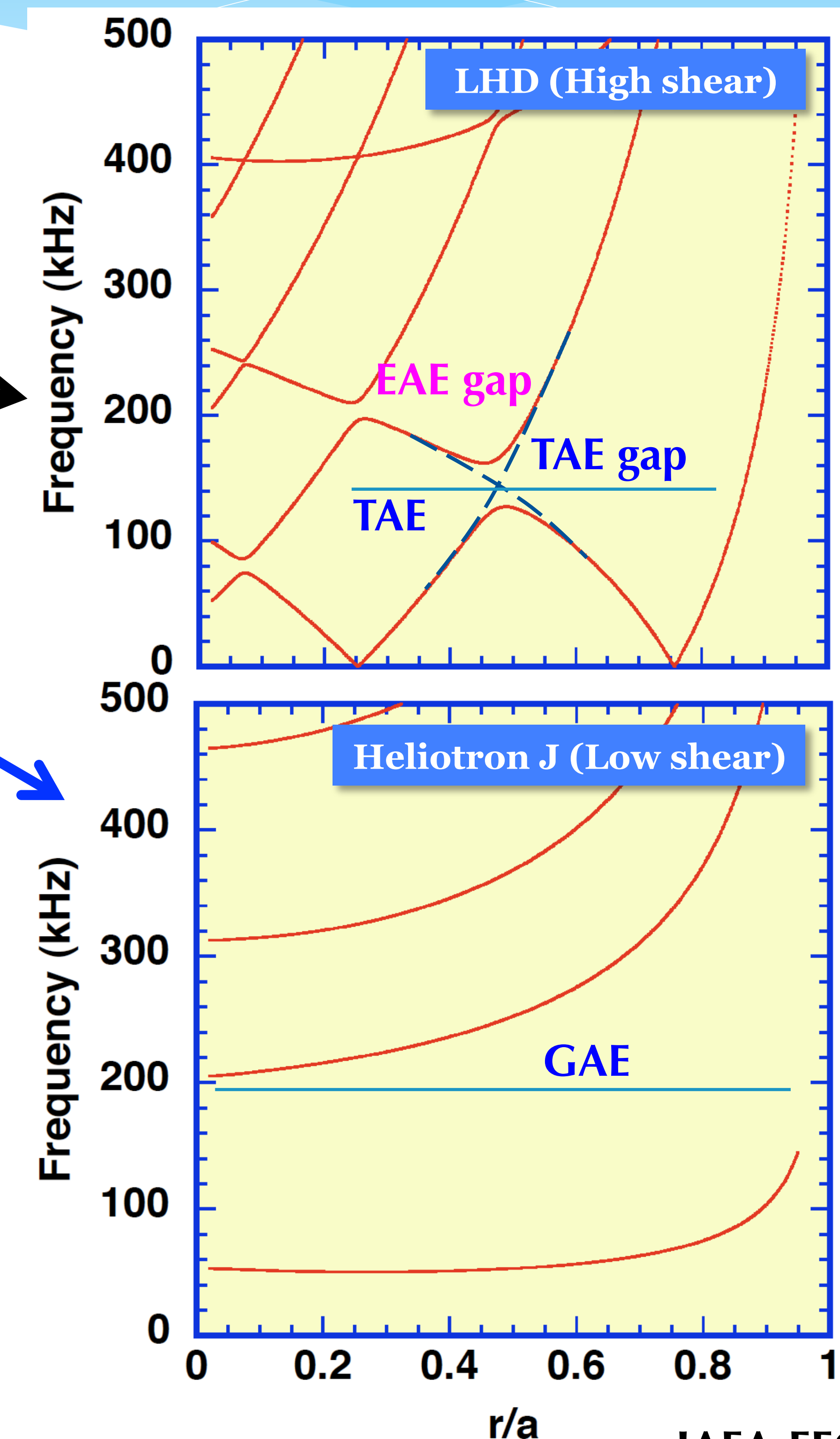
- ✓ The research collaboration between Heliotron J (low iota) and TJ-II (high iota) aims to clarify the energetic-ion-driven MHD instabilities appearing in the plasmas with low magnetic shear and low toroidal field period.
- ✓ In the helical plasmas with low magnetic shear, GAEs which consisted of a few modes are mainly observed in the case of low iota (Heliotron J). The results of iota scan exp. support the observed modes are GAEs.
- ✓ The observed AEs in high iota configuration (TJ-II) is thought to be both GAEs and HAEs from the results of iota scan exp.
- ✓ GAEs are mainly observed in low magnetic shear helical plasmas. In addition, HAEs are also destabilized in the case of high iota configuration.
- ✓ The Effect of toroidal mode coupling on low-n GAE due to low toroidal field period is weak.

Backup material

Shear Alfvén Continua in Two-dimensional Magnetic Configuration

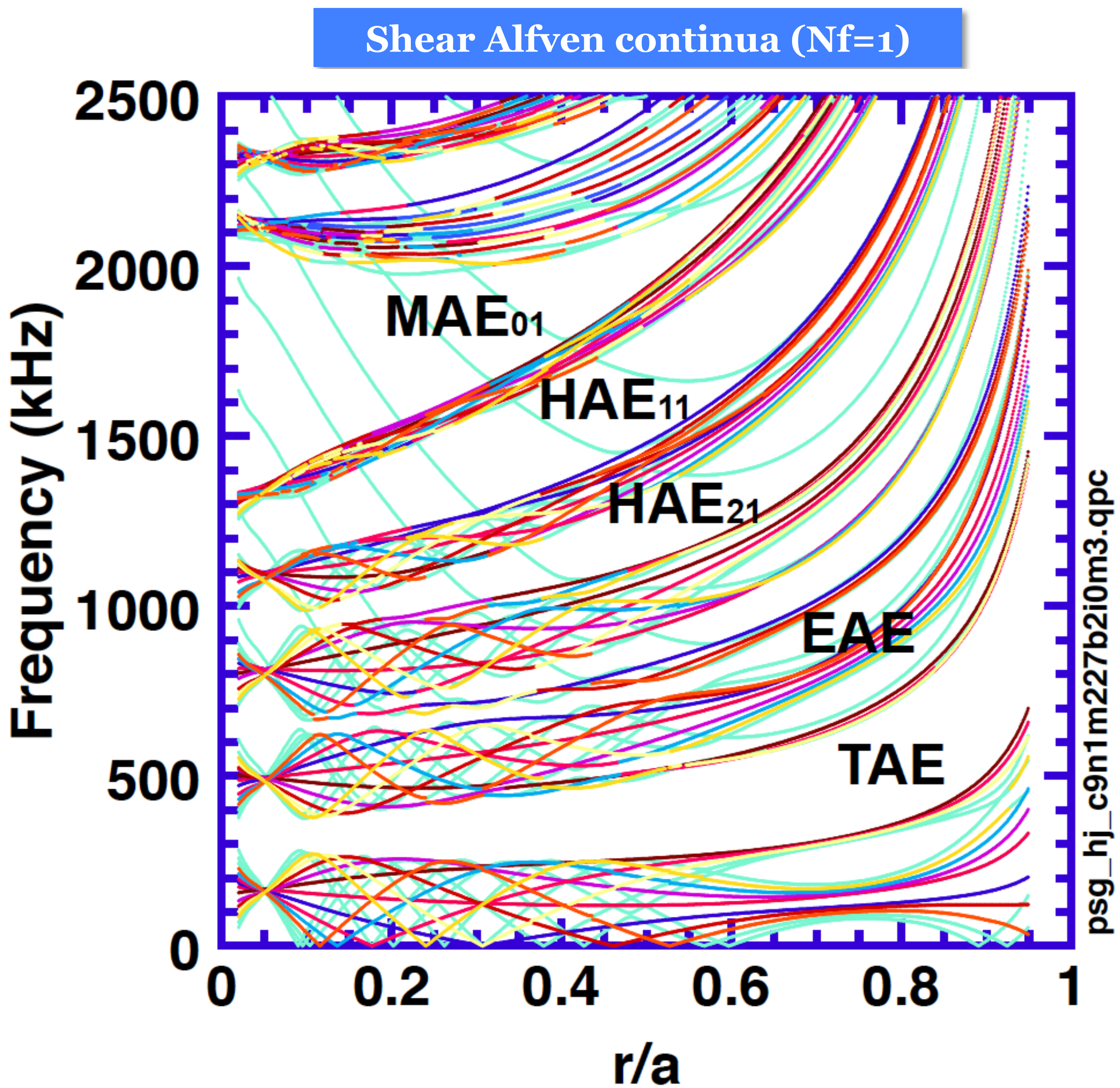
Profile of rotational transform (iota)





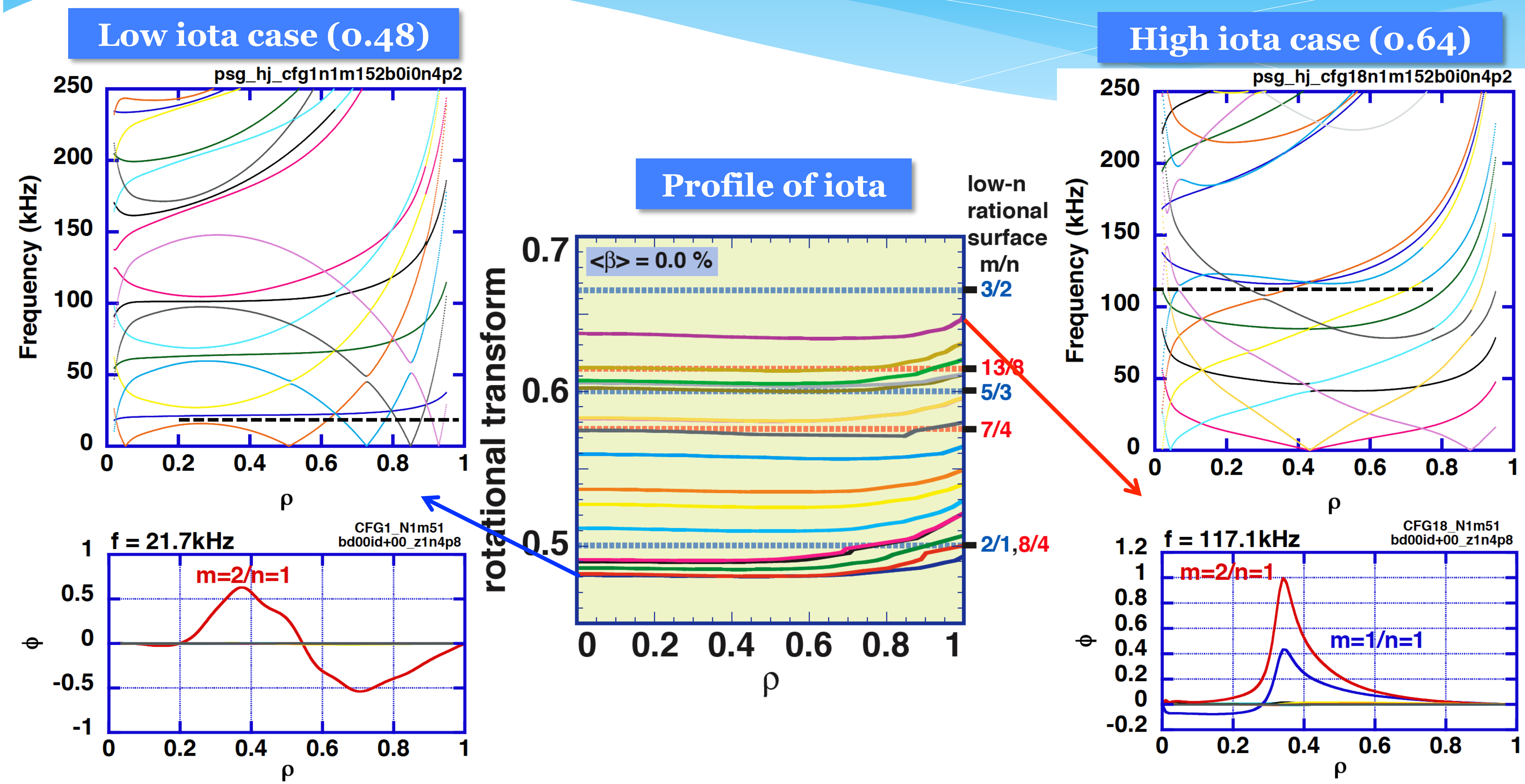
- ✓ In high magnetic shear configuration, shear Alfvén continua will intersect each other, then TAE and EAE gaps will be formed.
- ✓ In low magnetic shear configuration, GAE can lie below and/or above the continuum instead of TAE (low-*n*).

Where are the HAEs in Heliotron J?



- ✓ HAEs have not been measured or identified yet.
- ✓ Continua with high mode number *m* and *n* intersect each other, and TAE, EAE and HAE gaps are formed in the high frequency region.
- ✓ HAE gaps exist above 1000 kHz.
- ✓ Main Fourier components of magnetic field of Heliotron J, ε_t, ε_b and $\varepsilon_{h(1,1)}$ induce the wide frequency gaps of TAE, MAE and HAE_{11} in continua.

Dependence of Shear Alfvén Spectra on Iota



- ✓ We investigated **the iota dependence of observed mode in an iota scan** experiment. The frequency of GAE and HAE is related to the iota value.
- ✓ In the range of $0.45 < \iota/2\pi < 0.65$, **GAEs which consist of a few mode** are dominant in the range of $f < 500$ kHz from the simulation.