Optimization of pressure gradient driven modes and Alfven Eigenmodes stability by the neutral beam current driven in LHD plasma

J. Varela[1], K.Y. Watanabe[2], Y. Takemura[2], K. Nagaoka[2], K. Ida[2], M. Yoshinuma[2],
D. Spong[3], L. Garcia[1], J. Ortiz[1] and Y. Ghai[3]

[1] *Universidad Carlos III de Madrid, 28911 Leganes, Madrid, Spain*

[2] *National Institute for Fusion Science, National Institute of Natural Science, Toki, 509-5292, Japan*

[3] *Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831-8071*

The aim of the study is to analyze the stability of pressure gradient driven modes (PGDM) and Alfven Eigenmodes (AE) in LHD plasma heated by tangential neutral beam injector (NBI) showing a large current drive.

Advanced operation scenarios in nuclear fusion devices require MHD stable plasma. Unstable pressure / current gradient driven modes causes a decrease of the magnetic trap efficiency to confine the plasma, eventually leading to the plasma collapse or disruptions [1, 2]. The destabilization of Alfven eigenmodes induces large losses of energetic particles before thermalization, reducing the plasma heating efficiency [3].

The NBI current drive (NBCD) modifies the iota profile, leading to the stabilization or further destabilization of the PGDM and AE. The study consist in a set of experiments performed in the 22nd and 23nd LHD campaigns dedicated to analyze the effect of the NBCD on the stability of PGDM and AE for inward shifted configurations. The iota profile is measured using Motional Stark Effect (MSE) [4] and the plasma stability is analyzed using the code FAR3d [5]. The code FAR3d solves the reduced MHD equations describing the linear evolution of the poloidal flux and the toroidal component of the vorticity in a full 3D system, coupled with equations of density and parallel velocity moments for the energetic particle (EP) species, including the effect of the acoustic modes [6, 7].

Improved LHD operation scenarios are explored with optimized MHD stability, identifying the configurations that combine stable pressure gradient driven modes and Alfven Eigenmodes.

PGDM stabilization by iota profile up shift

Shot 167800 shows a strong $n/m = 1/2$ activity (n the toroidal and m the poloidal modes number) above a given threshold of the plasma thermal β (fig 1a). Rational surface $1/2$ resonates in the inner-middle plasma region (fig. 1c and d). PGDM $1/2$ is stabilized above a threshold of the NBCD intensity (fig 1b). The best fit of MSE data indicates the iota profile

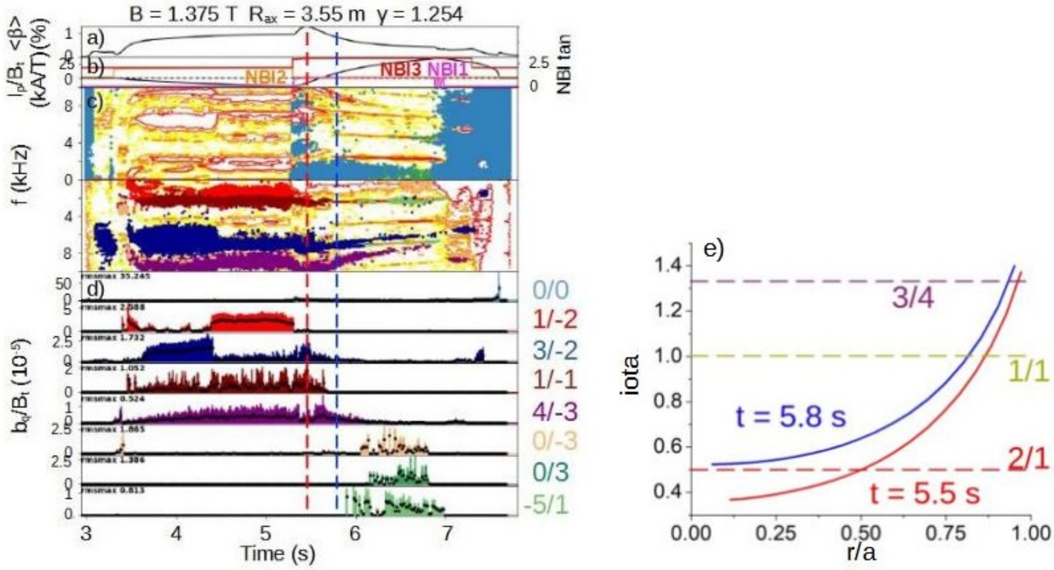

Figure 1: *a) Thermal β, (b) Toroidal current and NBI pattern, (c) Modes frequency, (d) Mode amplitude and (e) iota profile best fit.*

is up-shifted by the effect of the NBCD (fig. 1e). At $t \geq 5.5$ s the iota profile minima is above 0.5, thus the rational surface $1/2$ is non resonant and the $1/2$ PGDM is stabilized.

FAR3d code is applied to reproduce the MHD stability of shot 167800. Model iota profile is obtained from the MSE data (except $t = 5000$ ms that is an assumption) and thermal plasma profiles by Thomson scattering (fig. 2a to c). The simulations indicate $1/2$ PGDM is unstable at $t = 5.0$ and 5.5 s although stable at $t = 5.8$ s once $\iota_{min} > 1/2$ (fig 2d). Periphery PGDM as $1/1$ (and overtones), $3/2$ and $4/3$ are unstable from $t = 5.5$ s. Plasma periphery destabilized as ι_{min} increases (fig. 2d to g).

AE stabilization by iota profile up shift

Shot 167805 indicates the destabilization of AEs around the frequecy range of 60 - 75 kHz. Plasma density is lower compared to 167800 shot, thus the thermal β is smaller and the PGDM are stable (panel 3a to d). A lower plasma density leads to an enhancement of the EP resonance and the destabilization of AEs (fig. 3e). The iota minima decreases during the ctr-NBCD phase leading to a up-sweeping of the AE frequency. ι_{min} increases once the co-NBCD phase begins (fig. 3f).

The AE stability is modelled using FAR3d and Stellgap codes. The continuum shows slender gaps as iota minima decreases (fig. 4a). The $n = 1$ AE EP β threshold is 0.002 and the mode growth rate decreases as ι_{min} decreases (fig. 6c and d). The simulations reproduce $n = 1$ AE frequency sweeping as iota minima decreases (fig 6b). $n = 1$ AE is a TAE evolving from a dominant $1/2 - 1/3$ to a $1/3 - 1/4$ as ι_{min} decreases.

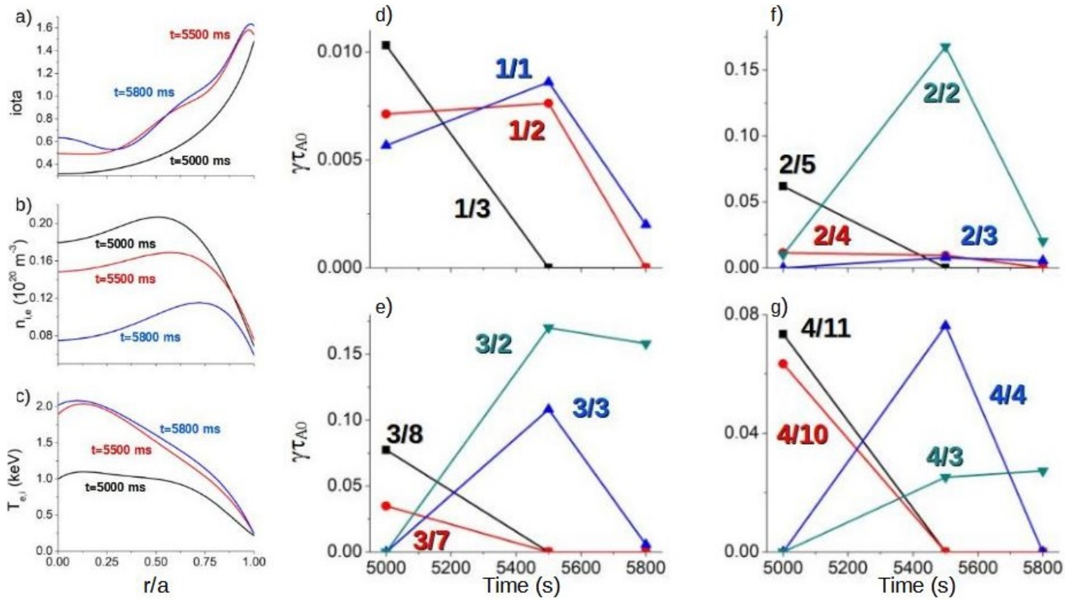

Figure 2: *a) Thermal β, (b) Toroidal current and NBI pattern, (c) Modes frequency, (d) Mode amplitude and (e) iota profile best fit.*

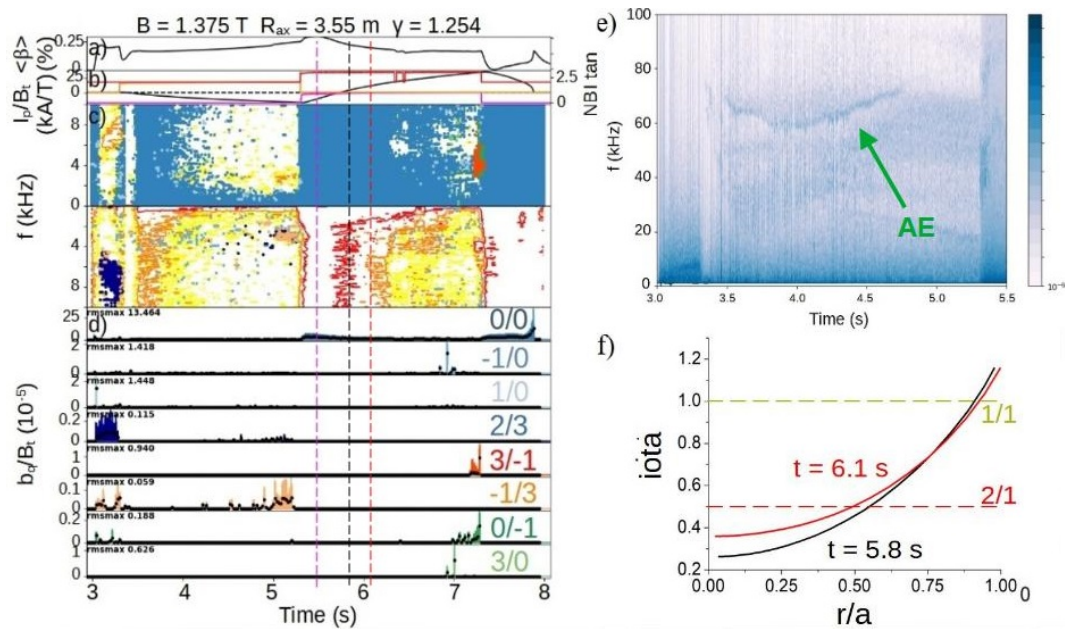

Figure 3: *a) Thermal β, (b) Toroidal current and NBI pattern, (c) Modes frequency, (d) Mode amplitude, (e) spectrometer data and (f) iota profile best fit.*

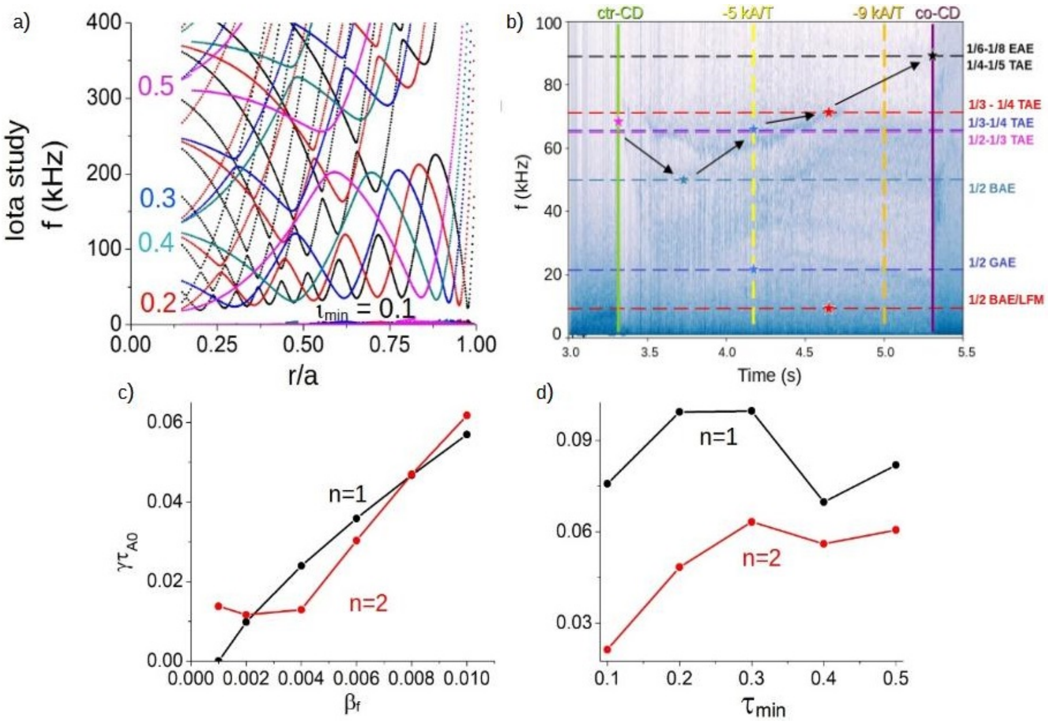

Figure 4: *a) Thermal β, (b) Toroidal current and NBI pattern, (c) Modes frequency, (d) Mode amplitude, (e) spectrometer data and (f) iota profile best fit.*

Conclusions and discussion

Experimental evidence of PGDM and AE stabilization above a given threshold of the NBCD. The best fit of MSE data confirms the stabilization of PGDM and AE is linked to the modification of the iota profile induced by the NBCD. FAR3d simulations reproduce the experimental observations: the stabilization of $1/2$ mode once the iota minima is above 0.5, the destabilization of peripheral modes as iota minima decreases and the$n = 1$ TAE frequency up-sweeping and growth rate decrease as iota minima decreases.

References

[1] K.Y. Watanabe et al, Nucl. Fusion **45**, 1247 (2005)

[2] S. Sakakibara et al, PFR **1**, 003 (2006)

[3] Y. Todo, Reviews of Modern Plasma Physics **3**, 1 (2019)

[4] M. Sanders et al, Review of Scientific Instruments **92**, 053503 (2021)

[5] J. Varela et al, Nucl. Fusion **57**, 046018 (2017)

[6] J. Varela et al, Nucl. Fusion **60**, 026016 (2020)

[7] J. Varela et al, Nucl. Fusion **59**, 046008 (2019)