Triggering of Neoclassical Tearing Modes by Sawteeth in the TCABR tokamak

ID: 132

G.A.P. Vaccani[1], F.M. Salvador[2], M.A. Ridenti[1], G.P. Canal[2], M. Roberto[1] (in memory of)
[1]Technological Institute of Aeronautics - ITA, São José dos Campos (SP) , Brazil
[2] University of São Paulo - USP, São Paulo (SP), Brazil
gstv.vaccani@gmail.com/gustavogapv@ita.br

ABSTRACT

In this work, a collaborative study is carried out that aims to improve our understanding of the physical mechanisms behind the triggering of neoclassical tearing modes (NTMs) by sawteeth (ST). This collaboration involves a theoretical/computational approach in the TCABR tokamak, operated by the Plasma Physics Laboratory of the Institute of Physics at the University of São Paulo, and the use of the M3D-C¹ code, a state-of-the-art tool developed at the Princeton Plasma Physics Laboratory, USA, to model plasma evolution. The knowledge acquired during this work is expected to lead to the development of strategies that inhibit the coupling between ST and NTMs. This model can then be used predictively to indicate safer operating zones with higher plasma pressure in tokamaks.

BACKGROUND

Nuclear fusion may offer a solution to current energy problems, but several unresolved factors delay the development of this technology. The stability of magnetically confined plasmas in tokamaks is a challenging and complex task. Instabilities arise in both ideal and resistive magnetohydrodynamic (MHD) theory approaches. The ST is one of these instabilities, the work of which we cannot yet safely predict, and its consequences in triggering other types of instabilities.

The STs are periodic relaxations at the plasma column's core, expelling impurities from this region (Figure 1 and 2). However, this process can generate magnetic islands, disrupting the system's equilibrium. The STs have a complex relation with NTMs. STs are believed to be the primary sources of NTMs and magnetic islands. The inability to reliably predict the formation, development, and completion of the magnetic island formation process by STs is a problem that must be addressed for the International Thermonuclear Experimental Reactor (ITER) to succeed.

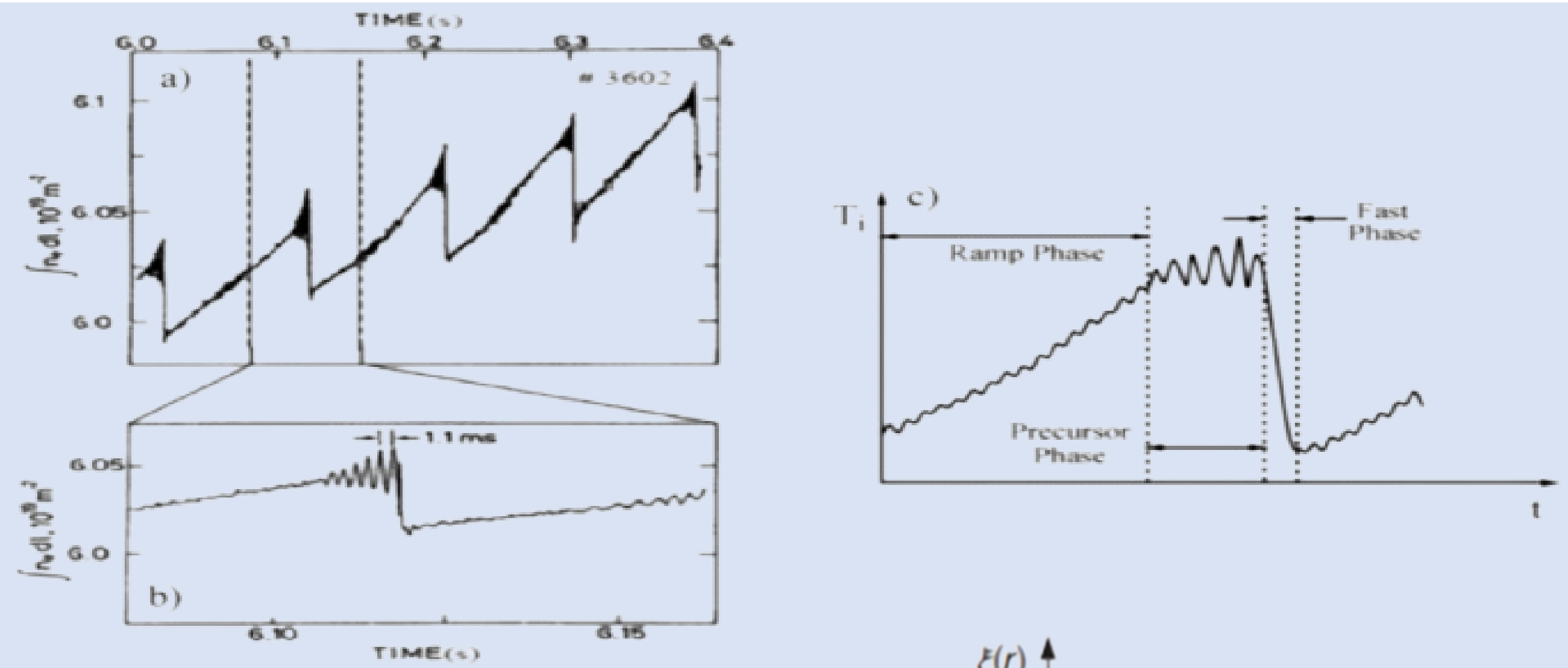

FIGURE 1: Characteristic process of an ST oscillation [1].

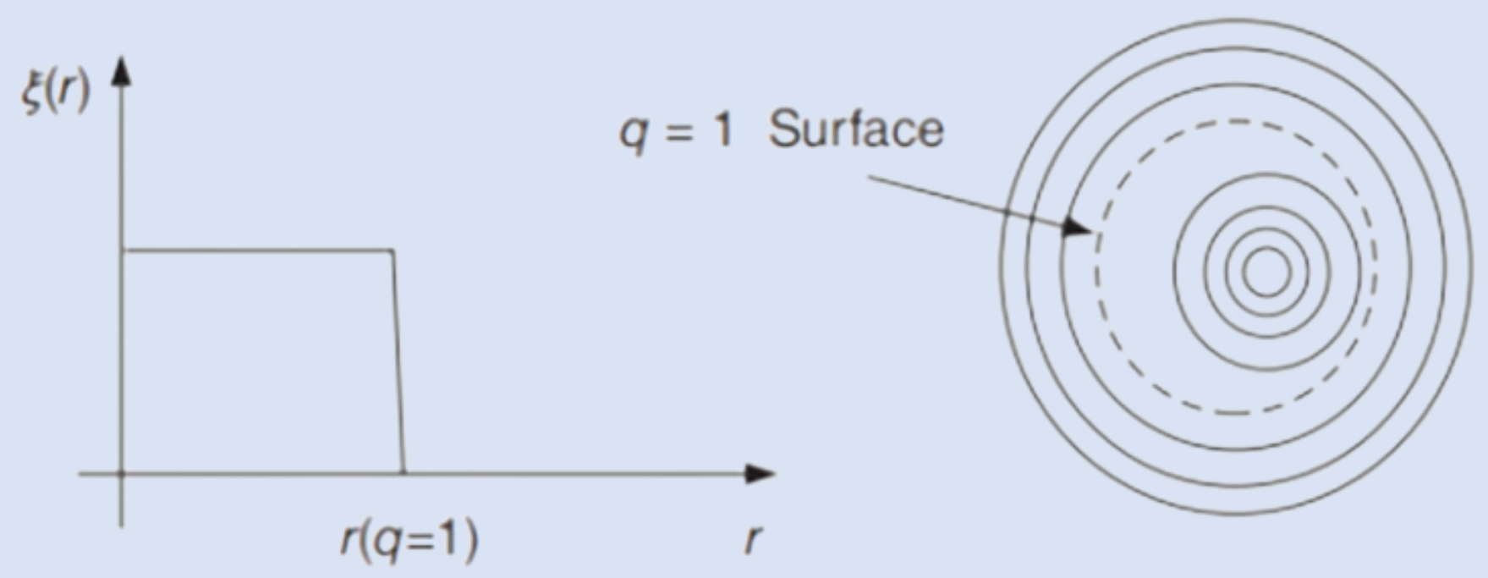

FIGURE 2: Characteristic region of an ST oscillation [2].

METHODS

Our approach uses two core simulation codes: Plasma Scenario Design (PSD) and M3D-C¹. PSD creates equilibrium scenarios using MHD equations, which are then input into M3D-C¹ to evolve the two-fluid system.

$$\frac{\partial n}{\partial t} + \nabla \cdot (n\mathbf{u}) = \Sigma$$

$$n\left(\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u}\cdot\nabla\mathbf{u}\right) = \mathbf{J}\times\mathbf{B} - \nabla p - \nabla\cdot\Pi + n\mathbf{g} - \Sigma\mathbf{u}$$

$$\frac{1}{\Gamma-1}\left[\frac{\partial p_e}{\partial t} + \nabla\cdot(p_e\mathbf{u})\right] = -p_e\nabla\cdot\mathbf{u} + \frac{d_i}{n}\left(\frac{n\nabla T_e}{\Gamma-1} - T_e\nabla n + \mathbf{R}\right)\cdot\mathbf{J} + d_i\Pi_e : \nabla\frac{\mathbf{J}}{n} + Q_\Lambda - \nabla\cdot\mathbf{q}_e$$

$$\frac{1}{\Gamma-1}\left[\frac{\partial p}{\partial t} + \nabla\cdot(p\mathbf{u})\right] = -p\nabla\cdot\mathbf{u} + \frac{d_i}{n}\left(\frac{n\nabla T_e}{\Gamma-1} - T_e\nabla n + \mathbf{R}\right)\cdot\mathbf{J} + d_i\Pi_e : \nabla\frac{\mathbf{J}}{n} - \Pi : \nabla\mathbf{u} + \frac{1}{2}\Sigma u^2 - \nabla\cdot\mathbf{q}$$

$$\frac{\partial \mathbf{B}}{\partial t} = -\nabla\times\mathbf{E} \qquad \mathbf{E} + \mathbf{u}\times\mathbf{B} = \eta\mathbf{J} + \frac{d_i}{n}\left(\mathbf{J}\times\mathbf{B} - \nabla p_e - \nabla\cdot\Pi_e\right) \qquad \mathbf{J} = \nabla\times\mathbf{B}$$

OUTCOME

We built the equilibrium system of equations MHD using the PSD code for different plasma cross-section shapes. Instabilities can be characterized by their respective safety factors, given by a ratio between the poloidal (m) and toroidal (n) modes. One possible relation between STs and NTMs is the coupling between their modes, which is directly related to geometric effects (Figure 3). While the toroidal mode (n) is related to the toroidal global system geometry, the poloidal mode (m) is dependent on the geometry of the plasma cross-section.

$$\text{Circularity}(\epsilon = r/R_0) : m \to m \pm 1$$
$$\text{Elongation}(\kappa) : m \to m \pm 2$$
$$\text{Triangularity}(\delta) : m \to m \pm 3$$

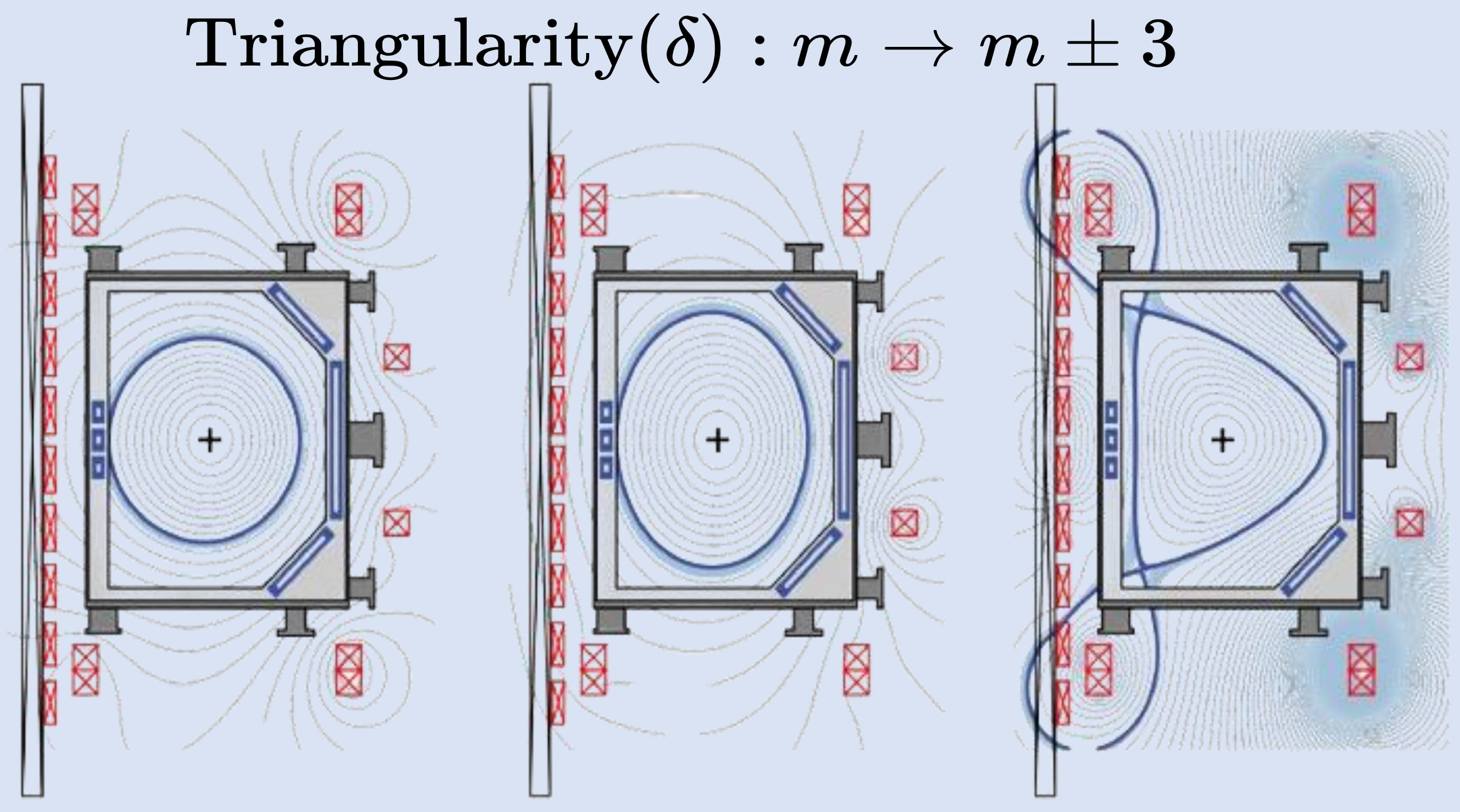

FIGURE 3: Equilibrium construction using the PSD diferents cross-sections.

The M3D-C¹ evolves the two-fluid system using the desired equilibrium created by the PSD and provides the instabilities' growth rate. In Figure 4, we have fluctuation values around the given equilibrium, in this case, total pressure eigenmodes. Note that we have ST as desired; however, Edge-Localized modes (ELMs) make data analysis difficult. Isolating the instabilities of interest is essential for their specific study.

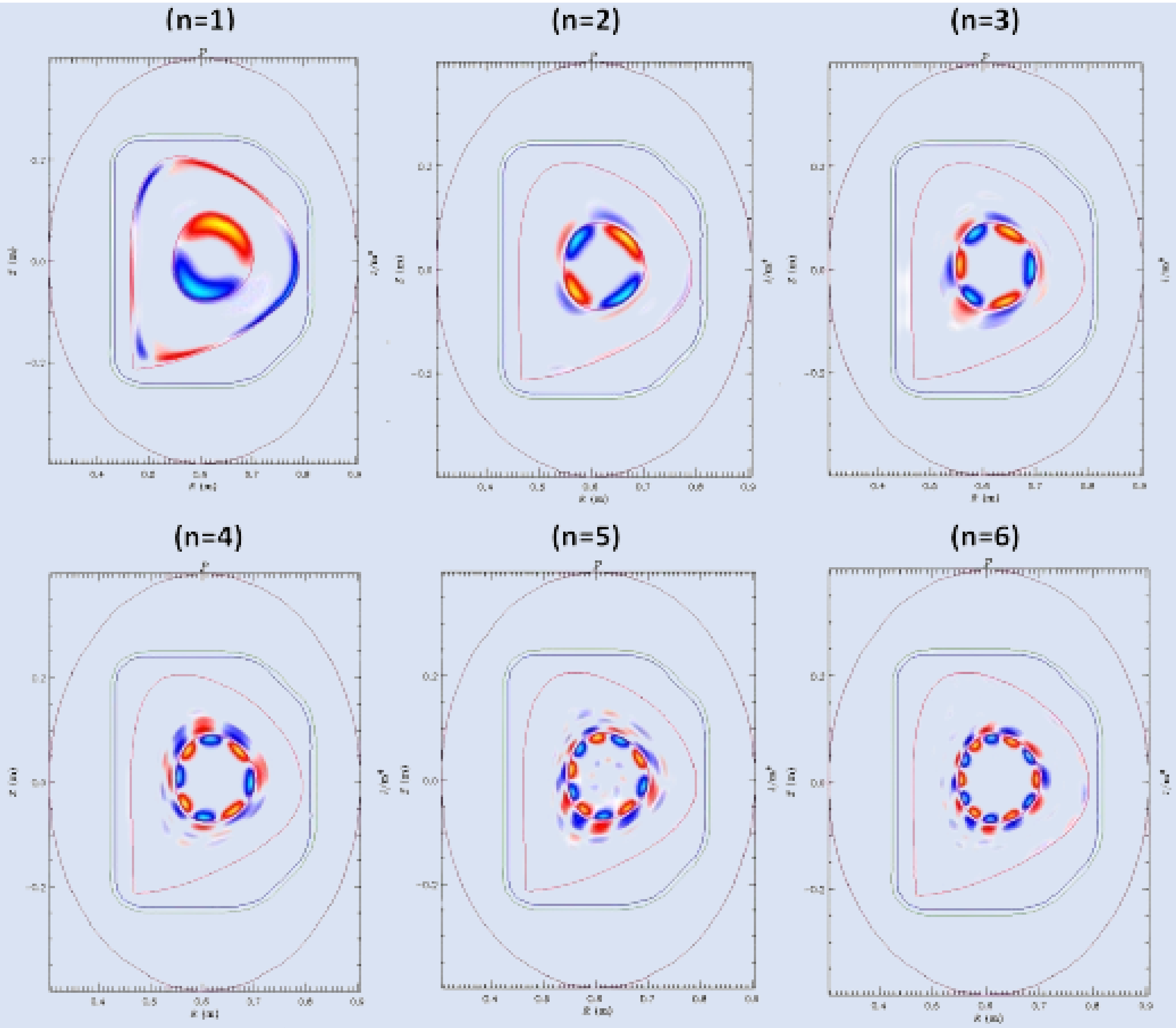

FIGURE 4: Eigenmodes for total pressure. Values variating the toroidal mode between n=1 and n=6.

CONCLUSION

By obtaining the equilibrium values provided by the PSD, we have the essential inputs for the evolution of the perturbed MHD equations using M3D-C¹ two-fluid equations. However, the results are not ideal due to other instabilities that reduce their clarity. The reason for this is the small size of the surface q=1 that supports the STs. We need to isolate the STs and to do this; we need to create a favorable scenario with a large enough surface q=1.

ACKNOWLEDGEMENTS / REFERENCES

CNEN, ITA, USP, PPPL.

[1] J.A. Bittencourt. Fundamentals of Plasma Physics. Springer, New York, 2004. [2] Hartmut Zohm. Magnetohydrodynamic Stability of Tokamaks. Wiley-VCH, 2015. [3] N.M. Ferraro, S.C. Jardin. Calculations of two-fluid magnetohydrodynamic axisymmetric. J. Comp. Phys. 226 228 (2009) 7742–7770.