Self-consistent interaction between MHD island and turbulence

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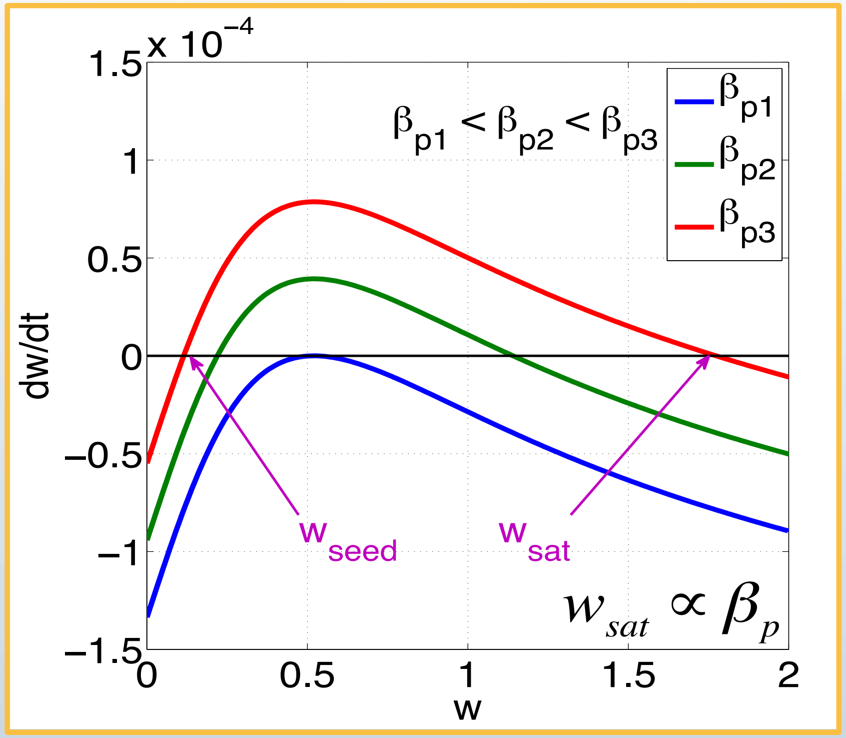
Context

- Growth of Neoclassical Tearing Modes (**NTMs**) : **magnetic island** degrading the plasma pressure and sometimes causing disruption

- Behavior of NTMs : modified **Rutherford equation**



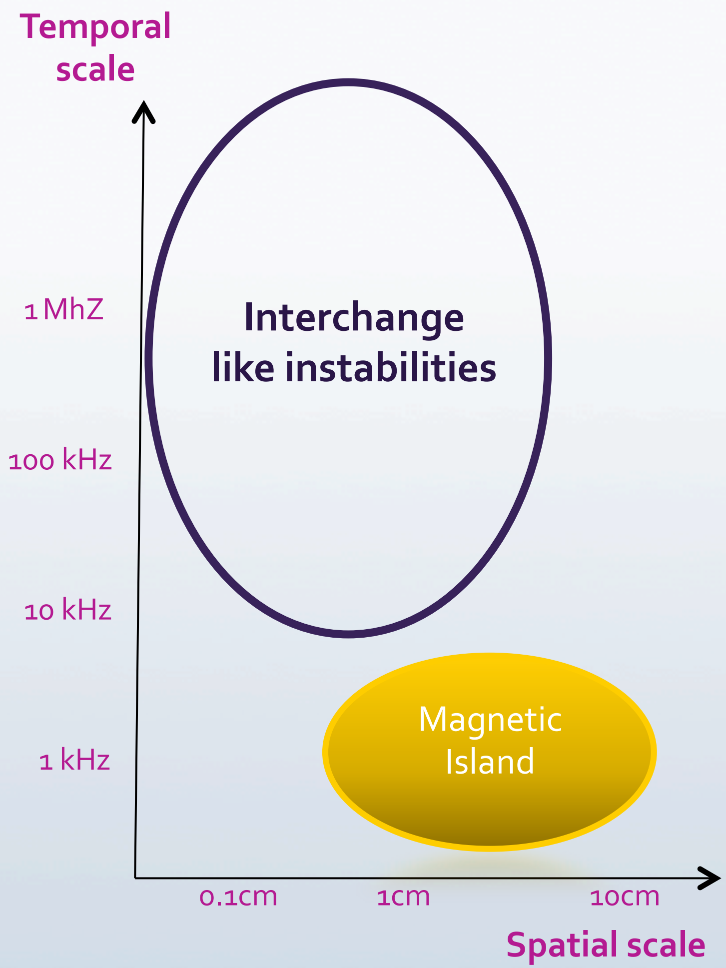
[R.J. La Haye, POP 13 (2006)]

- NTMs precursors :
  - Sawtooth oscillations
  - Fishbones instabilities
  - Edge localized modes
  - … ?

- In JT-60U, **80% of high β discharges**, a (2/1) NTM appears without precursor event **[A. Isayama et al, PFR 8 (2013)]**

Open question : origin of seed island ?

Context



- Interchange like instabilities coexist with macro MHD instabilities and lead to micro-turbulence in fusion devices.

- The interaction of magnetic island with interchange is a multi-scales problem.

[F. Militello et al, POP 15 (2008)]
[F.L. Waelbroeck et al, PPCF 51 (2009)]
[M. Muraglia et al, PRL 103 (2009)]
[A. Ishizawa et al, POP 17 (2010)]
[F. Hariri et al, PPCF 57 (2015)]

- **Previous result :**

Turbulence Driven Magnetic Island (TDMI)

[M. Muraglia et al, PRL 107 (2011)]
[A. Poyé et al, POP 22 (2015)]
[A. Ishizawa et al, POP 17 (2010)]
[W. Hornsby et al, 42nd EPS conference, Lisbon (2015)]

Questions : Can turbulence be at the origin of a NTM?

Outline

I. Introduction (fluid model and numerical tool)

II. « Classical » NTM wo turbulence in a 2D slab geometry (no turbulence)

III. Turbulence Driven Magnetic Island (TDMI) in a 2D slab geometry **(seeding regime)** (with and wo bootstrap current)

IV. Nonlinear growth of **NTM from a TDMI (amplification regime)**

V. Conclusions

I. Model: Reduced MHD

- Reduced MHD equations for electrostatic potential ϕ, pressure p and magnetic flux ψ .

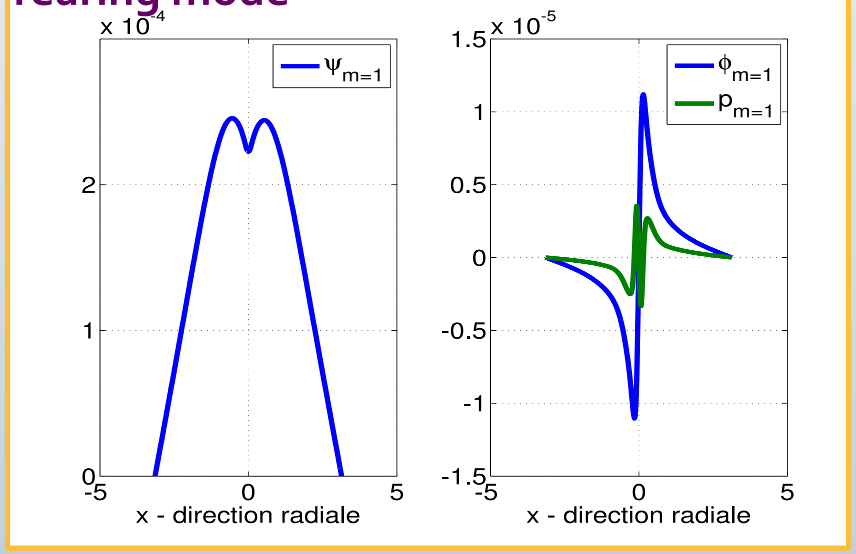
- Model includes both resistive **Interchange** and **Tearing Mode** in a 2D slab geometry:

$$
\begin{aligned}
\partial_t \nabla_\perp^2 \phi + [\phi, \nabla_\perp^2 \phi] &= [\psi, \nabla_\perp^2 \psi] - \kappa_1 \partial_y P + \nu \nabla_\perp^4 \phi \\
\partial_t P + [\phi, P] &= -v_\star((1-\kappa_2)\partial_y \phi + \kappa 2 \partial_y P) + \rho_\star^2 [\psi, \nabla_\perp^2 \psi] + \chi_\perp \nabla_\perp^2 P \\
\partial_t \psi + [\phi - P, \psi] &= -v_\star \partial_y \psi + \eta \nabla_\perp^2 \psi + \eta C_b \partial_x p
\end{aligned}
$$

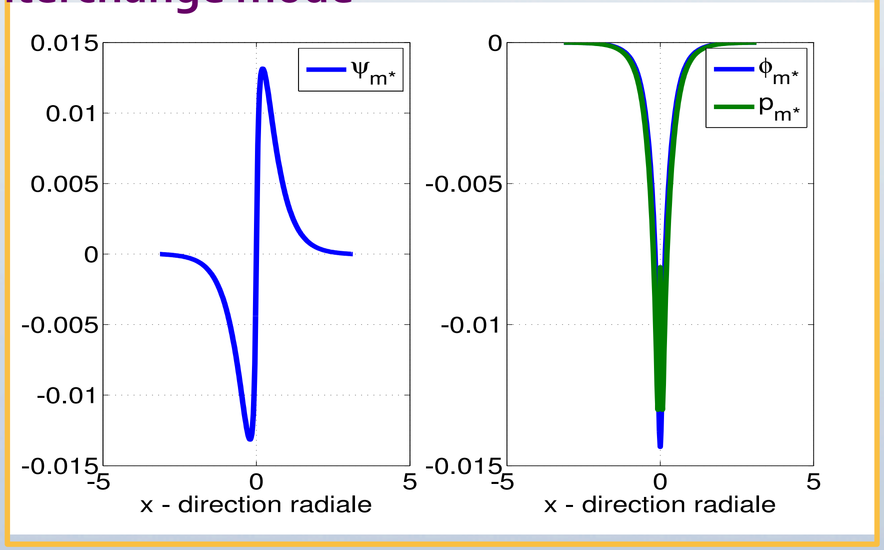
[M. Muraglia et al, NF 49, 055016 (2009)]

- Instability characterization : **THE PARITY**

Tearing mode



Interchange mode



I. Numerical tool : AMON code

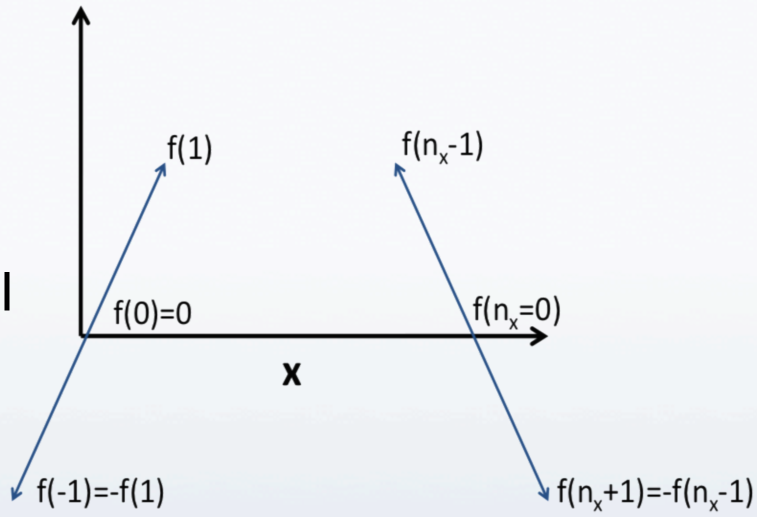
◆ Semi-spectral code :

Radial direction : finite difference

Nx =1025

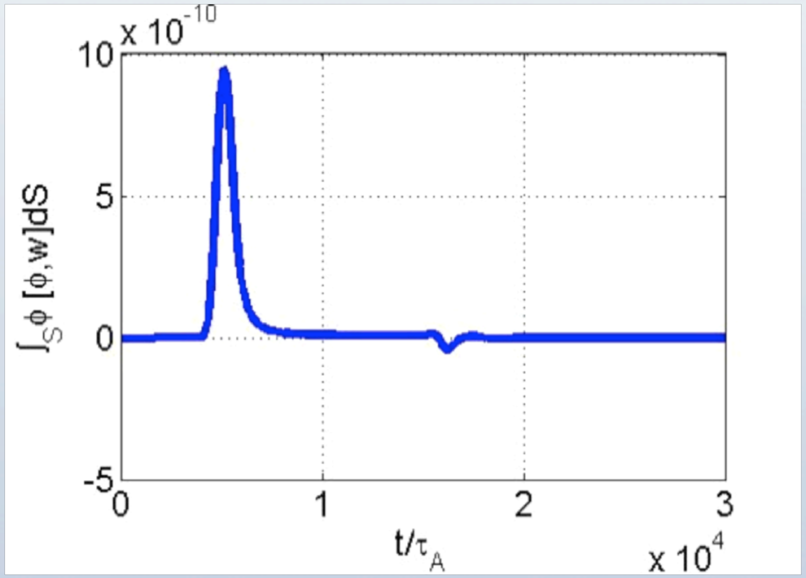
Poloidal and axial (for 3D) directions : spectral

Ny = 256



◆ Temporal scheme :

Runge-Kutta 4



◆ Boundary conditions :

Radial direction : 0 at the boundaries

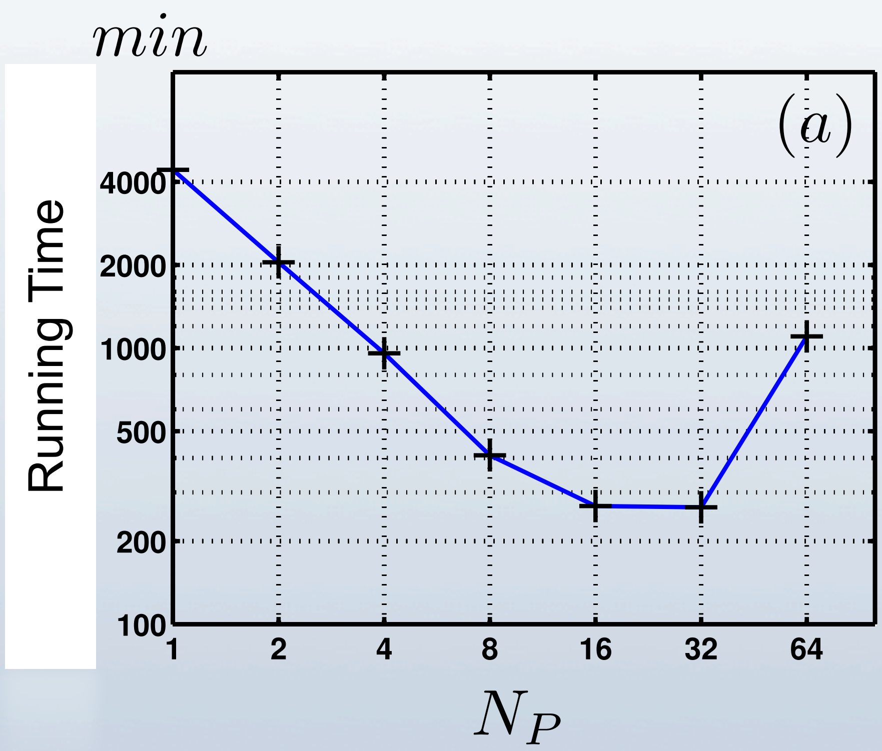
Poloidal and axial directions : periodic

◆ Nonlinear terms :

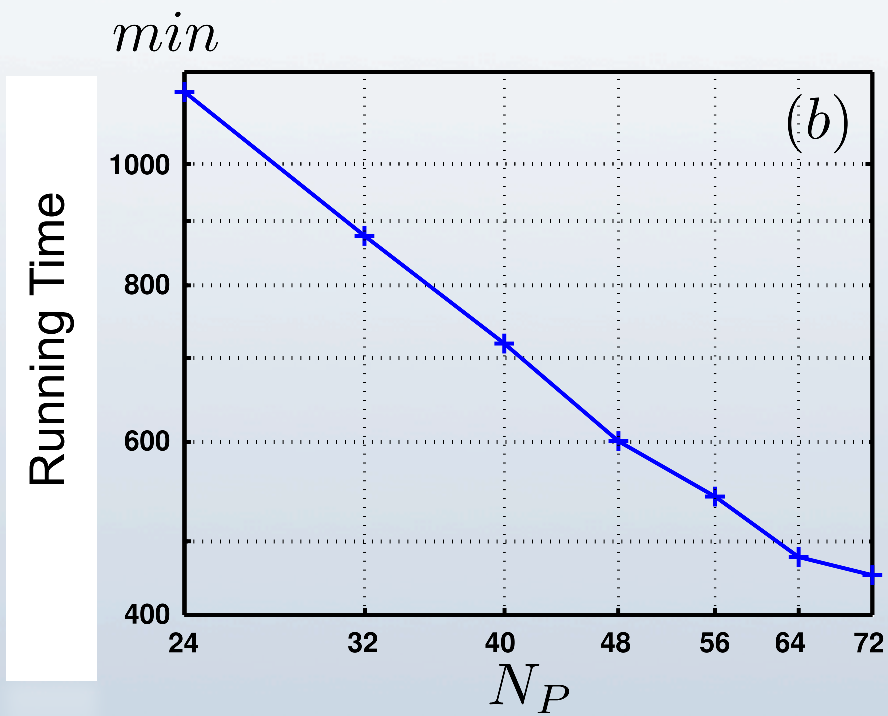
Quadratic terms conservation

I. Numerical tool : Performances code

◆ 1024*512, 2D simulations with 2 fields, 500000 iterations on Nestor (8 procs/node) :

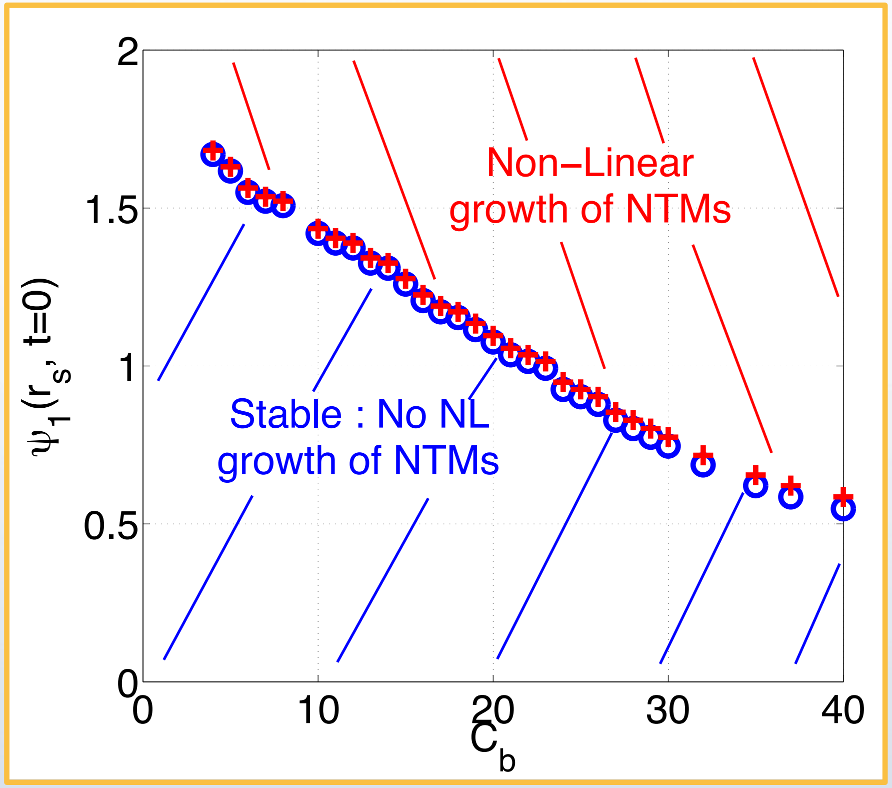


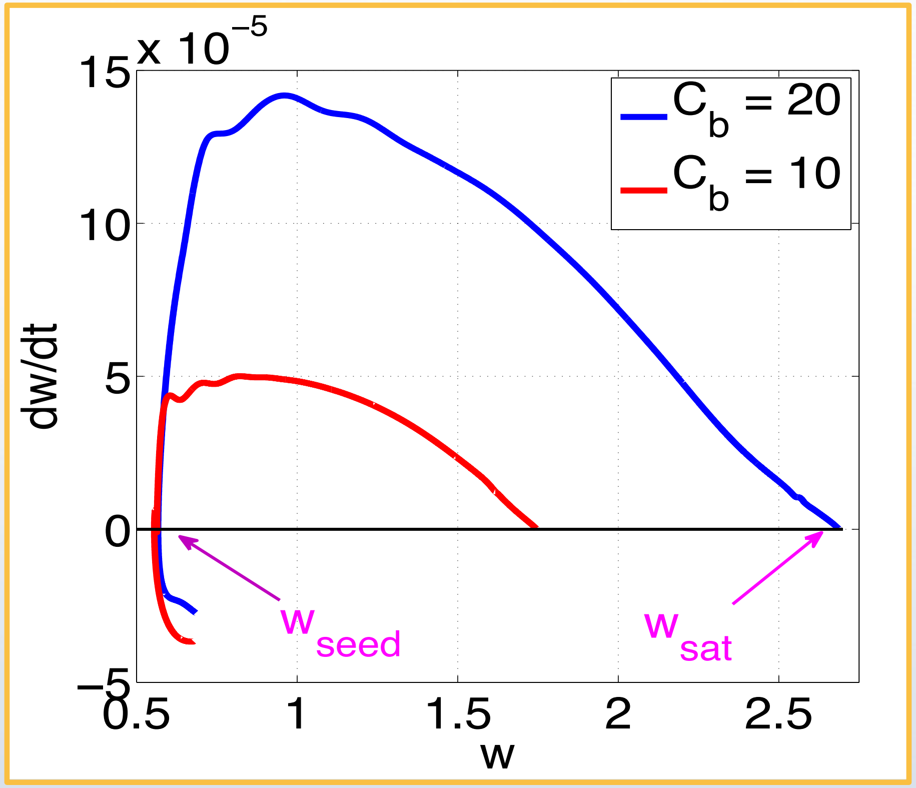
◆ 256*256*128, 3D simulations with 3 fields, 500000 iterations on Juelich (8 procs/node) :



II. NL growth of NTMs wo turbulence

Δ' = - 0.45 – no turbulence





◆ Seed island imposed in the initial conditions with $w_{seed} \propto \sqrt{\psi_1(r_s,\ t=0)}$

◆ For a NTM to grow, Bootstrap current should be strong enough for a given value of $\psi_1(r_s, t=0)$

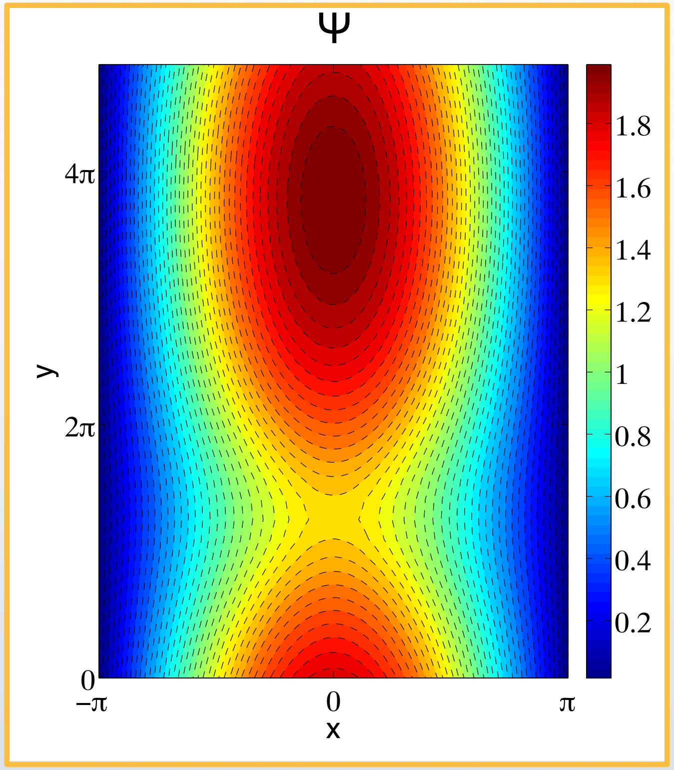
[F. Militello et al, POP 15 (2008)]

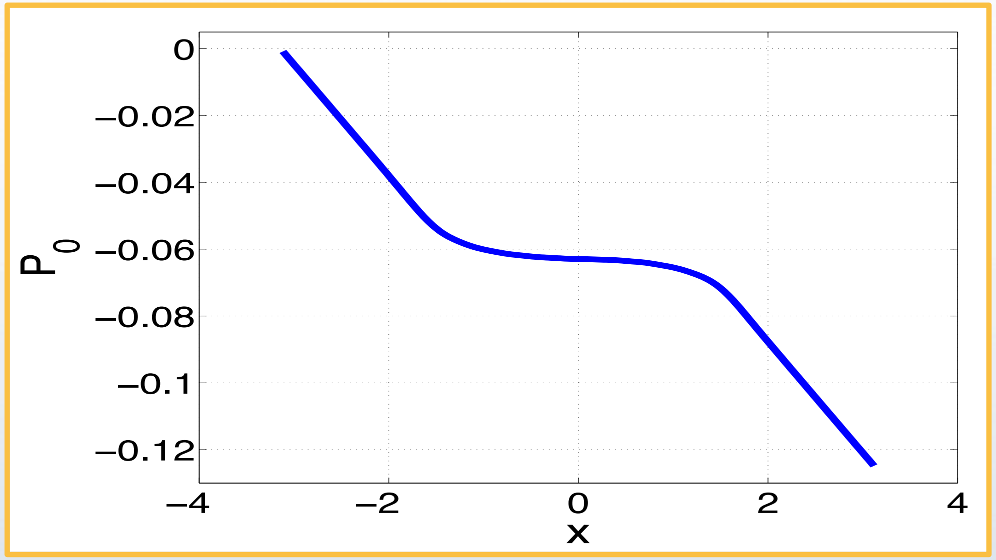
◆ Recover the Rutherford behavior

◆ From a seed island, a NTM grows and flattens the pressure decreasing back the bootstrap current effect : the island size saturates

II. NL growth of NTMs without turbulence

Δ' = - 0.45 – no turbulence
C_b = 20

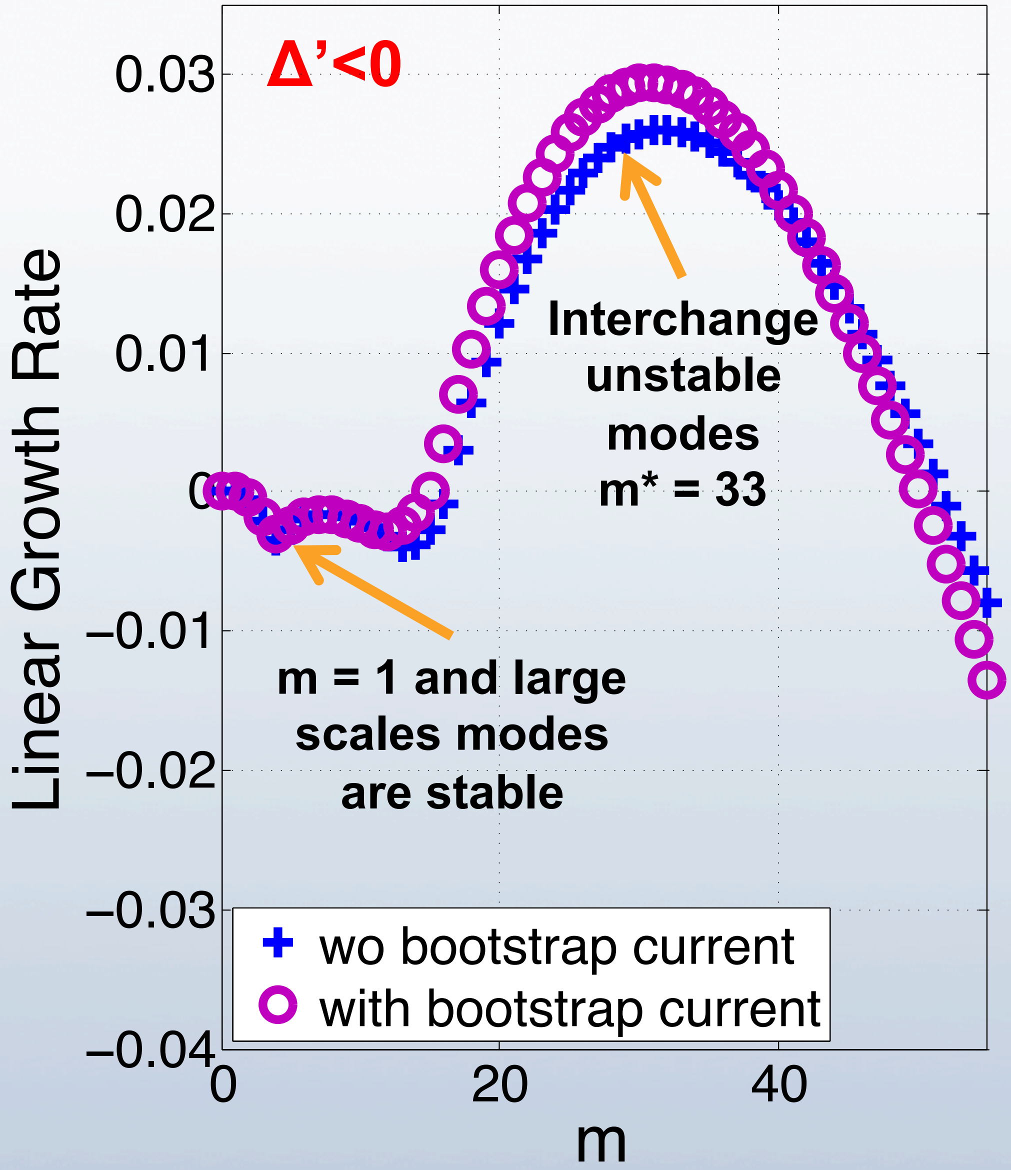




- Nonlinear growth of a large island => NTM
- Flattening pressure **[R. Fitzpatrick POP 2, 3 (1995)]**

III. NL generation of TDMI

Linear Spectrum



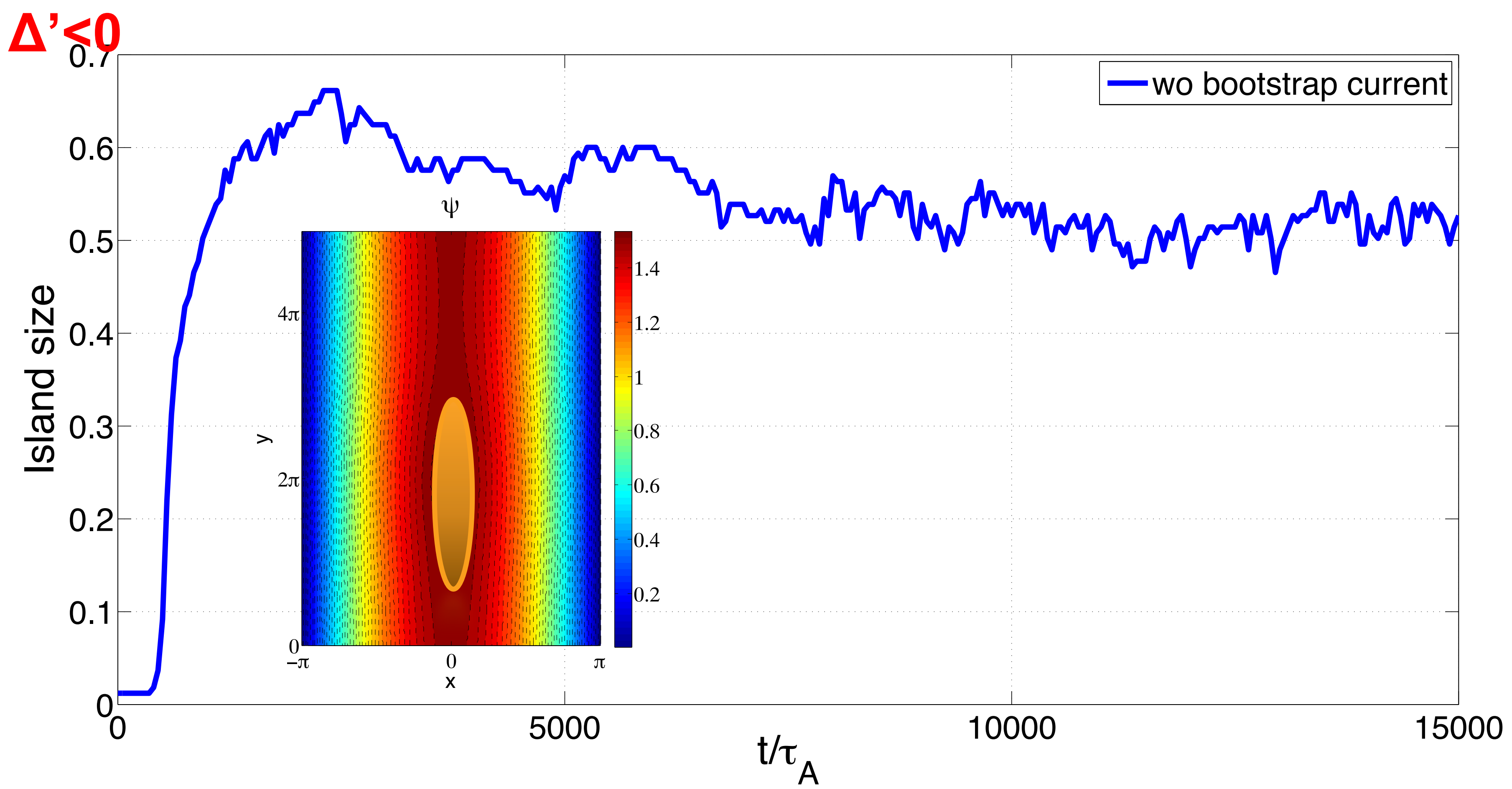
- Δ'<0 Linear spectrum is stable with respect with tearing instability

=> **No island**

- Stable large scales modes
- Small scales turbulence driven by interchange instability
- Bootstrap current has a week effect on the linear spectrum

=> **What 's about non-linear dynamics ?**

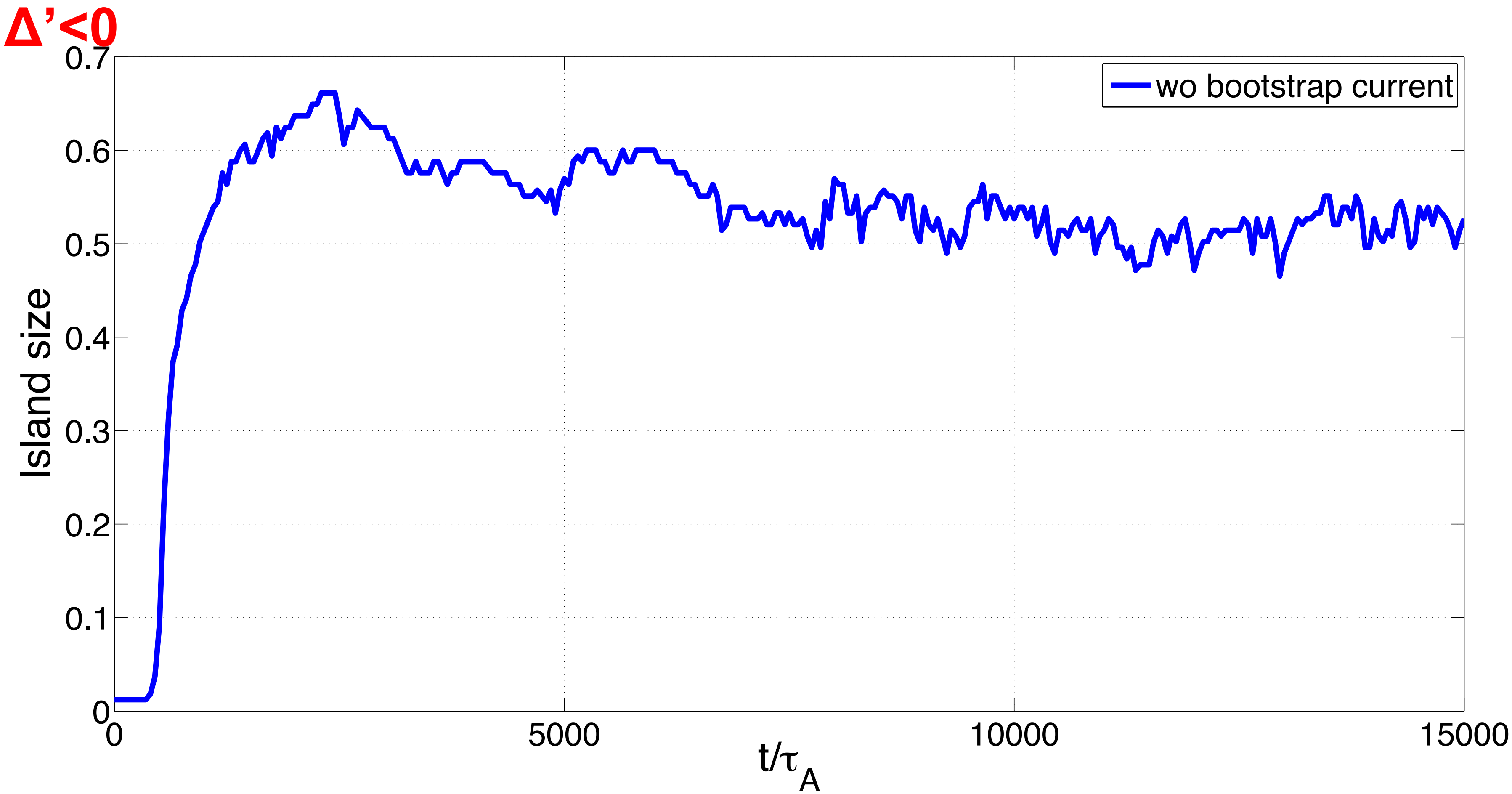
III. NL generation of TDMI



◆ NL generation of TDMI by a beating of interchange modes

[M. Muraglia et al, PRL 107 (2011)] & [A. Poyé et al, POP 22 (2015)]
[W. Hornsby et al, 42nd EPS conference, Lisbon (2015)]

III. NL generation of TDMI



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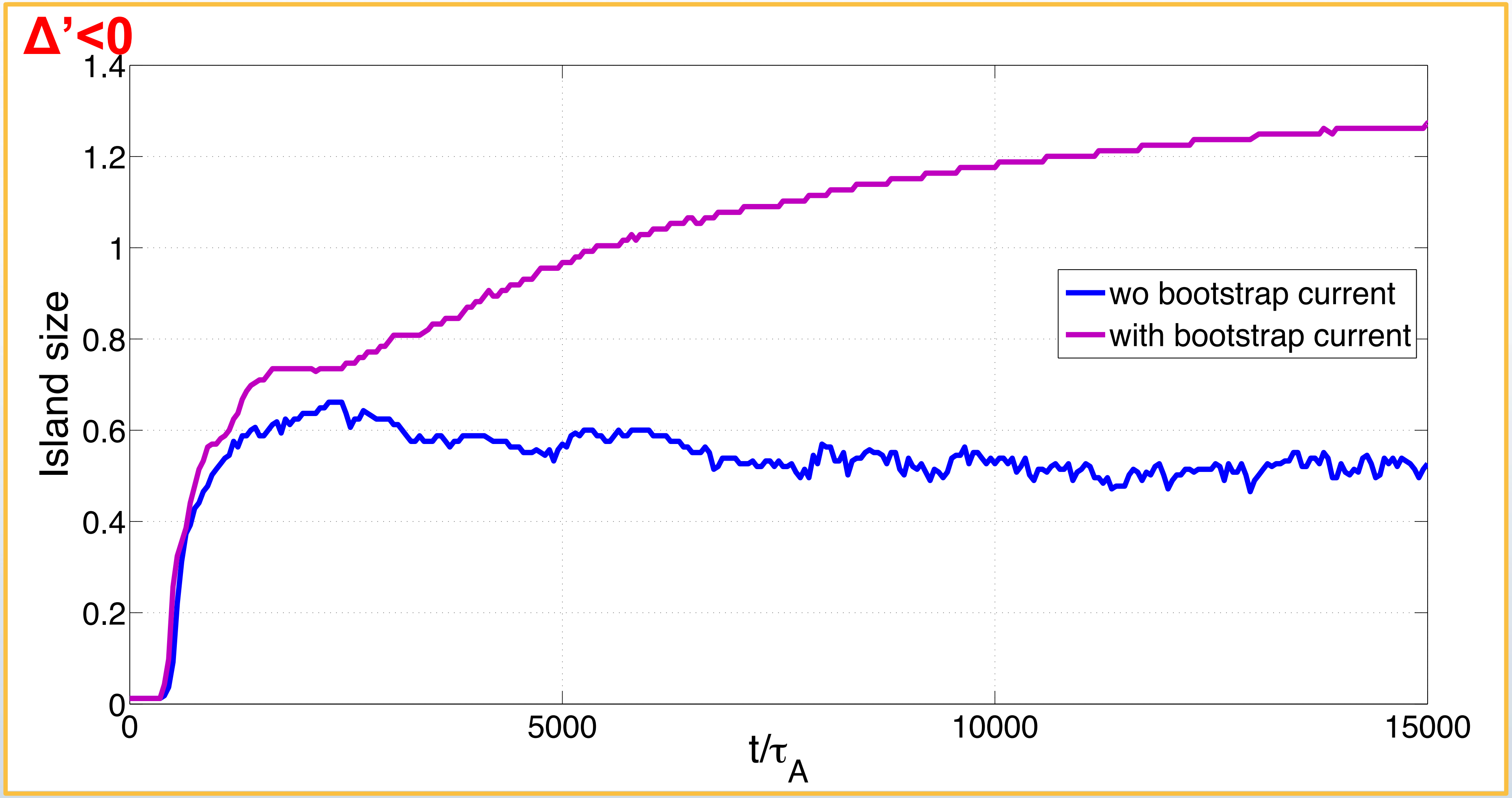
[M. Muraglia et al, PRL 107 (2011)] & [A. Poyé et al, POP 22 (2015)]
[W. Hornsby et al, 42nd EPS conference, Lisbon (2015)]

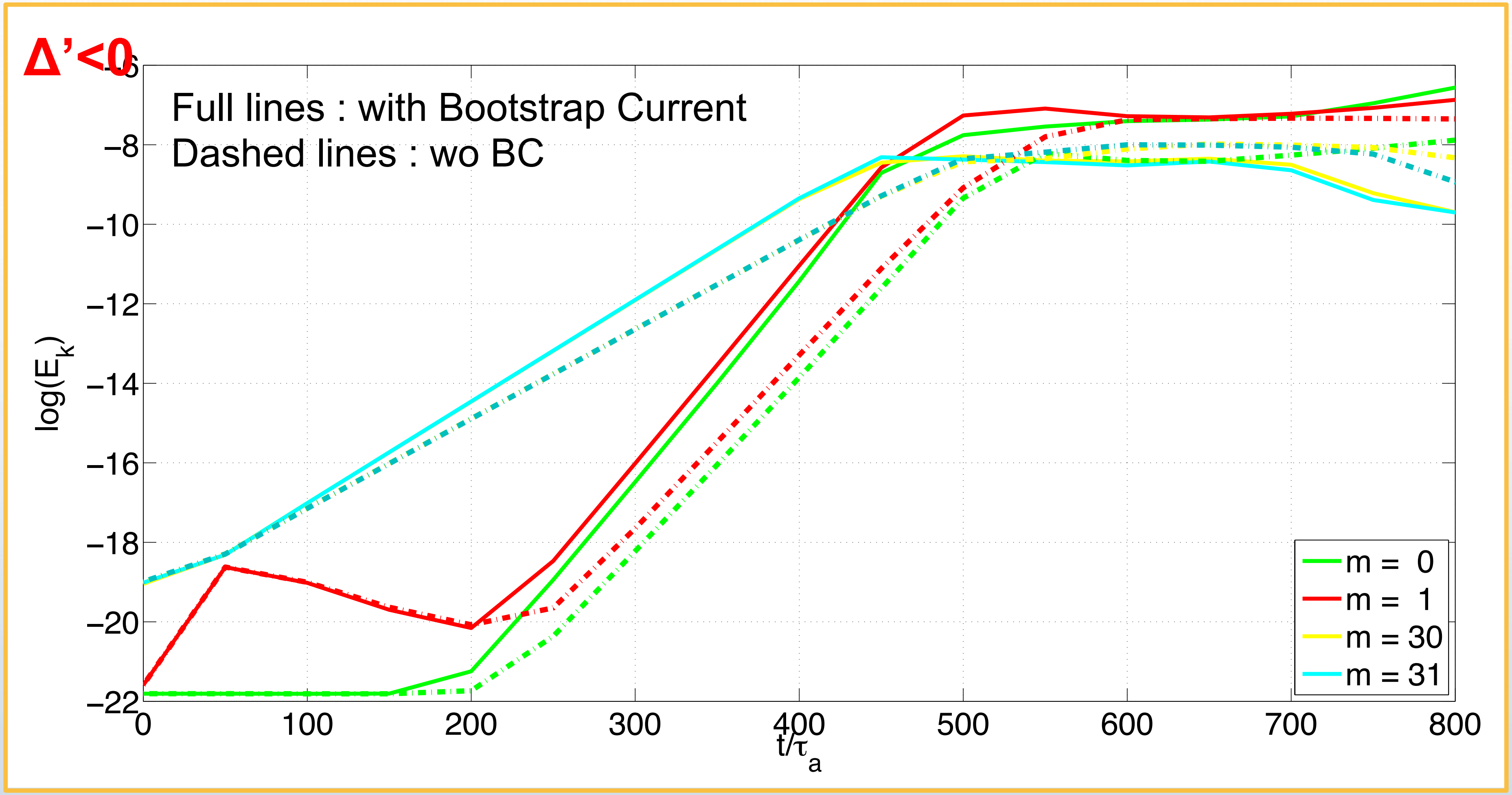
III. NL amplification of TDMI by bootstrap current



◆ Self-consistent generation of NTM from TDMI

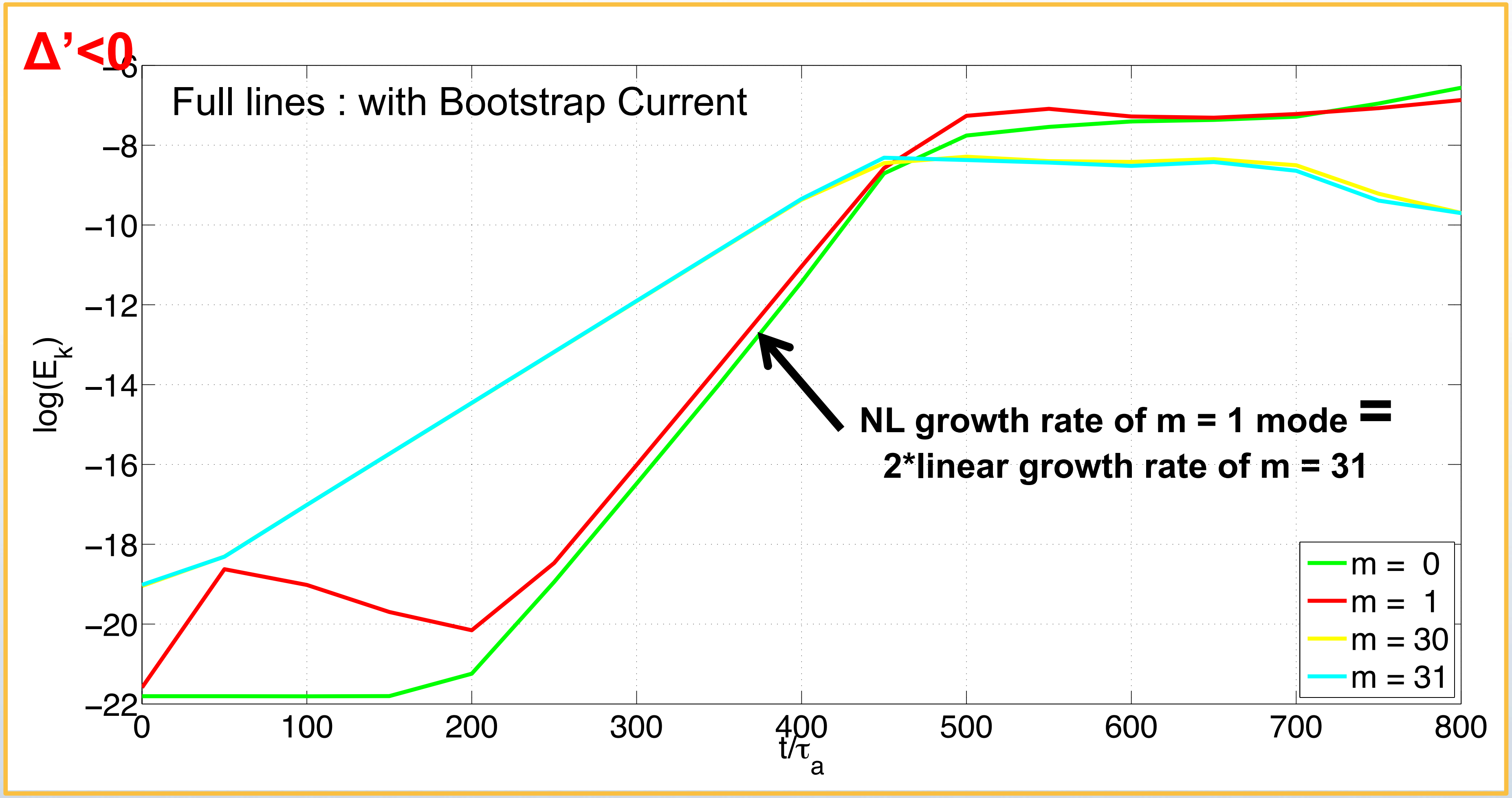
1. TDMI formation => **Seeding regime**
2. NL growth of NTM => **Amplification (by bootstrap current) regime**

III. NL generation of TDMI



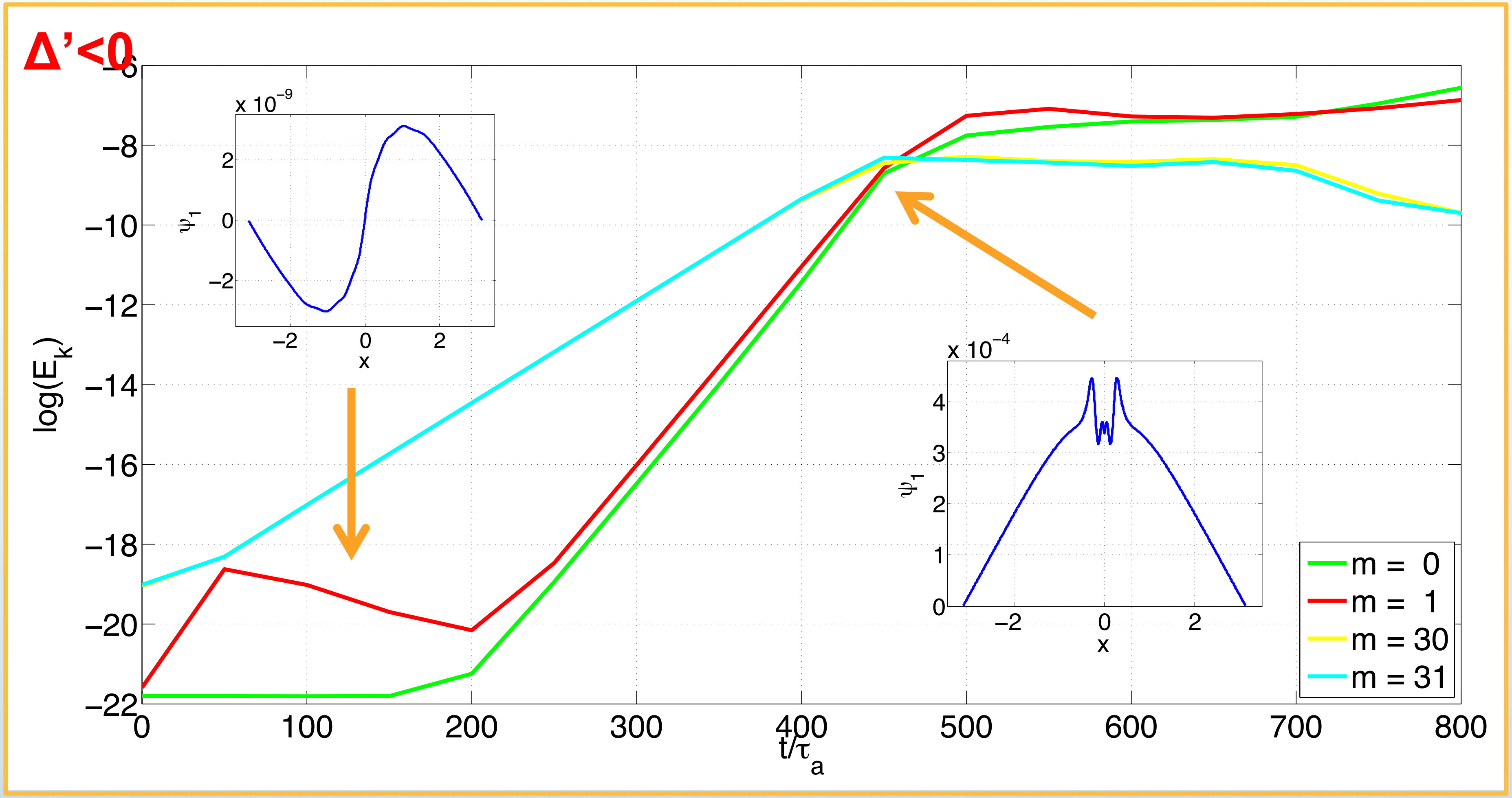
=> Weak impact of the BC during the quasi-linear regime i. e., during the TDMI formation

III. NL generation of TDMI



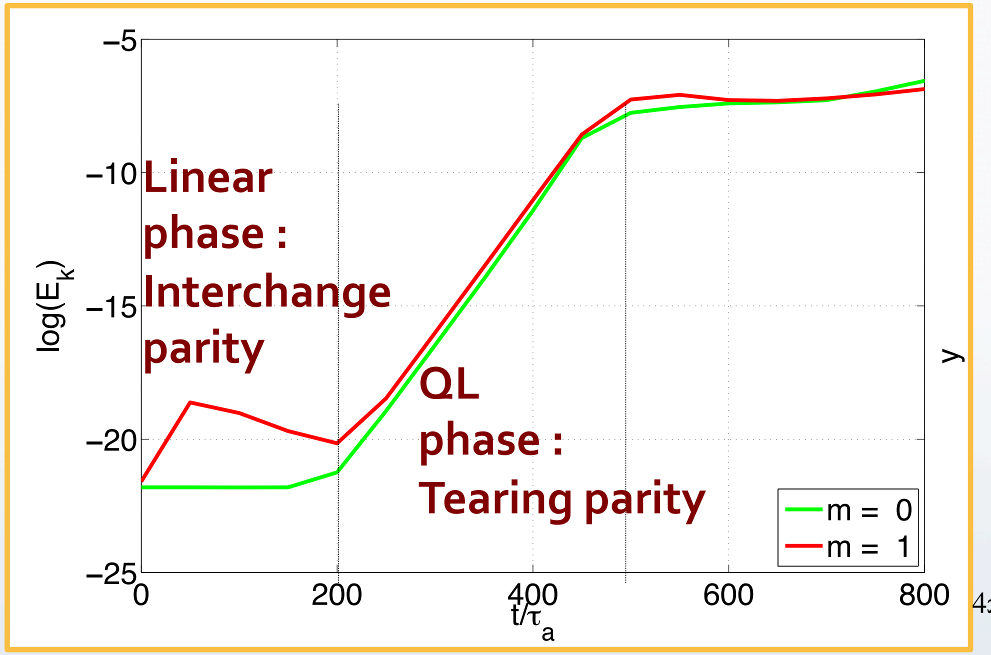
=> TDMI formation due to NL beating of interchange modes

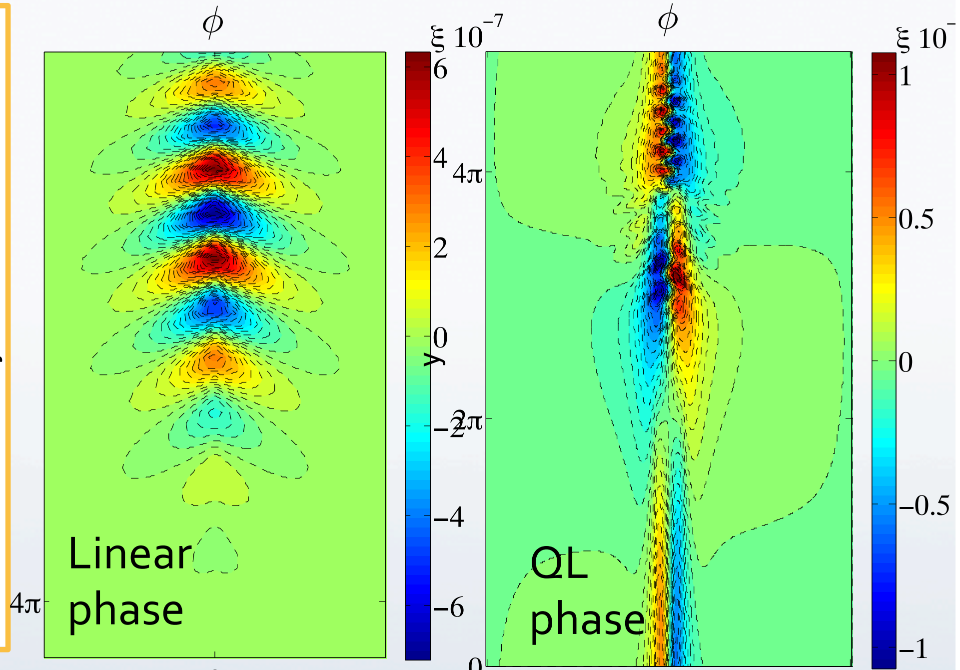
III. NL generation of TDMI



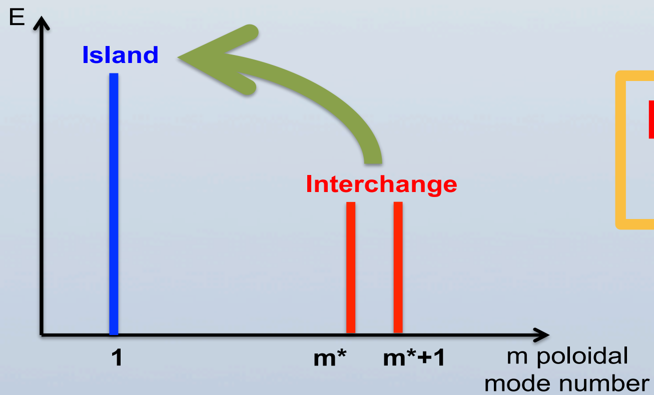
=> TDMI formation due to NL beating of interchange modes

III. NL generation of TDMI



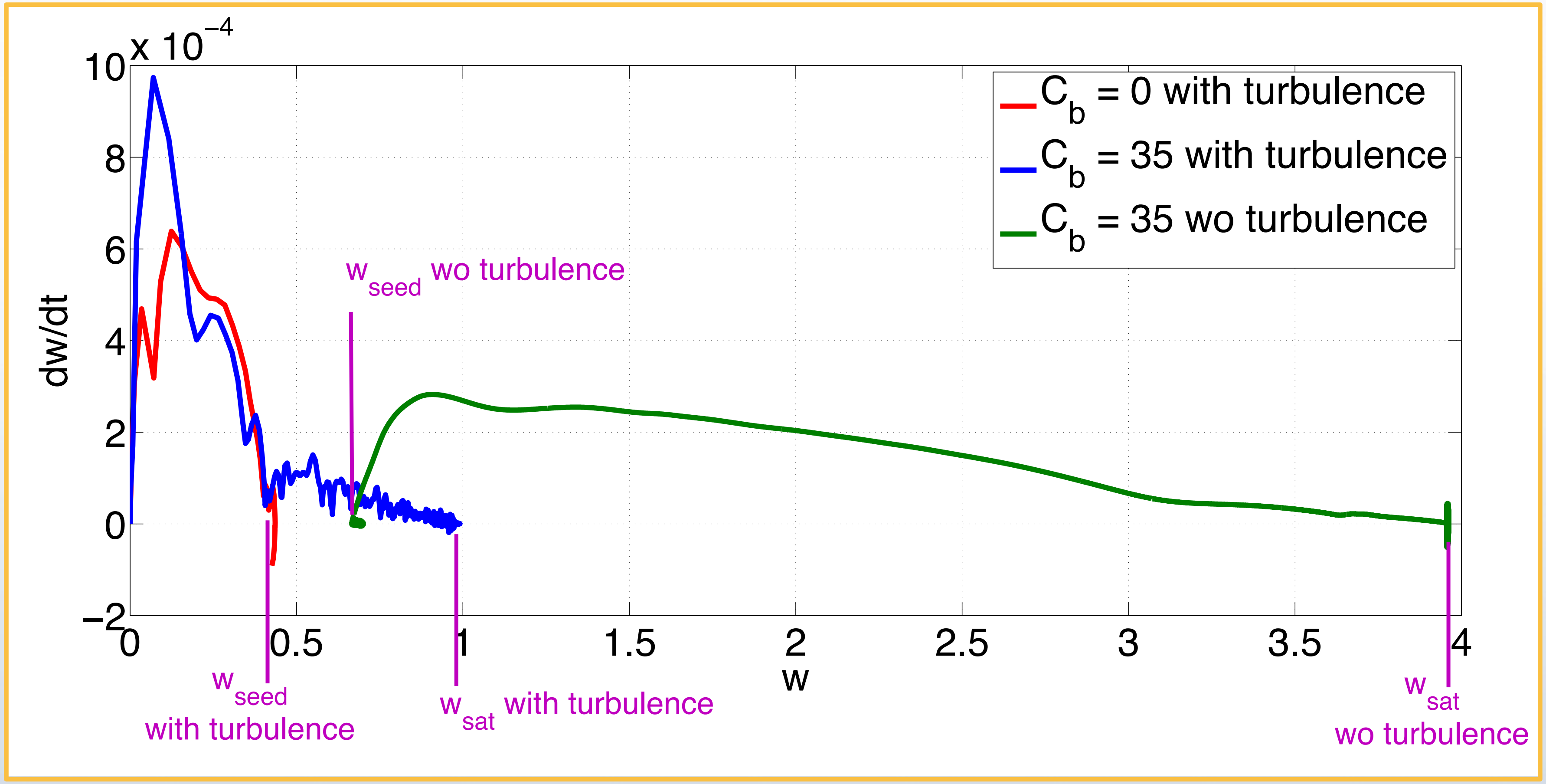


- Sym. breaking: large scale modes switch from interchange to tearing structure
- *All the non linearities* of the model satisfy $[\mathrm{Int}_{ss}, \mathrm{Int}_{ss}] \rightarrow \mathrm{Tear}_{ls}$



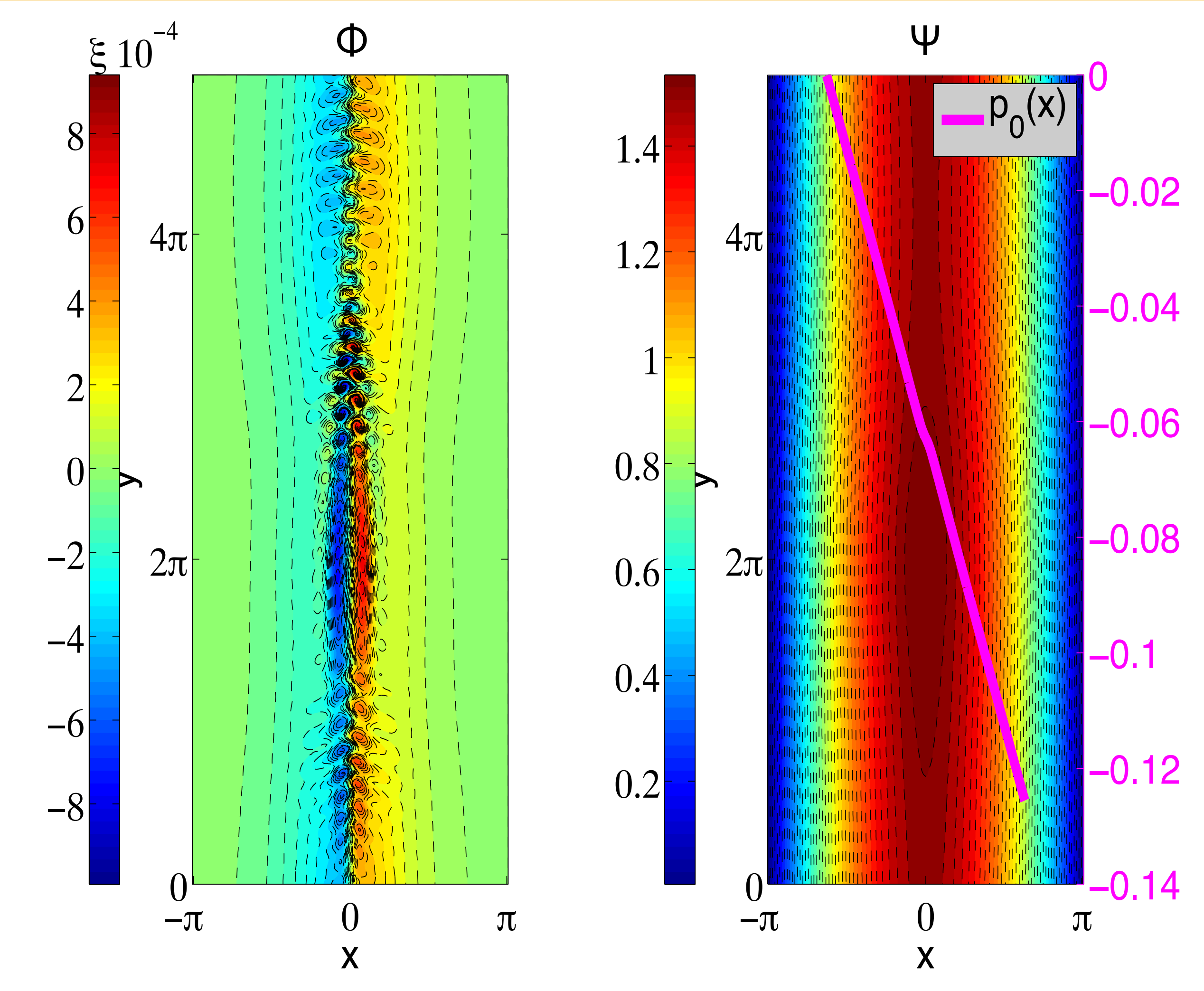
Magnetic island generation by nonlinear beating of interchange modes

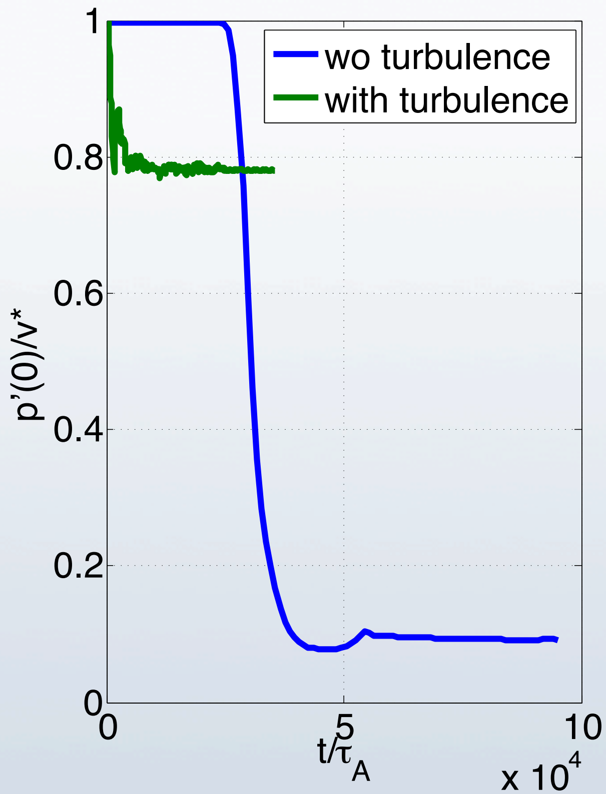
IV. NTM generation from TDMI



- Without Bootstrap current, island is generated by NL beating and saturates.
- With Bootstrap current, island dynamics presents two regimes :
  1. island is NL generated by interchange modes
  2. island is amplified by the current Bootstrap

IV. NTM generation from TDMI

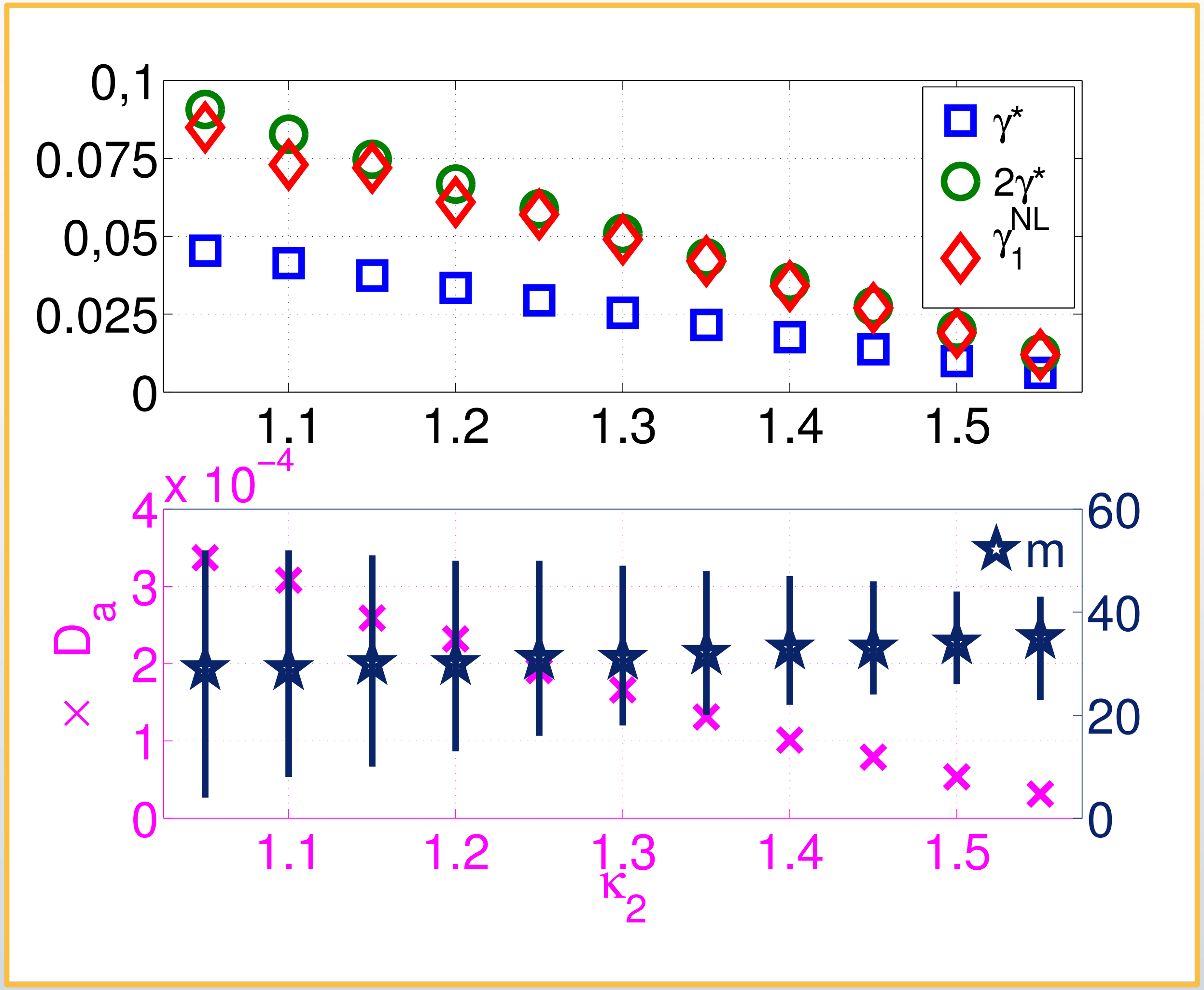




[O. Agullo et al, POP 21 (2014)]

- Bipolar structure of the electrostatic potential
- Partial pressure flattening

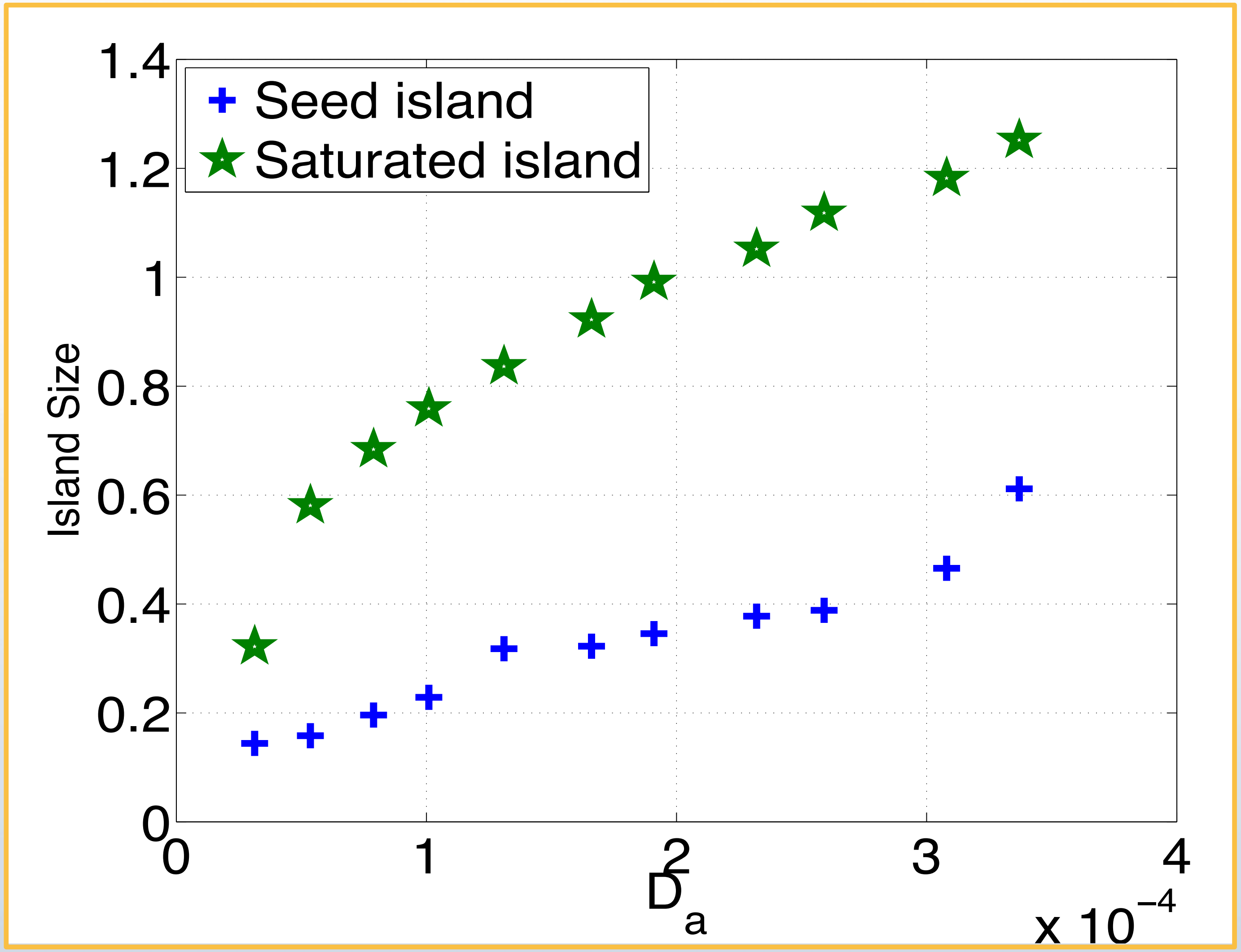
IV. NTM generation from TDMI



◆ NL simulations are performing with different turbulence levels Da = (γ*/m*²)

◆ Large scale modes are stable while small scales modes are unstable and present an interchange parity

IV. NTM generation from TDMI



=>Turbulence level controls both the seed island size and the saturated island

IV. Impact of the resistivity ?

Recipe for an island :

1. Non ideal and local phenomenom to violate the frozen flux condition

=> modification of the magnetic field line topology allowed

« Classical » Tearing : **resistivity η**

Turbulent Driven NTM : **bootstrap current ?**

2. Free energy to let the islang grows

« Classical Tearing » : **equilibrium magnetic field $\gamma_{island} = f(\Delta' > 0)$**

Turbulent Driven NTM : **NL beating of interchange modes $\gamma_{island} = f(\gamma^*)$**

=> Turbulence driven NTM mechanism is consistent with weak collisions plasmas (to be check…)

V. Conclusions

◆ A basic RMHD model has been used to investigate the interaction between **small scale interchange turbulence** and **magnetic islands** when tearing instability is marginally stable.

◆ **NTM can be generated thanks to turbulence.** The dynamics of a such turbulent driven NTM can be decompsed into 2 regimes :

1. TDMI is genrated due to an interchange modes beating, bootstrap current has a weak impact on that regime (**seeding regime**).
2. Bootstrap current amplifies TDMI => NL growth of NTM

◆ Impact of the turbulence level on NTM dynamics :
Turbulence level controls the seed island size and the saturated island size

◆ **Futur work :**

- Focus on regimes with high turbulence level to investigate the saturated mechanism and study the impact on the pressure profile of a large turbulence driven NTM.
- Investigate regimes with weak resistivity.