

Generation of NTM seed islands by edge turbulence

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Abstract

Fluid simulations had demonstrated that the micro scales turbulence is able to generate macro scales effect such as magnetic island. Here those 2D results are enhanced to 3D, and we show here that only specific location are available for the birth of magnetic island or NTM seed island.

The magnetic islands are a problem still under study in astrophysics [1] and in magnetic fusion. The understanding of their birth, growth and saturation is a key point to understand solar flare in astrophysics for example. In magnetic fusion, the magnetic islands modify the transport confinement and can degenerate into disruption. The last experiments on magnetic island demonstrated the existence of so-called Neo-classical Tearing Mode in tokamaks [2]. From a seed island, they observe a growth of the island due to the bootstrap current if the island seed is large enough [3]. Those NTM can drive to large island which are critical for the confinement. The problem we address here is the generation of seed island before the NTM. There is several sources that generate a magnetic island. It can rise from a tearing mode, from a pressure-driven tearing mode but also from turbulence. According to [4, 5], the interchange instability can generate a magnetic island by mode beating. The work done here is a generalisation of this result in a 3D cylindrical geometry.

The magnetic island and the interchange turbulence are described by the resistive MHD equations for the electrostatic potential Φ , magnetic flux Ψ and the pressure P . Each field A is composed of an equilibrium component A_{eq} plus and perturbation noted a . The model is derived from the four-fields model [6, 4]:

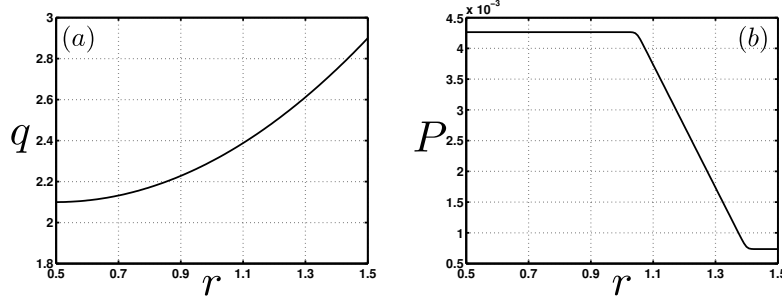


Figure 1: Magnetic and pressure equilibrium.

$$\partial_t \psi = \nabla_{\parallel} \phi - \nabla_{\parallel} P + \eta j \quad (1)$$

$$\partial_t \omega + \{\phi, \omega\} = \nabla_{\parallel} J - \frac{\kappa_1}{r} \partial_{\theta} p + \nu \Delta_{\perp} \omega \quad (2)$$

$$\partial_t p = \{P, \phi\} + \rho^{*2} \{\Psi, J\} + \chi_{\perp} \Delta_{\perp} p \quad (3)$$

where η is the plasma resistivity, ν the plasma viscosity, ρ^* the ionic Larmor radius, χ_{\perp} the perpendicular diffusivity, κ_1 the poloidal curvature term, $\omega = \nabla_{\perp}^2 \phi$ the vorticity perturbations, $j = \nabla_{\perp}^2 \psi$ the current density perturbations. The equations are normalised with $\tau_A = L_{\perp}/V_A$ for the time, $L_{\perp} B_{0z}$ for Ψ and $L_{\perp} V_A$ for ϕ , V_A being the Alfvén velocity, τ_A is the Alfvén time, and L_{\perp} is the shear length. The parameters values are $\eta = 1 \cdot 10^{-4}$, $\nu = 3 \cdot 10^{-5}$, $\chi_{\perp} = 1 \cdot 10^{-5}$, $\kappa_1 = 0.1$ and $\rho^{*2} \in [1.5 \cdot 10^{-4}, 4 \cdot 10^{-4}]$. The geometry is cylindrical with axial periodic boundary conditions. The simulation radius r belong to $[0.5, 1.5]$. We consider no fluctuations at boundaries $r = 0.5$ and $r = 1.5$. Simulations of Eq. (1,2,3) are carried out with a 3D semispectral code including a 2/3 dealiasing rule in the poloidal direction with resolutions reaching 256 poloidal modes, 128 axial modes and 128 radial grid points. We use for equilibrium value the q profile and the pressure profile P_{eq} presented in Fig. (1). The curvature is present everywhere in the cylinder with the parameter κ_1 . The interchange grows only when $P'_{eq} < 0$: when the pressure gradient opposes itself to the curvature.

The modes are associated to their resonant surface labelled by their value of q . As an example, the mode $(m, n) = (5, 2)$ is associated to $q = \frac{5}{2} = 2.5$. The label of the poloidal modes is m . The one of toroidal modes is n . We identify the two instabilities with several criteria. The interchange eigen function presents sign changes while tearing one do not. The interchange modes grow with high m (small structures) while the tearing modes grow with the lowest m available on its resonance (large structures). The interchange eigen function is localised at narrow vicinity of its resonance while the tearing one is radially spreaded. Some eigen function examples are presented in Fig. (2).

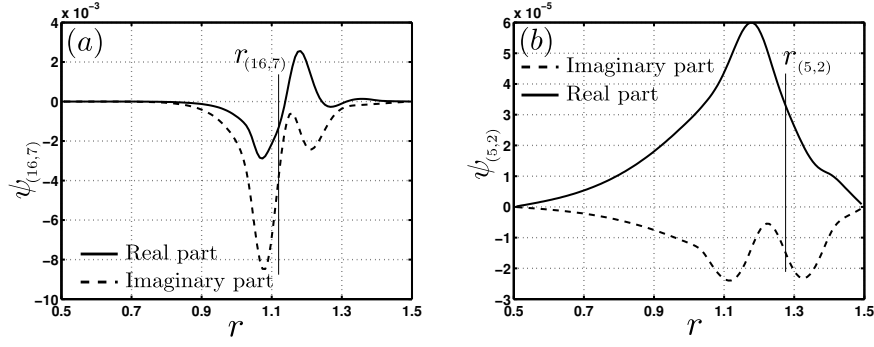


Figure 2: Example of eigen functions for interchanges modes (a) and tearing modes (b).

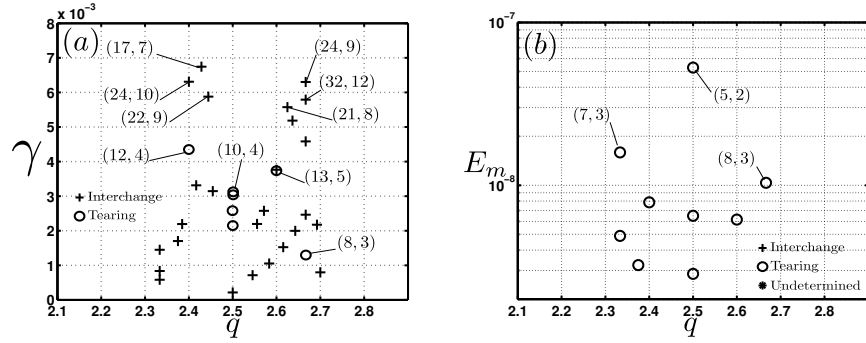


Figure 3: (a): linear grow rate and identification of modes. (b): Spectrum of magnetic energy and identification of modes

Since we are able to identify the instabilities, one can compare now the situation at the linear stage, Fig. (3a) and at the stationary stage, Fig. (3b). The system start with a situation where the interchange modes are dominating to a situation where the tearing modes are dominating. This result is analogous to the one obtains in 2D. But one can notice additional features here: the dominant tearing mode at saturation is localised to the highest rational surface reachable in the simulation box, as q belong to $[2.1, 2.9]$, it corresponds to $q = 2, 5$. The 2D results was limited to a single helicity with an undefined rationality: this observation was not possible. A second important observation is the radial localisation of the dominant modes. Since the value of q is a profile, each helicity is at a radial position, Fig. (1a). The change of the dominant helicity from linear stage at saturated stage leads us to make the hypothesis of radial interaction between the modes.

The Fig. (4) present a poloïdal section of ψ on steady state. The observation of those confirms that a magnetic island (5,2) is created at the position of $q = 2.5$, is present. The islands are visible on the field $\Psi^{*,(m,n)}(r, \theta, 0) = \frac{r^2}{\pi L_Z} \left(\frac{1}{q(r)} - \frac{n}{m} \right) + \psi(r, \theta, 0)$, a section of the magnetic flux in the helicoidal framework (m, n) .

We have shown here that the turbulence develop magnetic island on high order rational sur-

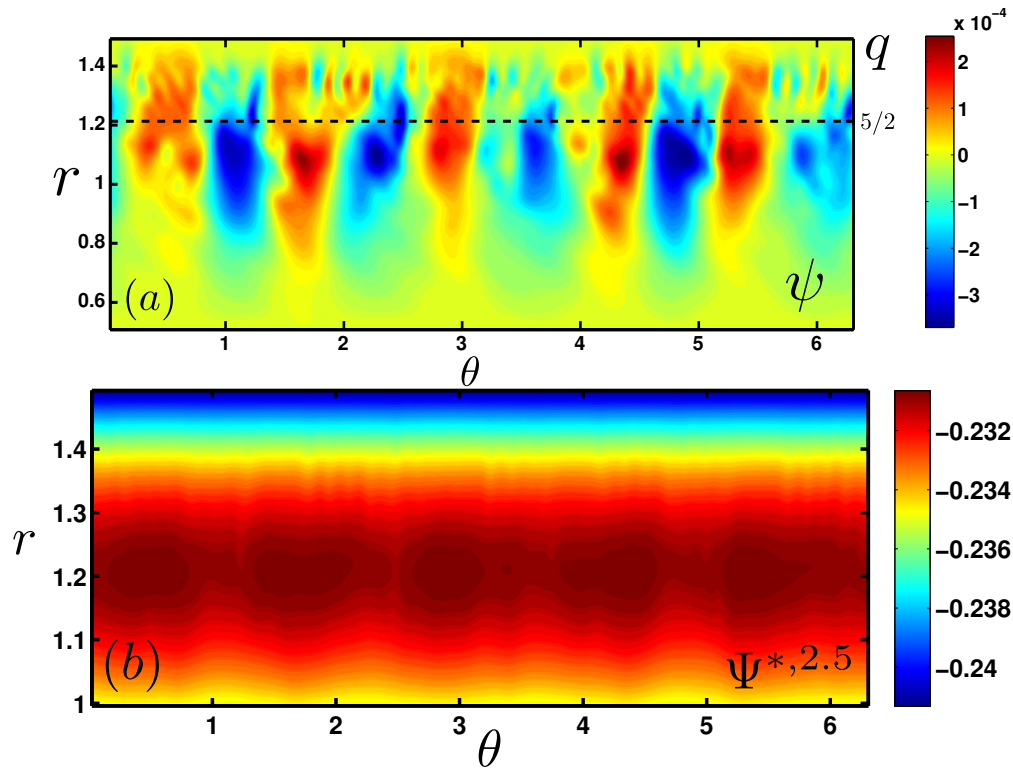


Figure 4: (a) Fluctuation of ψ . (b) Total magnetic flux in the helicoidal framework $q = 2.5$

faces. Compared to 2D results, the growth of those magnetic island has different conditions about the rationality of the helicity. In a future work, we will explore the mechanism of this magnetic island generation.

This research has been enabled by the use of computing resources provided by WestGrid, Compute/Calcul Canada, Juelich and was supported in part by CNRS, AMU, CEA, EURATOM, JUELICH and NSERC Canada. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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