

## Action of magnetic islands on GAMs and zonal flows

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### Introduction

Zonal flows are global poloidal flows which tend to be excited by the convective plasma turbulence and in turn control the level of turbulence [1]. The oscillating variant of the better known zonal flows, the geodesic acoustic modes (GAM) [2], has been the first global flow to be detected, and is still the only example of a measurable acoustic mode in tokamak plasmas. For these properties it can serve in principle as a diagnostic for the local ion temperature (due to its dependence on the local sound speed) and contribute to the regulation of turbulence by shear flows. The possibility of generation of GAMs by external magnetic perturbations has been studied in [3].

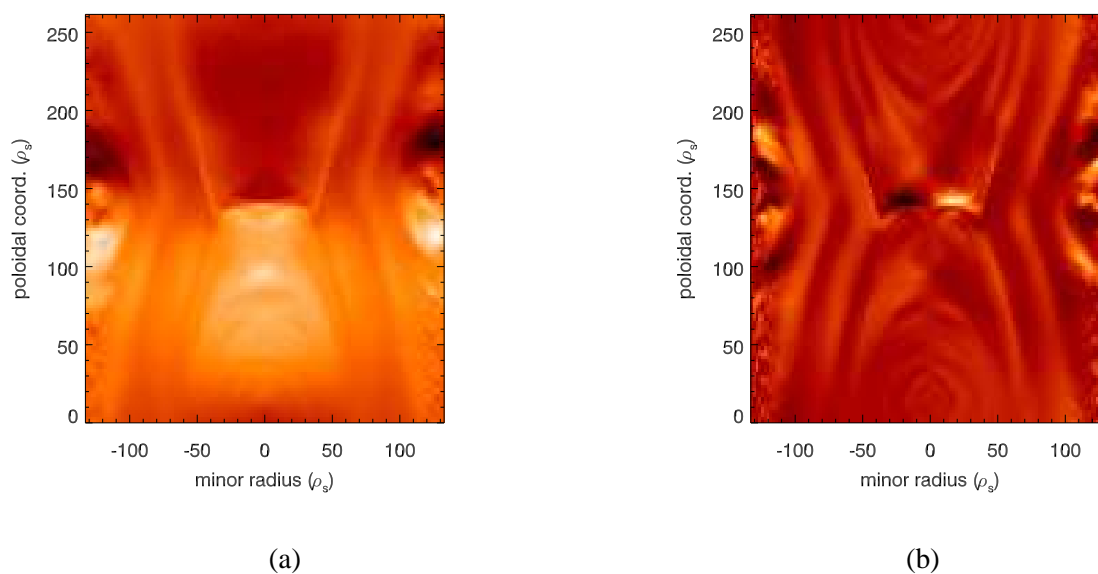


Figure 1: Decaying island; (a)  $B_r$  perturbation showing the jump of in the (re-) reconnection region, (b)  $v_r$  perturbation showing the divergent flow with in the current sheet of the reconnection region.

The interaction of turbulence induced GAMs and zonal flows with ambient magnetic islands (which frequently are induced in present day tokamaks by tearing modes) has been studied with the non-Boussinesq NLET-code [4] in electromagnetic two-fluid turbulence runs. Among the questions are whether the zonal flows follow the perturbed flux surfaces or instead advectively perturb the whole island chain, whether the frequency of the GAMs changes [5] in the presence of the islands, whether there exist “micro”-GAMs or zonal flows within islands, and in how far

the turbulence mediated radial communication among the GAMs and the zonal flows is altered. The latter effect becomes particularly noticeable in the presence of non-Boussinesq turbulence, i.e., fluctuation levels of the order of the ambient quantities.

This is particularly relevant for the question whether the GAMs could be excited by oscillating torque produced by external static perturbations on rotating magnetic islands.

### Setup of the island

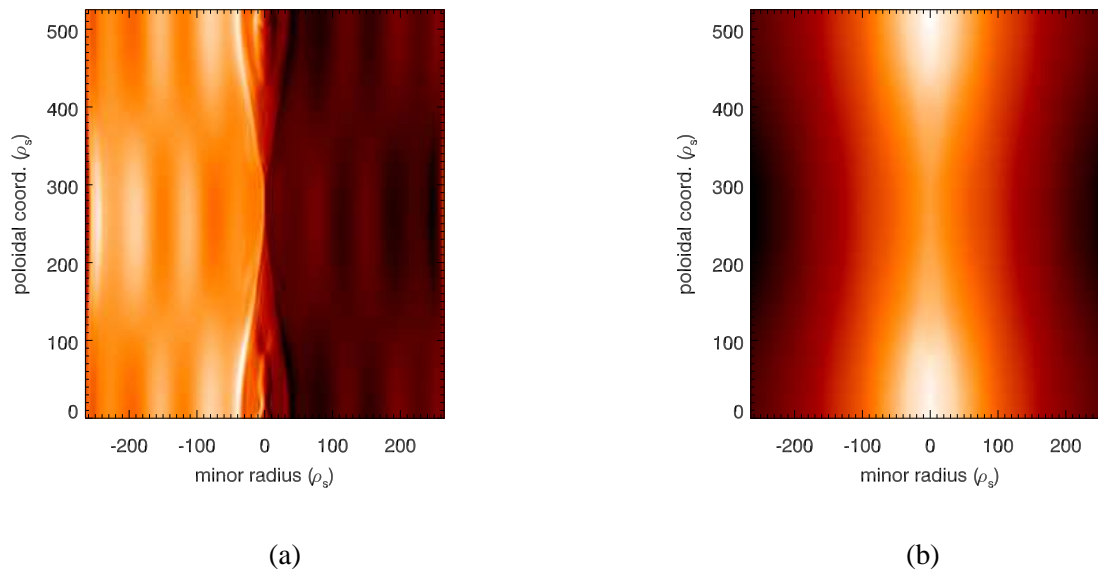


Figure 2: Initialization phase of island; (a)  $B_\theta$  perturbation showing the jump of the background profile and the island boundary, (b)  $\delta\psi$  perturbation.

The perturbation of the flux away from the resonant surface is described by an ideal equilibrium perturbation described approximately by the well known tearing-mode equation for cylinder geometry

$$\frac{d^2 \delta\psi}{dr^2} + \frac{d\delta\psi}{rdr} - \left( \frac{m^2}{r^2} + \frac{dj/dr}{B_\theta(1-nq/m)} \right) \delta\psi = 0 \quad (1)$$

with the helical flux perturbation  $\delta\psi$ , the minor radius  $r$ , the poloidal angle  $\theta$ , and the safety factor  $q$ . The (full) island width in a linearized case is

$$w = 4\sqrt{\delta\psi|_{resonant} r / (sB_\theta)}. \quad (2)$$

Any  $\delta\psi$  perturbation non-vanishing at the resonant surface will produce an island with the given width (2). Even if the perturbation does not fulfill the ideal equilibrium condition (1) at the beginning, the equilibrium is established quickly via the emission of (damped) Alfvén waves. (Of course (1) is only an approximation to the true *toroidal* equilibrium conditions.)

An island generated without additional change of the background equilibrium has a positive free energy, which causes a fast decay and leads to reconnection of the island (see fig. 1) – via a kind of “reverse” tearing mode instability. To obtain a long lived island that can be studied in together with the turbulence, the background current profile must be modified, so that the island is energetically favorable, i.e., the background current profile must be tearing mode *unstable* against islands with the considered mode numbers.

This can be achieved most directly by adding a negative  $\delta$ -layer of parallel current density, which corresponds to a negative radial jump in the poloidal magnetic field or a positive  $\delta$ -layer of magnetic shear. This prevents the reconnection of the islands and causes a further growth up to the equilibrium state of the island (see fig. 2). However, the “constant  $\psi$  approximation” and (2) becomes invalid.

### GAMs and ITG turbulence

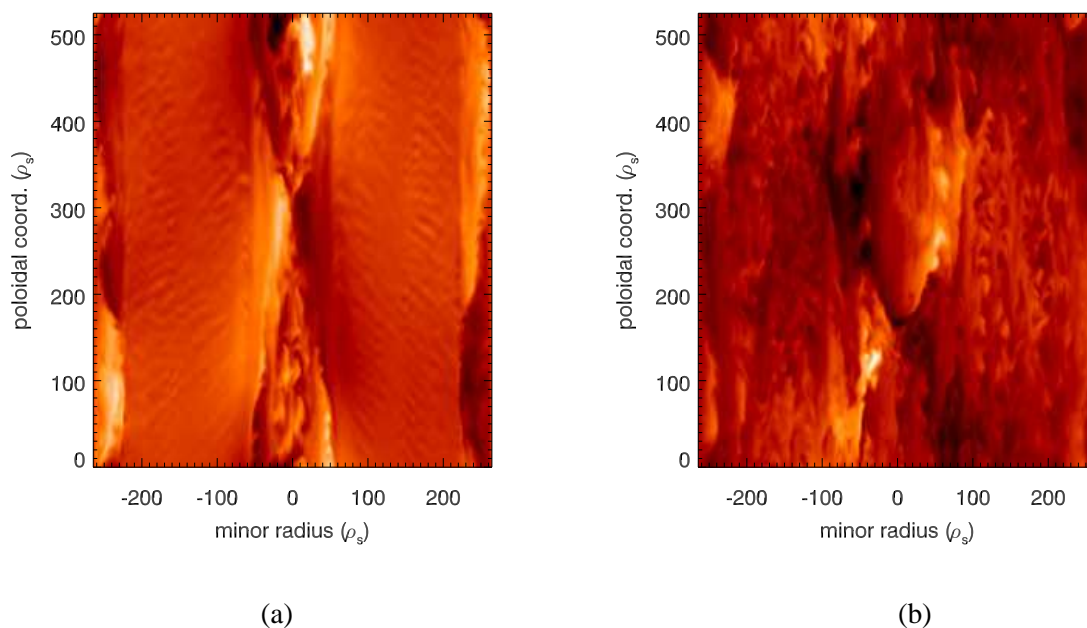


Figure 3: Stable island with ITG turbulence (a) at  $t = 1.27qR/c_s$ ; (b) at  $t = 4.26$  where the whole domain is permeated by turbulence. (The structures beyond  $x = \pm 200\rho_s$  are boundary artifacts.)

Using the described setup, an NLET-run with the parameters  $\eta_i = 3$ ,  $\varepsilon_n = 0.05$ ,  $\alpha_d = 0.6$ ,  $\alpha = 0.1$  for  $q = 3.8$ , i.e., high safety factor pertaining to the GAMs, without resistivity has been started. After the island has been established the turbulence develops first within the island, leading to a local flattening of the background temperature profiles there (fig. 3a). This causes a reduction of the ion diamagnetic velocity, and in a local  $\mathbf{E} \times \mathbf{B}$  flow due to momentum conservation (fig. 4a). The time evolution of the flow takes the form of a GAM oscillation (fig. 4b)

just outside the island.

Later, when the turbulence has permeated the complete computational domain (fig. 3b), GAMs are also established farther away from the island (fig. 4b).

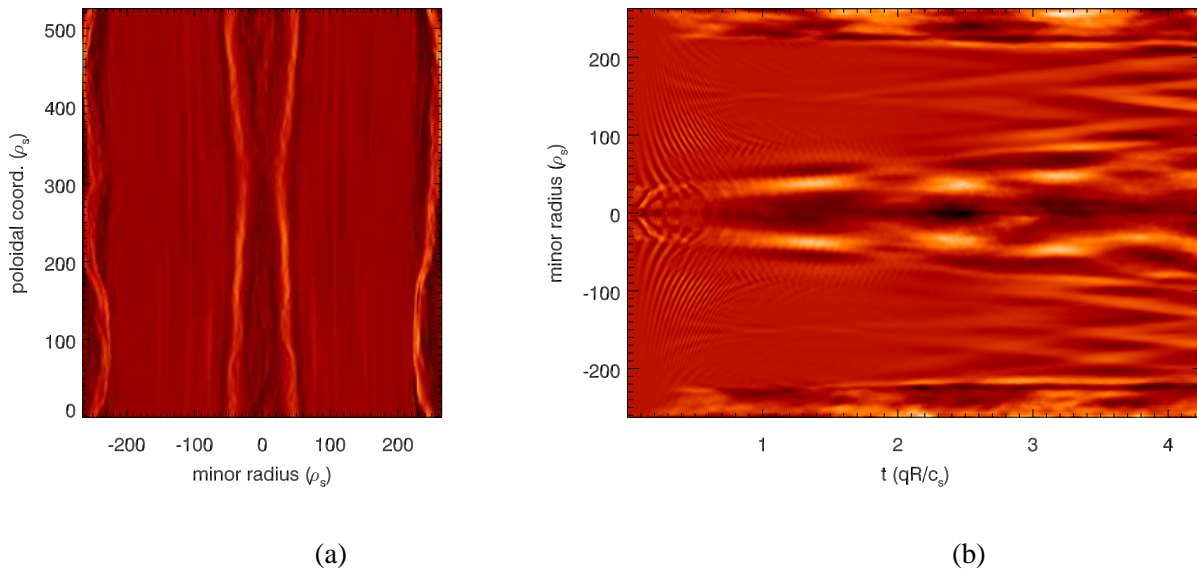


Figure 4: Poloidal flow distribution (a) at  $t = 1.27qR/c_s$ ; (b) flux surface average of poloidal flow as function of minor radius and time.

## Summary

Overall one of the difficulties of combining a turbulence computation with an island structure is to obtain a stable island in a self consistent framework. In a realistic system, the free energy source of the islands is controlled by the large scale magnetic geometry or by bootstrap current effects, which one would like to ignore for the analysis of the turbulence and zonal flows. Islands can be made persistent by adding a current layer at the resonant surface, which however alters the magnetic geometry at the island position, which might change the local turbulence properties.

Nevertheless, initial runs in the GAM regime have successfully produced GAMs surrounding the islands, due to modulation of the diamagnetic velocity due to profile flattening. So far no micro-GAMs within the island or overall island motion have been observed.

## References

- [1] K. Hallatschek, Phys. Plasmas **49** B137 (2007)
- [2] G.D. Conway, et al., Phys. Rev. Lett. **106**, 065001 (2011)
- [3] K. Hallatschek, G.R. McKee, Phys. Rev. Lett. **109** 245001 (2012)
- [4] K. Hallatschek, et al., Phys. Plasmas **7**, 2554 (2000)
- [5] R. Hager, K. Hallatschek, Phys. Rev. Lett. **108**, 035004 (2012)