Global simulations of GAMs and Alfven instabilities in tokamaks with the gyrokinetic codes NEMORB and LIGKA.

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Introduction

Global instabilities in tokamak plasmas are particularly important to understand because by interacting with fast particles and turbulence they can modify heat and particle transport. Geodesic acoustic modes (GAMs) are oscillation of radial electric field observed in the external region of tokamak plasmas, with characteristic frequencies of the order of the sound frequency, m=0 n=0 potential perturbation and m=1 n=0 density perturbation [1, 2, 3, 4]. Alfvén Eigenmodes (AEs) are electromagnetic oscillations, with frequency ranging from sound frequency to Aflvén frequency, and m≠0, n≠0 perturbation [5, 6]. GAMs observed at ASDEX Upgrade (AUG) and in particular their frequency scalings and localization have been studied in details in a recent paper by G. D. Conway (Ref. [7]). Here, we want to show preliminary results of numerical simulations of GAMs and AEs for global profiles which are representatives of some AUG shots. For GAMs simulations, we consider in particular an equilibrium with the characteristics of AUG shot #20787 taken as one of the reference shots in Ref. [7], and we use the global nonlinear gyrokinetic PIC code NEMORB [8], that is the multispieces, electromagnetic version of the code ORB5. For AEs simulations, we show preliminary results of numerical simulations with profiles characteristics of AUG shot #28112, and we use the Linear Gyrokinetic Shear Alfvén physics code LIGKA [9].

GAM frequency and damping rate

We report here about linear electrostatic simulations, where electrons are treated adiabatically. Collisionless simulations are considered, and only zonal perturbations are let evolve (all perturbation with dependence on the toroidal angle are filtered out). Ion temperature (that is not measured in such AUG shots) is considered equal to electron temperature. Our reference simulation has a spatial grid of (s,θ,ϕ) = 128x64x4 and a time step of 10 Ω_i^{-1}, with 10^8 markers. The length is $10^5\,\Omega_i^{-1}$, corresponding to 10000 time steps.

In Fig. 1 we show the radial profile of the electric field oscillation frequency, and we compare it with the fluid scaling formula $\omega = \sqrt{2}\,c_s/R_0$, with $c_s = \sqrt{(T_e+T_i)/M_i}$, and with the explicit formula of Sugama-Watanabe (Eq. 2.9 of Ref. [2]). We notice that the frequency measured in NEMORB fits quite well with the prediction of Sugama-Watanabe, expecially near the tokamak

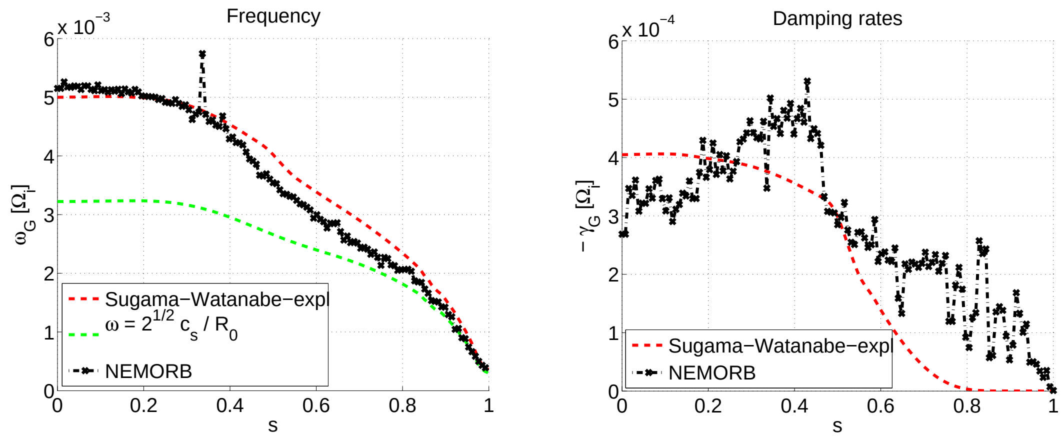

Figure 1: *Radial profiles of electric field GAM frequency (left) and damping rate (right). In black, the values measured with NEMORB, in green (for the frequency) the analytical fluid theory and in red the kinetic explicit formula of Sugama-Watanabe.*

axis, with just some little divergence at the center of the simulation box. For the damping rate of GAMs, we are less confident on this measurement because our benchmark of damping rates vs analytical theory in the local limit is still in progress. Qualitatively the damping rate profile measured in NEMORB is in agreement with the analytical theory of Sugama-Watanabe, namely GAMs are more strongly damped at the center and less in the external region of the plasma. Still we find in the external region a damping that is larger than the analytic prediction.

Zonal flow residuals

The zonal electric field that remains after the GAM oscillation is damped due to Landau damping, or analogously the residual zonal flow (ZF) $A_r = u_E(t=\infty)/u_E(t=0)$ (with u_E being the ExB drift), can be measured in NEMORB and compared with analytical prediction. In particular we compare with analytic theories of Rosenbluth and Hinton, which calculated the residual ZF in a collisionless plasma, and in the limit of radial wave-length much larger than the poloidal gyroradius $\rho_p = \rho_i q/\varepsilon$, with $\varepsilon = r/R_0$ [10], and of Xiao and Catto, which extended this formula to radial wave-lengths of the same order of magnitude of the poloidal gyroradius, and added

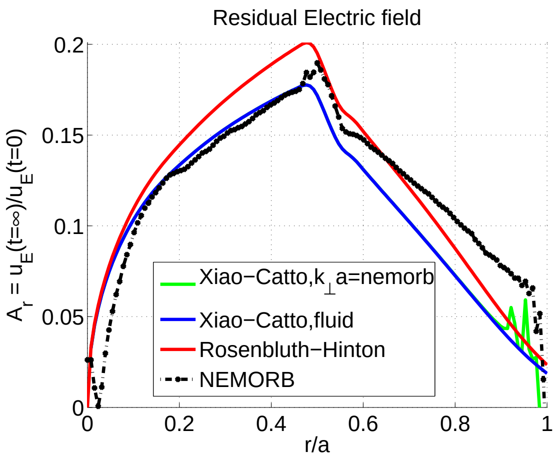

Figure 2: *Radial profile of residual zonal electric field of NEMORB and analytic theory.*

higher-order corrections of aspect-ratio [11]. We find that the radial profile of the residual electric field given by NEMORB fits well with Xiao-Catto analytic predictions especially in the inner half of the radial domain. In the external part, on the other hand, there is a divergence which is probably due to the large value of $\varepsilon = r/R_0$, which is taken into account in Xiao-Catto theory only to some ordering, or to finite shear. Xiao-Catto prediction with FLR corrections included, which is shown in Fig. 2 as a green line, is observed to depart from the prediction without FLR only in a thin layer at the edge, due to our k_r which becomes big at the edge depending probably on our boundary condition.

Shear Aflvén wave continuous spectrum and AEs radial structure

Toroidicity induced Alfvén Eigenmodes (TAE) [5] have been observed tokamak plasmas even in purely Ohmically heated discharges [12]. A possible explanation of the excitation of Alfvén modes without fast particles is the coupling to short wavelength drift Alfvén turbulence. Here we show numerical simulations obtained with LIGKA, with profiles similar to recent AUG shots which are reproducing the conditions of AUG shot of Ref. [12]. In particular, we consider here AUG shot #28112, where only ECRH is present. TAE are observed at f∼200 kHz. The peak of electron temperature gradient is measured at s=0.7-0.8. ECE is required to study more in details the TAE radial structure. We calculate the radial structure of continuous spectrum and AEs for these profiles. Continuous spectrum has been calculated for n=1,2,3. The TAE frequency and position has been found consistent with experimental data (see Fig. 3). The eigenfunction has also been calculated with LIGKA, as superposition of many m-modes, with one peak at s=0.7, that is the position of the maximum of equilibrium electron temperature gradient. This is consistent with the conjecture that the TAE could be effectively driven by TEM turbulence.

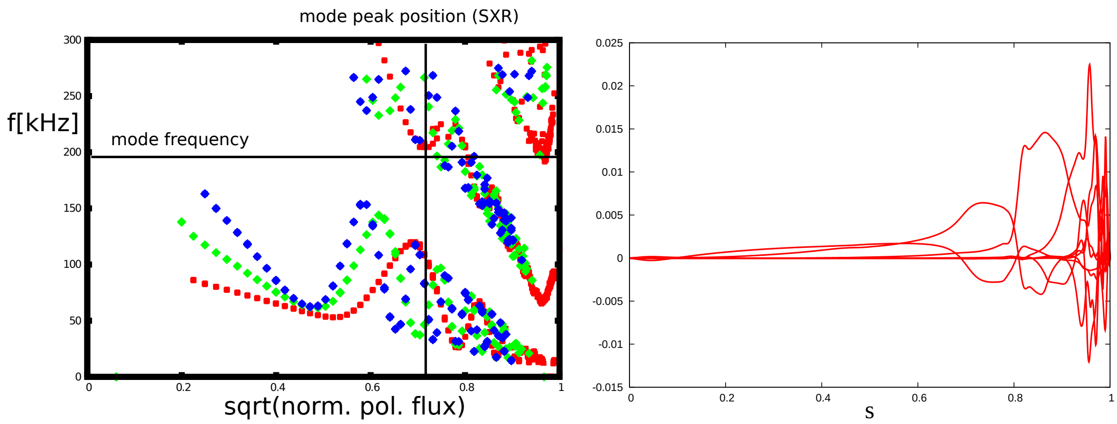

Figure 3: *Continuous spectrum (left) and radial structure (right) of AE calculated with LIGKA. The black straight lines point at the experimentally measured TAE frequency and location.*

Conclusions

The radial profiles of frequency, damping rate and residual zonal electric field of GAM oscillations have been measured with NEMORB and compared with analytical predictions [2, 3, 10, 11]. We have found good agreements of GAMs frequency and residuals with analytical theory, and we are still working on understanding better the damping mechanism. Quantitatively, we notice that the GAMs in NEMORB are more strongly damped than what predicted by analytical theory of Sugama-Watanabe. Other theories (like Ref. [14, 4, 15]) are also going to be compared with NEMORB's results. The linear radial structure of AEs has also been calculated with LIGKA and compared with the continuous spectrum structure and experimental measurements of AUG shots. As next step for GAMs, we want to repeat our simulations with kinetic electrons and in electromagnetic mode, allowing for the formation of the electromagnetic side bands and of modes with nonzero toroidal mode number. Nonlinear runs with global instabilities and turbulence are the ultimate goal of our modelling of these AUG shots. With these, we hope to understand better the nonlinear interaction of GAMs and AEs with turbulence.

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