33rd EPS Conference on Plasma Phys. Rome, 19 - 23 June 2006 ECA Vol.**30I**, P-5.070 (2006)

Microstability analysis of collisional plasmas

G. Regnoli[1], M. Romanelli[4], C. Bourdelle[3], M. De Benedetti[1], M. Marinucci[1], V. Pericoli[1], G. Granucci[2], C. Sozzi[2], O. Tudisco[1], E. Giovannozzi[1], ECRH, LH and FTU Team

[1]*Associazione EURATOM-ENEA sulla fusione, C.R. Frascati, C.P. 65, 00044, Frascati, Italy*

[2]*Associazione EURATOM-ENEA sulla fusione, IFP-CNR, Milano, Italy*

[3]*Association EURATOM-CEA sur la Fusion DRFC/SCCP, CEA/Cadarache, France*

[4] *EURATOM/UKAEA Fusion Association, Culham Science Centre, Abingdon, 0x143DB, UK*

The study of stability of electrostatic drift modes is a key topic in fusion research. It is common understanding that anomalous transport in tokamak fusion devices is driven by electrostatic drift turbulence. Furthermore phenomena such as the formation of internal transport barriers (ITB) are believed to be associated to local turbulence stabilization and consequent improvement of the thermal conductivity. Several mechanisms are candidate for explaining the stabilization of turbulence such as magnetic shear, ExB shear, Zonal flows and collisionality stabilization[1].

In this work we analyze the effect of collisionality on the stability of electrostatic modes using the gyrokinetic stability code Kinezero [2]. Among the different tokamak experiments, the Frascati Tokamak Upgrade (FTU) is particularly suited to explore turbulence and transport in high collisionality regimes since FTU plasmas are characterized by high density values (central density up to $10^{21}m^{-3}$). We also present the microstability analysis of an FTU pulse characterized by the formation of a robust electron-Internal transport barrier (e-ITB).

Electrostatic drift modes in a toroidal plasma are characterized by wave numbers $k_\theta\rho_i$ ranging between 0.1 and 10^3 (where ρ_i is the ion Larmor radius). In particular two subranges can be identified: modes linked to the ion drift dynamics and to trapped electrons ($0.1 < k_\theta\rho_i < 2$), commonly referred to as ion temperature gradient driven modes (ITG) and trapped electron modes (TEM) and modes linked to the electron drift dynamics ($2 < k_\theta\rho_i < 10^3$), commonly known as electron temperature gradient driven modes (ETG). In order to include collisionality in Kinezero we have taken the linearized Vlasov equation for the perturbed electron distribution function $f_{1,e}$ with a Krook collision operator [3]:

$$\frac{\partial f_{1,e}}{\partial t} + [f_{1,e}, H_{0,e}] + [f_{0,e}, H_{1,e}] = -\nu_{fe} f_{1,e} - \nu_{fe}\frac{H_{1,e}}{T_e} f_{o,e} \qquad (1)$$

where $\nu_{fe}(\varepsilon,\lambda) = \nu_{ei}(\mathrm{v_{the}}/\mathrm{v})^3 Z_{eff}\left(\frac{1}{|(1-r/R_0)-\lambda|^2}\frac{0.111\delta+1.31}{11.79\delta+1}\right)$, with $f_{o,s}$ is the equilibrium maxwellian distribution and $\delta = [|\omega|/(\nu_{ei}Z_{eff}\times 37.2R_0/r)]^{1/3}$ [3, 4]. The corrections for finite collisionality are negligible for passing particles as long as $k_{\parallel} v_{\parallel} \gg \nu_{\mathrm{fe}}$. The use of of a Krook operator allows for fast estimation of the effect of collisions on the growth rate and fast parametric scan . Results can be eventually double checked against a complete linear gyrokinetic code including the Lorentz operator.

We further consider "banana regime" ordering $\nu_{fe} < \omega_{be}$ where ω_{be} is the electron bounce frequency. It is worth noting that although Eq. (1) does not conserve momentum and energy, the fraction of trapped electrons remains unchanged in the banana regime and the total number of particles is conserved. By fourier transforming Eq. (1), a dispersion relation of the form $D(\omega) = 0$ can be obtained and following the same procedure used in [2] one can arrive to the modified non adiabatic response of trapped electrons in the dispersion relation for electrostatic drift modes:

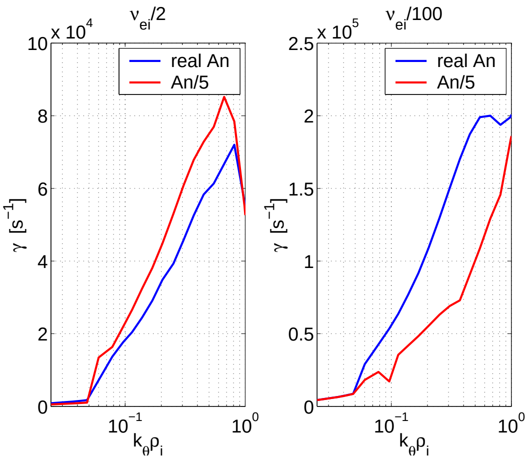

Figure 1: *Growth rate dependence on collisionality and density gradient A_n*

$$L_{te} = \langle \int \frac{dk_r}{2\pi} J_0^2(k_\perp \rho_{ce}) J_0^2(k_r \delta_e) \frac{\omega - n\omega_e^*}{\omega - n\omega_{de} + i\nu_{fe}} |\tilde{\phi}(k_r)|^2 \rangle_t \tag{2}$$

$J_0^2(k_\perp \rho_{ce})$ and $J_0^2(k_r \delta_s)$ are the Bessel functions standing for the gyro-average over the cyclotron and the bounce motion respectively. The term $n\omega_{de}$ is the vertical drift frequency. The average $\langle ... \rangle_t$ implies an integral on energy $\varepsilon = E/T_e$ and on $\lambda = \mu B/E$. The new version of the code has been benchmarked with the results obtained with the gyrokinetic code GS2 [4] and presented in [5] where calculations at different collisionalities and two different values of the gradient of the logarithm of the density A_n, have been performed. It has been shown in [5] that at high collisionality the density gradient has a stabilizing effect for low $k_\theta \rho_i$ instabilities whereas at low collisionality the effect is opposite. We used Kinezero to study the microstability of the shot 12747 as in [5] and performed the same parametric scan. The results obtained are schematically shown in Fig. 1. The maximum linear growth rate γ as function of $k_\theta \rho_i$ at the radial position $r/a = 0.7$, for two values of A_n and at two different collisionality is plotted. The results are in good agreement with GS2 outputs and confirm the above dependence of the growth rate on the density gradient at different collisionalities. Furthermore values of the growth rate obtained with Kinezero are of the same order as those obtained with GS2 runs as can be seen by comparing Fig. 1 with Fig. 8 of the [5]. For a chosen radial position r/a and wave number $k_\theta \rho_i$, Kinezero finds the zeros in the form $\omega = \omega_r + i\gamma$ of a dispersion relation

$D(\omega) = 0$

Under certain simplified conditions the dispersion relation can be easily inverted in order to compute the values of normalized density and temperature gradients $A_n = R/L_n$ and $A_t = R/L_T$, necessary to destabilize modes of a chosen frequency range and fixed wave number. By assuming $A_{ti} = A_{te} = A_t$, $T_e = T_i$, neglecting the effects of magnetic shear and of the α ballooning (in particular we consider $\alpha = 0$) and choosing a wave number and a range of mode frequencies $\omega_1 < \omega_r < \omega_2$ with slightly positive fixed γ, we can compute the instability threshold curves of electrostatic drift modes. The results for FTU parameters, varying the collision frequency, for modes with wave number $k_\theta \rho_i \simeq 0.4$, are plotted in Fig. 2.

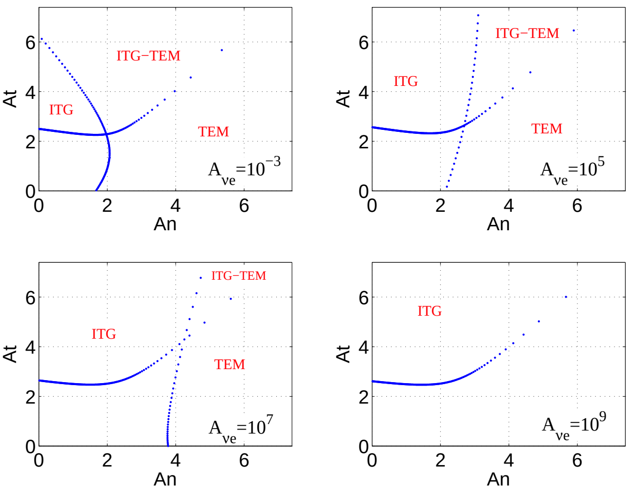

Figure 2: *Stability threshold of drift electrostatic modes ($k_\theta \rho_i \sim 0.4$) computed for different values of the collisionality parameter A_{ve}: the areas withouth any label are stable regions of the (A_n, A_t) plane.*

Collisionality here is expressed in terms of the adimensional parameter A_{ve} which is proportional to the effective collision frequency defined above. Typically $A_{ve} \sim 10^7$ for FTU plasmas and it goes up to $A_{ve} \sim 10^9$ for pellet injected discharges. From Fig. 2 it can be seen that as collisionality increases the area where both ITG and TEM are unstable gets smaller, and pure TEM can be destabilized only for very high values of the density gradients. When $A_{ve} \sim 10^9$ TEM becomes always stable. This result is consistent with what expected for an highly collisional plasma where the effects of trapped electrons is less important and can be clearly understood also by noting that denominator of Eq. 2 goes to infinite for high collisionalities. Because of the

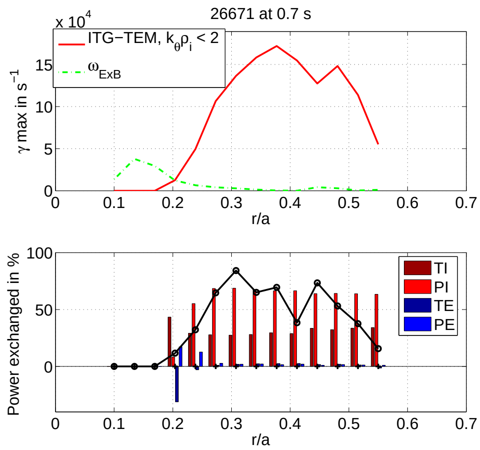

Figure 3: *Growth rate of drift modes and power exchanged with plasma particles*

important approximations done in evaluating the stability threshold of Fig. 2, any comparison with experimental observations ought to be validated by a complete analysis carried out with Kinezero. The results of Kinezero analysis including collisionality, of an e-ITB FTU plasma (pulse 26671) are shown in Fig 3 where we reported the maximus growth rate versus the normalized radius of modes in the range of low $k_\theta \rho_i$ and the power exchange between the wave and the different classes of particles divided in trapped ions (TI) and electrons (TE), passing ions (PI) and electrons (PE). Modes are stable well inside the barrier ($r/a < 0.3$) where the magnetic shear is negative, see Fig. 4.

Whereas outside the barrier, where magnetic shear is positive and temperature and density gradients are large the mode's are found unstable. A more detailed parameter scan is needed to rule out the effect of the other parameters, but what is already evident is that the turbulence has a clear dominant ITG nature. Indeed the power exchange with the trapped electrons is negligible (see Fig. 3) and the mode frequencies are found to be negative which suggests that they rotate in the ions diamagnetic direction. Setting $A_{te} = A_{ne} = 0$ but $A_{ni} \neq 0$ and $A_{ti} \neq 0$, we find that maximum growth rate decreases of 10% only. By setting $A_{te} = A_{ne} = 0$ we have canceled any possible drive for TEM and the result that the growth rate decreases only by 10% proves that turbulence is dominated by ITG. At $r/a \sim 0.4$ the normalized density gradient for the pulse 26671 is $A_n \sim 3$ and $A_{ve} \sim 10^7$. The result that only unstable ITG are found is consistent with the stability threshold graph of Fig. 2

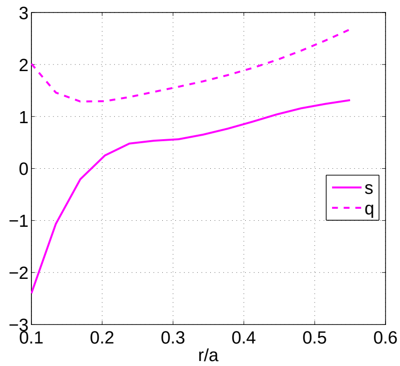

Figure 4: *Safety factor q and magnetic shear s for pulse 26671.*

References

[1] X. Garbet et al., Plasma Phys. and Contr. Fusion **46** (2004),B557–B574.

[2] C. Bourdelle, X. Garbet et al., Nuclear Fusion **42**, (2002), 892.

[3] G. Rewoldt, W. M. Tang and E. A. Frieman, Phys of Fluids **20** , No 3, (1977), 402.

[4] M. Kotschenreuther, G. Rewoldt, W.M. Tang, Comp. Phys. Comm. **88** (1995), 128.

[5] M. Romanelli, C. Bourdelle, W. Dorland, Phys. of Plasmas **11**, No 8, (2004), 3845.