27th EPS Conference on Contr. Fusion and Plasma Phys. Budapest, 12-16 June 2000 ECA Vol. **24B** *(2000) 1092 -1095*

Stability Analysis of Internal Transport Barrier on Tore Supra

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Electron Internal Transport Barrier (ITB) has been sustained in plasmas heated by Ion Cyclotron Radio Frequency (ICRF) power [1]. For understanding the main physical mechanisms leading to ITB formation, we have used a linear gyro-kinetic code to analyse the drift waves stability. The results show that the ITB is triggered by negative magnetic shear (s), and then maintained by ExB shear.

The linear gyro-kinetic code

Our goal is to calculate the growth rates spectra at given radii from the experimental temperature, density and q profiles.

Some approximations are made to get reasonable computing times. Magnetic fluctuations are neglected. The electrostatic linearised form of the Vlasov equation is coupled to the variational form of the electroneutrality constraint [2]. The problem is further simplified by using the first order ballooning representation and gaussian trial functions for the electrostatic potential. The modes are supposed to be ballooned on the low field side, which is the most unstable zone with respect to toroidal instabilities. The gaussian trial functions are the most unstable exact solutions in the fluid limit.

The validity of the results is extended close to the stability threshold as the kinetic form of the Vlasov equation is kept. Ions and electrons, passing and trapped particles, are taken into account, which means that Ion Temperature Gradient modes, Trapped Electron Modes and Electron Temperature Gradient modes are included. So important parts of the physics as the resonant Landau damping or the passing electrons role are included. It allows us to expect good qualitative information about the stability from the computed growth rates (γ).

The search of the eigenvalues is made using a generalised Nyquist's method [3]. The growth rates spectra at each radius are obtained after about 5 hours calculation on 1 Dec Alpha EV6 workstation for 50 toroidal wave numbers (n) and 20 normalised radii (r/a).

Fig. 1 illustrates a typical result for a standard L-mode discharge (I_p = 1.4 MA, $T_e(0)$ = 4 keV, $T_i(0)$ = 3 keV, n_e (0) = 6 x $10^{19} m^{-3}$). Looking at the radial dependence, one finds the highest growth rates in the gradient zone. For n between 10 and 100, ITG modes and TEM are destabilised. Over 100, only the ETG modes remain.

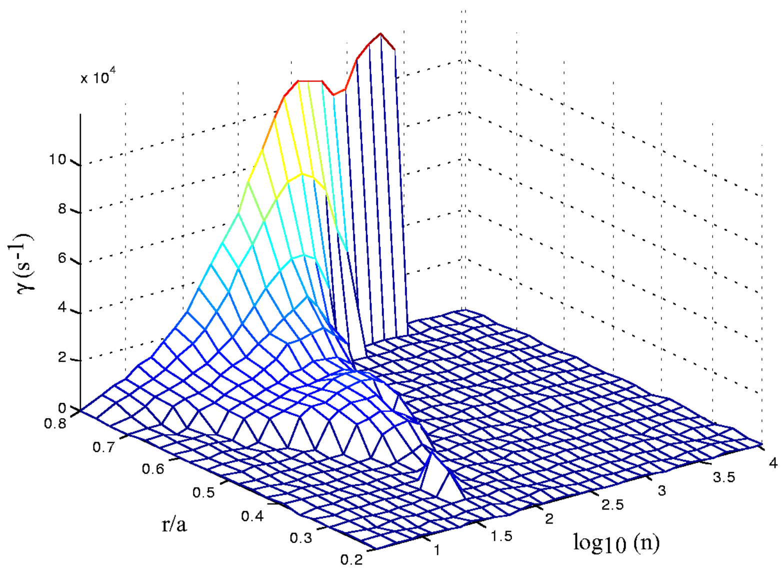


Fig. 1: Growth rate spectra for n between 5 and 10^4 at r/a from 0.2 to 0.8 #TS25222 at 7s

ITB plasmas analysis

Experiments are performed at n_e (0) = 6.5x$10^{19}$$m^{-3}$, and the working gas is Helium. Magnetic shear reversal is preformed by a fast current ramp-up. I_p is raised from a 0.4 MA stationary phase to 1.2 MA, at the rate dI_p/dt = 1.6 MA/s. An ICRF power of 4 MW is applied at the end of the I_p ramp-up (Fig. 2). Transient hollow current density profiles are observed during the ramp-up. Fig. 3 shows the evolution of q-profile at the beginning of the 1.2 MA flat top. The electron pressure profiles show an ITB at normalized radius r/a around 0.6 (Fig. 4). The electron energy content is 40% higher than the Rebut-Lallia-Watkins prediction, which fits well Tore Supra L-modes (Fig. 2b). The total energy content improves by the same factor as the electron energy. This suggests that the ion channel also improves (Fig. 2c).

The magnetic shear reversal is correlated with a drop of the density fluctuations measured by a laser scattering experiment.

The stability of the discharge #TS25196 (Fig. 2) is analysed at the end of the current ramp-up (at t = 9.1s) at a radius where s is strongly negative. To quantify the effect of s, we calculated γ with a positive s of 0.2 instead of the measured value of – 0.1. The comparison is shown in Fig. 5. A clear stabilising effect of negative magnetic shear is observed. The growth rates decrease by roughly a factor of 2 for toroidal numbers between 10 and 100.

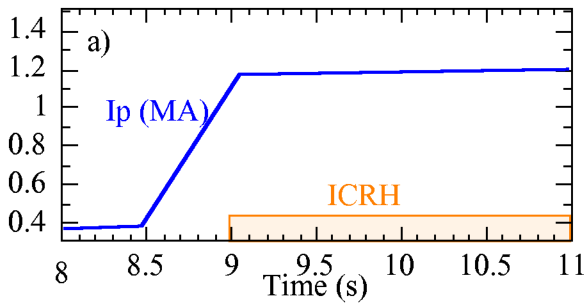
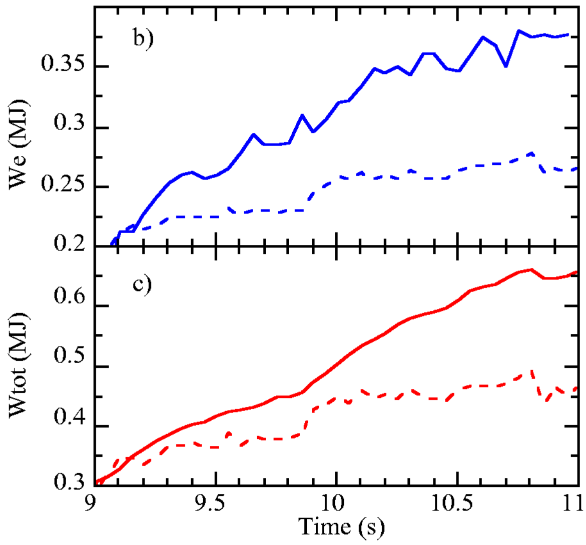


Fig 2: Typical ITB plasma (shot #TS25196).
a) Plasma current and RF power.
b) Electron energy (full curve) and the RLW L-mode scaling (dashed curve).
c) Total energy (full curve) and the ITER L-mode scaling (dashed curve).



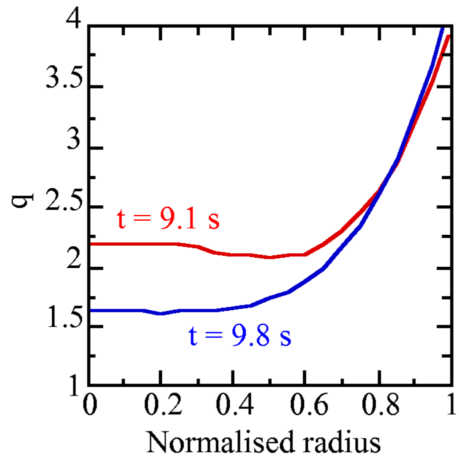


Fig. 3: q-profiles of shot #TS25196.

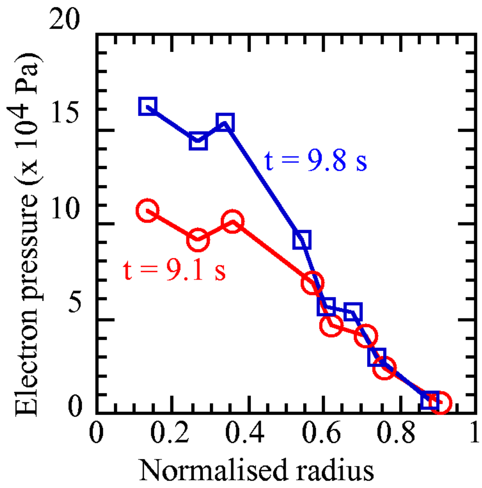


Fig. 4: Electron pressure profiles of shot #TS25196.

During the current flat top, the computed γ increase as the density and temperature profiles are more peaked and the q-profile monotonic (Fig. 6). The stability analysis is performed in the lowest order ballooning representation, and therefore does not account for ExB shear. To complete the analysis, the ExB shearing rate (γ_E) has to be evaluated separately. Non-linear simulations show that Ion Temperature Gradient modes are stabilised if γ_E is higher than γ [4]. To allow this comparison, the E_r–profile is evaluated using the neo-classical set of equations. E_r can be obtained if one breaks the axisymmetry condition. In this evaluation we have taken into account for the ripple because it can reach up to 7% in Tore Supra. The particles trapped in the ripple wells are undergoing the vertical drift, the collisions and the ExB drift. They are lost unless their collision frequency and/or the ExB drift are high enough to detrap them. The radial electric field is then deduced from the ambipolarity constraint on the ripple losses [5]. For thermal particles, the collision frequency on ions is much weaker than the one on electrons; therefore the flux of lost thermal ions is stronger. In ohmic Tore Supra plasmas, this evaluation of E_r is in good agreement with the measured ion toroidal rotation (20 km/s), in counter-current direction [6].

The time evolution of the maximum radial value of γ_E over the flat top is shown in Fig. 7. The shearing rate increases up to values higher than the maximum growth rates.

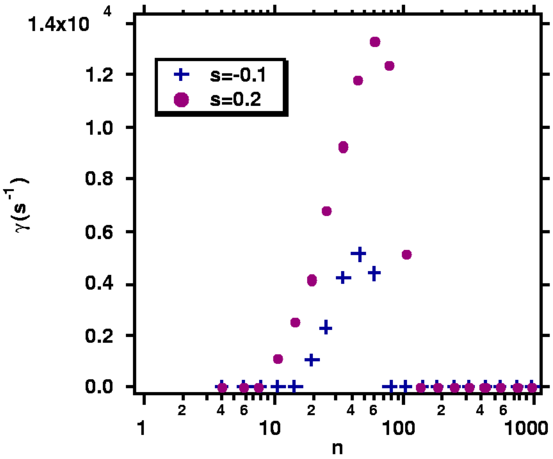


Fig. 5: Growth rates spectra computed for shot #TS25196, at 9.1s, with measured non-monotonic (plus) and with a assumed monotonic q-profiles (dot).

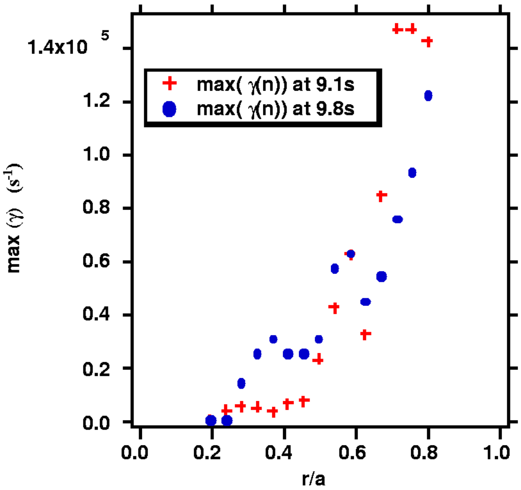


Fig. 6: Radial profile of maximum growth rates spectra computed for shot #TS25196, at 9.1 s (plus), and t = 9.8 s (dot).

Conclusion

Stability of ITB Tore Supra plasmas has been analysed using a powerful linear gyro-kinetic code. Local stabilising effect of negative magnetic shear is likely acting as a trigger for the Internal Transport Barrier formation. Stationary ITB was maintained over the current flat top by the increase of ExB shear due to peaked density and temperature profiles.

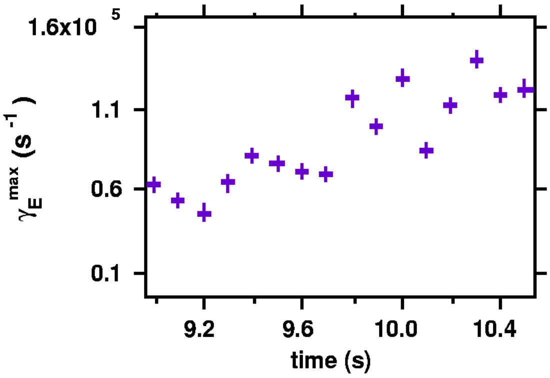


Fig. 7: Time evolution of the maximum radial value of ExB shearing rate for shot #TS25196.

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