Effects of high density peaking and high collisionality on the stabilization of the electrostatic turbulence in the Frascati Tokamak Upgrade

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Experiments carried out on the Frascati Tokamak Upgrade (FTU) [B. Angelini et al., Nucl. Fusion 43, 1632 (2003)] with the injection of deuterium pellets in ohmic, high density plasmas show that a remarkable enhancement of the energy confinement time is achieved when the pellet penetrates deeply in the plasma core. Here a study of pellet effects on the electrostatic turbulence is carried out with the gyrokinetic codes Kinezero [C. Bourdelle et al., Nucl. Fusion 42, 892 (2002)] and GS2 [M. Kotschenreuther, G. Rewoldt, and M. W. Tang, Comput. Phys. Commun. 88, 128 (1995)]. The analysis shows that the collisionality of FTU plasmas is high enough to detrap the electrons. The low wavelength unstable modes remaining are then pure ion temperature gradient modes that are stabilized by more peaked density profiles. In the postpellet phase the density peaking stabilizes also strongly the high wavelength electron temperature gradient modes. © 2004 American Institute of Physics. [DOI: 10.1063/1.1766031]

I. INTRODUCTION

Many Tokamaks have shown a significant enhancement of the energy confinement time as a consequence of the injection of pellets (see, for example, Refs. 1–5); the so called pellet enhanced plasma was explained by a mixture of effects mainly dominated by turbulence suppression due to reversed magnetic shear, $E \times B$ shear and density peaking stabilization (see, for example, Refs. 1, 2 and 4). The Frascati Tokamak Upgrade (FTU) is a medium size Tokamak, characterized by a strong toroidal magnetic field (nominal value 8 T) which allows the confinement of plasma densities of the order of $4 \times 10^{20}$ m$^{-3}$ (line average density). The transport analysis of FTU PEP mode discharges does not show an important change in the current density profile following the injection of the pellet, mainly due to the high collisionality leading to a low fraction of bootstrap current. In the absence of reversed magnetic shear, the change in the confinement regime seen experimentally (increased neutron rate) has to be linked to the modification due to the pellet of the density and temperature profiles. We also expect the high collisionality of FTU plasmas to play an important role in turbulence stabilization along with the peaking of the density profile. It is well known that in fluid theory an increase of the density gradient could stabilize the ion temperature gradient modes (ITG modes) by decreasing the parameter $\eta_i = \langle T_i, n_i \rangle / \langle n_i \rangle$, however in gyrokinetic calculations including trapped electron modes (TEM), density peaking is found to be destabilizing (as given in Ref. 7). Therefore the stabilizing role of density peaking will depend on the actual fraction of trapped electrons and therefore on plasma collisionality. In order to investigate qualitatively the effect of density peaking on the electrostatic turbulence in FTU, we have linearly solved the gyrokinetic equation in realistic geometry using the experimentally measured density and temperature profiles and the inferred current profiles. The gyrokinetic equation is solved numerically with the codes Kinezero (see Ref. 8) and GS2 (see Ref. 9). The unstable modes are characterized by a growth rate $\gamma$ for a given wave number $k\rho_i$ and radial positions $r$. By comparing the result of GS2 and Kinezero, we are assessing the role played by collisionality in FTU with respect to the impact of density peaking. We are showing that the stability thresholds change dramatically when trapped electrons are either included or not included. A scan is performed to calculate the growth rates for $k\rho_i$, ranging from ITG-TEM values to the electron temperature gradient modes (ETG modes) values, and for different radial position. The changes in the growth rate spectrum from the prepellet profiles to the postpellet profiles and the sensitivity to changes in collisionality, density, and temperature gradients are studied. The $E \times B$ shearing rate is evaluated based on neoclassical assumptions, and, despite the changes induced by the density peaking, it is found to remain too low to have an impact on the ITG growth rates. This analysis of FTU plasma shows also that the growth rates are very sensitive to the slight temperature changes from the pre to the postpellet, as well as to the slight $q$ profile changes. Nevertheless, due to the high collisionality, the increased density peaking is found to be stabilizing, on both ITG and ETG branches, with a stronger impact on ETG.

The paper is organized as follows: in Sec. II we briefly introduce the experiments of pellet injection on FTU; in Sec. III an extended discussion on the impact of density peaking
on microturbulence with and without collisions is proposed; in Sec. IV the analysis performed on FTU plasmas with Ki-nezero and GS2 is described and finally we report the conclusion.

II. EXPERIMENT

The Frascati Tokamak Upgrade is a medium size Tokamak \( (R=0.937 \text{ m}, a=0.3 \text{ m}) \) with nominal toroidal magnetic field and plasma current, respectively, of 8 T and 1.6 MA. The high field allows for electron densities in the plasma center close to \( 10^{21} \) particles per cubic meter, these are among the highest densities achieved on present Tokamaks leading to high electron collisionality. In ohmic discharges the electron temperature is of the order of 1 keV. The transport analysis of pellet injected discharges shows that following the injection of the pellet the ion heat transport coefficient \( \chi_i \) becomes neoclassical (of the order of 0.1 \( \text{m}^2\text{s}^{-1} \)), electron heat transport does improve also, \( \chi_e \) becoming lower than \( \chi_i \) in a large inner region up to half the plasma minor radius (see Ref. 5). In this paper, we concentrate on two identical discharges (FTU 12744 and FTU 12747) at 7 T and 800 kA. The time traces of main plasma parameters are shown in Fig. 1. Two consecutive pellets (of about \( 10^{20} \) deuterium atoms, 3 mm radius and at 1.3 km/s speed) are injected in a well developed ohmic plasma at times \( t=0.6 \text{ s} \) and \( t=0.75 \text{ s} \). The fast polychromator shows the penetration of the cold front on a 50 \( \mu \text{s} \) time scale and the Thomson scattering reconstruction of the density profile after the injection shows the development of a peaked density profile \( \{ n(0)/\langle n \rangle =3 \} \) as shown in Fig. 2. Transport analysis of the two discharges show that the confinement time increases from 50 ms in prepellet phase up to above 100 ms in shot 12744 postpellet phase (shot 12744 has a confinement time in the postpellet phase of 70 ms, this difference is probably due to a different pellet penetration). Although the increase of the confinement time is transient, it is proven to be reproducible with consecutive pellets. Up to five consecutive pellets have been injected in FTU shot 18598 (see Ref. 5), demonstrating a steady improved confinement. The transport analysis of the 7 T discharges shows that there is no magnetic shear reversal due to the injection of the pellet, although a flattening of the \( q \) profile in the core is observed that accounts for the transient suppression of the sawtooth in the phase immediately after the injection. The reason for the nearly unchanged current density profile despite a strong density gradient is the high collisionality regime that leads to a negligible number of trapped particles, responsible for the bootstrap current. In Fig. 3, we show the gradients of temperature, density, and magnetic shear profiles in the prepellet and postpellet phase together with the equilibrium parameter \( \alpha \) as used for the microturbulence analysis. Data available for the microstability analysis are the radial measurements of the electron temperature and density from Thomson scattering with an average error of 10%, the ion temperature profile and the current profile are calculated from energy balance and using the measured neutron emission rate, therefore they come with large uncertainties. The sensitivity of this analysis to variations of the profiles has been carried out and the results are presented in Sec. IV.

III. DISCUSSION

We present here a general discussion on the effects of collisions and density peaking on microturbulence. It is commonly believed that high density peaking has a stabilizing impact on microinstabilities. This result is true for clearly unstable modes, far above the threshold, where the normalized frequency of the modes, \( \Omega \), is the solution of the following second order polynomial equation (see Ref. 6):
\[
3/2 \Omega^2 + \Omega \left[ A_n (1 + f_t) + 3/2 \right] + \left[ f_t (1 - f_t) \right] (A_n + A_T) = 0,
\]

with \( n_i = n_e, \ T_i = T_e \), the main ion being deuterium. The finite Larmor radius effects are not included; \( A_n = 3/2 n \omega_{pi}^2 / n \omega_{ge} \) is a function of the magnetic shear \( s \) and is taken to be equal to 1 in the following. The solution, \( \Omega_n \), of Eq. (1) is characteristic of an unstable mode if it has a positive imaginary part, so if

\[
\Omega_n \geq \left[ \left( 1 - f_t / 6 f_t \right) \left( 1 + f_t / A_n + 3/2 \right) - A_n \right].
\]

The limit between stable and unstable surfaces in the plane \( (A_n, A_T) \) is plotted on Fig. 4 with a fraction of trapped particles, \( f_t = 35\% \). The figure illustrates clearly the well known fact that, in the fluid limit, an increase of the density gradient (i.e., a higher \( A_n \)) is systematically stabilizing. The more realistic but more complex case of gyrokinetic equations requires the use of numerical calculation. In these more realistic cases, a higher density gradient can be destabilizing. This result had already been discussed by Romanelli and Briguglio (see Ref. 7). In their paper, it is shown that a higher density peaking is always stabilizing for pure ITG modes, when the trapped electrons are taken adiabatic, experimentally it is the case in highly collisional plasmas. But when the collision frequency is not high enough to detrap all the electrons, the combination of ITG modes and TEM leads to cases where a higher density gradient is destabilizing. Here, we will show the same results as in Ref. 7 in a slightly different form. We are adding to what was already shown in Ref. 7 the interesting case of the high wave number ETG modes due to passing electrons, where a higher density gradient is systematically stabilizing. The code used is based on Kinezero (see Ref. 8). Kinezero is a linear gyrokinetic code, which is using a Gaussian trial function as ansatz for the fluctuating electrostatic potential; the effect of collisions is not retained explicitly but high collisionality is recovered by switching off the TEM part of the equation. Kinezero is adapted here to look for the threshold in the plane \( (A_n, A_T) \). The threshold is fixed at a growth rate, \( \gamma_0 \), such that \( \gamma_0 = 2 \times 10^3 \ \text{s}^{-1} \) or \( \gamma_0 / (c_{ui} / a) \sim 3 \times 10^3 \) for \( c_{ui} = (1 \ \text{keV} / m_t)^{0.5} \) and \( a = 0.3 \ \text{m} \) for the mixed ITG-TEM case (see Fig. 5) as well as for the pure ITG case (see Fig. 6), and
at $\gamma_0 = 4 \times 10^4 \text{ s}^{-1}$ or $\gamma_0/(c_w/a) \sim 9 \times 10^{-4}$ for $c_w = (1 \text{ keV}/m_e)^{0.5}$ for the ETG case (Fig. 7). The surface above the threshold is labeled “unstable,” and the surface below the threshold “stable.” Note that the point $(A_n = 0, A_T = 0)$ is, by definition, part of the “stable” surface. As already shown in Ref. 7, Figs. 5 and 6 show the stability limits in the plane $(A_n, A_T)$ for two cases. The first one is taking passing and trapped electrons to be adiabatic, this means that the unstable modes are pure ITG modes. In this case, by increasing the density gradient, so by increasing $A_n$, one goes from an unstable area to a stable area. Therefore, for pure ITG, a higher normalized density gradient is stabilizing. On the contrary, in the second case shown on Fig. 6, the trapped electrons are nonadiabatic, so the unstable modes are a mixture of TEM and ITG modes. Indeed, in some parts of the plane $(A_n, A_T)$ both an electron root and an ion root are simultaneously unstable. In this ITG-TEM case, a higher normalized density gradient, $A_n$, is destabilizing. In the last case, Fig. 7, the passing electrons are the only unstable species, so the unstable modes are pure ETG modes. As for pure ITG also pure ETG modes are stabilized by a more peaked density profile. In the following, we will relate these results to the impact of electron collision on the physics of density peaking stabilization.

We are using data of the FTU discharge 12747 at $t = 0.7 \text{ s}$ from the ITPA profile database. We have tested the respective impacts of electron collisions and density peaking using the gyrokinetic code GS2 (see Ref. 9). The GS2 code, as the Kinezero code, has been coupled to the ITPA profile database (see Ref. 10). The collision frequency is not explic-
ity included in Kinezero, so the code cannot be used to perform such a test. Figure 8 is showing GS2 growth rate spectra for \( k_{ur} \) up to 1 at \( r/a = 0.7 \). Here, the role of the density peaking, \( A_n \), going from its experimental value to an artificial value five times lower, is tested for different electron frequencies (\( \nu_e \)) ranging from 0 to twice the FTU experimental value. One can see in Fig. 8 that, when going from the experimental \( \nu_e \) to twice its value, the growth rates remain unchanged. This means that the experimental \( \nu_e \) is so high that, despite a high fraction of trapped particle \( \nu_e \approx 40\% \), all the electrons are already detrapped. Therefore, for the experimental value of \( \nu_e \), an increase of the density peaking, from \( A_n/5 \) to the experimental \( A_n \), is stabilizing. On the other extreme, where \( \nu_e = 0 \) (where ITG modes and TEM coexist), a higher density peaking is destabilizing. Intermediate cases are also illustrated on Fig. 8. For the real \( \nu_e \) divided by 5, there is no impact of the change from \( A_n \) to \( A_n/5 \), except for the part of the spectrum above \( k_{ur} \approx 0.7 \), where the ITG modes are off and where only the TEM are unstable, and where an increase of \( A_n \) is stabilizing. These qualitative observations are in complete agreement with Figs. 5, 6, and 7, where we have shown that a higher density peaking is always stabilizing except when both ions and electrons are simultaneously nonadiabatic.

IV. MICROSTABILITY ANALYSIS

In the following analysis the linear growth rates of microinstabilities are calculated using the linear electrostatic gyrokinetic code Kinezero (see, for example, Refs. 8 and 11). This code does not treat collisions, so to analyze the highly collisional FTU discharges, we assume all electrons to be detrapped and switch off the TEM. We will justify this assumption later, and we will also present benchmarks of Kinezero with GS2, a more complete gyrokinetic code (see, for example, Ref. 9) which includes the effect of collisions. For a linear, electrostatic, collisionless, shifted circular cross-section geometry case, Kinezero is about 380 times faster than the equivalent GS2 run. In order to test extensively the different parametric dependences of the unstable modes in the prepellet and postpellet phases, we need a relatively fast tool such as Kinezero. The speed of the code is due to the fact that we assume for the eigenfunction of the fluctuating potential a prescribed Gaussian function, this assumption has proved to be realistic when compared to a code solving self-consistently the eigenfunction such as GS2. Indeed, Kinezero has been satisfactorily compared with GS2 already in Ref. 8. This benchmark is completed on Fig. 9 with an example based on the ITPA profile database data (see Ref. 10) for Joint European Torus (JET) shot 46664 at 45.1 s and \( r/a = 0.4 \), with a \( Z_{eff} \) equal to one. The input files for Kinezero and GS2 have been created with open source tools available on the ITPA database website. Both Kinezero and GS2 are open source codes. This benchmark is completed by a more qualitative comparison of the impact of density peaking on low wave number spectra for the FTU shot 12747, Fig. 10. The maximum values over each growth rate spectra are similar in both codes, and a qualitative agreement between the

FIG. 8. GS2 growth rate of instabilities varying \( k_{ur} \) from 0.1 to 1 at \( r/a = 0.7 \) of FTU 12 747. From left to right, the electron collisionality goes from twice its experimental value to zero. On each graph, the full line with open squares is the spectrum for the experimental value of the density peaking, \( A_n \), and the dashed line with open circles stands for the same case but with \( A_n/5 \). So on these graphs, both impacts: density peaking and collisionality are tested.

FIG. 9. Benchmark of two growth rates spectra for \( k_{ur} \) up to 100, including therefore ETG modes, between Kinezero and GS2 on JET shot 46 664 at 45.1 s and \( r/a = 0.4 \), with a \( Z_{eff} \) forced to one.
codes is found. Indeed, both sets of results exhibit a destabilization due to density peaking, for the case without collision in GS2 and for the case treating both ITG modes and TEM in Kinezero. On the contrary, as expected, both sets of results exhibit a stabilization due to density peaking, for the highly collisional case in GS2, and for the case with TEM off in Kinezero. Since Kinezero does not include collisions, we can only treat either noncollisional cases or highly collisional cases which are equivalent to cases where the TEM are off. The qualitative agreement obtained in Fig. 10 shows that neglecting TEM (Kinezero) or correctly treating the impact of collisions (GS2) lead to similar results in the case of highly collisional FTU plasma. The similar parametric behavior of both codes also confirm that the physical treatment of the microturbulence as approximated in Kinezero is coherent. This allows therefore for a faster tool to be used for the following analysis of the pellet injected FTU plasma.

We have seen in the previous paragraph that FTU shots 12744, 12747, as most of FTU high density plasmas, are highly collisional. Indeed, as shown in Fig. 8, in the postpellet phase, at \( r/a = 0.7 \), all the electrons are detrapped. The effect of collisions is expected to be less important further in the center due to the decreasing fraction of trapped particles. In the prepellet phase, the electron density is roughly twice lower, and the electron temperature is about the same, so the electron collisionality, is about twice lower. By looking at Fig. 8, we see that, when \( \nu_e \) is twice lower than in the postpellet phase, the growth rates are higher, especially for the real high density gradient, \( A_n \). This means that running a case without trapped electrons instead of a case including the impact of \( \nu_e \) would lead to an understimation of \( \gamma \) of about 30% at high \( A_n \) and of about 5% at \( A_n/5 \). The prepellet phase is characterized by a maximum \( A_n \) 30% lower than in the postpellet phase. Therefore, switching off the TEM in the prepellet phase leads to an understimation of the ITG growth rates ranging from 0 to less than 30%. Nevertheless, even in the prepellet phase, \( \nu_{\text{eff}} = \nu_e (r/R) \), is at least seven times larger than the electron vertical drift at \( k_p \rho_i = 2 \), typical of the TEM range, as it can be seen on Fig. 11. We report here the analysis of shot 12744 carried out with Kinezero with no TEM. The linear growth rates are calculated for wave numbers \( k_p \rho_i \) ranging from the ITG to the ETG part of the spectrum and for radial position \( 0.2 < r/a < 0.8 \). Two time slices of the discharge have been chosen: immediately before the injection of the first pellet \( (t = 0.58 \text{ s}, \tau_E = 50 \text{ ms}) \) and after the second injection \( (t = 0.85 \text{ s}, \tau_E = 70 \text{ ms}) \). Our goal is to identify the key stabilizing parameters, on top of the change of temperature gradients, among the following options: (1) density peaking alone, (2) density peaking coupled to the consistent increase of \( \alpha \) \( (\alpha = -R^2 q^2 \mu_e B^2 dp/dr) \), (3) change of \( \nu_e \) due to a change of bootstrap current, (4) change of the rotation shear \( E \times B \) through an increase of the pressure gradient.

The \( E \times B \) shearing rate \( \gamma_{E} \) is calculated as \( \gamma_{E} = r/q \left| \nabla \left( q / r E_i / B \right) \right| \), where \( E_i = \nabla p_i / (n_i Z_i) - V_{\theta B} \).

FIG. 10. Comparison of growth rates spectra for \( k_p \rho_i < 1 \) calculated by GS2, left figure, and Kinezero, right figure, on shot FTU 12747 at 0.7 s and \( r/a = 0.7 \). The impact of density peaking and collisionality are tested and compared with both codes.

FIG. 11. Effective collision frequency, \( \nu_{\text{eff}} \), for FTU shot 12744 at 0.58 and 0.85 s compared to the electron vertical drift at \( k_p \rho_i = 2 \), typical wave number of the TEM range.
We take $V_{\phi} = 0$ for these ohmic discharges and $V_{\phi} = -k \nabla B_{\phi} / (B_{\phi} Z_i)$, where $k = -1.17$ in the banana regime, $k = 0.5$ in the plateau regime, and $k = 1.7$ in the highly collisional regime. The boundaries across these three regimes are taken from Ref. 11. In Fig. 12, we show the maximum growth rates on the ITG part of the spectrum ($k_{\phi} < 2$) and on the ETG part ($k_{\phi} > 2$, up to $k_{\phi} \rho_i \sim 2$) for the prepellet and postpellet plasma phases. In Fig. 13, we isolate the impact of the density profile by running a study case in which we used all prepellet profiles but the density, replaced by the postpellet density profile. The peaking of the density profile is stabilizing in the region $0.5 < r/a < 0.8$. In this region, the $E \times B$ shear is almost unchanged by the steeper density. On the contrary, for $0.2 < r/a < 0.5$, the $E \times B$ shear is sensibly enhanced. We have also run a case in which we kept the $\alpha$ parameter constant in the postpellet plasma without observing any significant change in the growth rates; indeed, in FTU high $B$ and low $R$ plasmas, $\alpha$ is very low ($0.1 < \alpha < 0.2$) and little $\alpha$ effects were expected in this pure electrostatic analysis. Starting from the postpellet phase, we also analyze the separate effects of the temperature, $q$, and density profiles on the growth rates of ETG and ITG, see Fig. 14. It is seen that the slight change in temperature gradients from prepellet to postpellet is destabilizing in the region inside $r/a \sim 0.7$ for both ITG an ETG, while at $r/a = 0.8$, where the normalized temperature gradient decreases in the postpellet phase, the new temperature profiles are suppressing ETG and stabilizing ITG. There is also a slight stabilizing effect due to the small increase of the magnetic shear. Nevertheless, adding to these effects, the density peaking brings a large stabilization on both ITG and ETG: 40% on ETG peak growth rate and 20% on ITG peak growth rate. It is important to stress here that the stabilization of turbulence due to density peaking on ITG is possible thanks to the high
collisionality of FTU, in a lower collisionality plasma with TEM, the density peaking would have been destabilizing and no enhancement of the confinement would have been observed without the appearing of other factors such as a larger change of the magnetic shear. From the above analysis it is seen that the experimental profiles of the postpellet phase, although stabilizing, do not appear to suppress completely the ITG turbulence, as it would be expected from JETTO transport analysis (see Ref. 12) where ion temperature evolution in the postpellet phase is well described by the neoclassical transport coefficient. This discrepancy could be due to uncertainties in the ion temperature profile, here it is important to note that FTU ion temperature profile, $T_i(r)$, is not directly measured, but it is reconstructed using a transport code (JETTO or EVITA) and the constraint on the central ion temperature derived from direct measurement of the neutron rate. Therefore the error bars on the ion temperature profile are large, especially in the outer region of the plasma where the contribution to the neutron rate is negligible. To assess the impact of these errors on our analysis, we have performed a scan of the temperature and density gradients. At $r/a = 0.25$, we have checked that, even with normalized ion and electron temperature gradients twice higher the ITG and ETG growth rates, respectively, remain stable with the postpellet density profile. So an uncertainty on temperature gradients is not affecting the fact that the modes are very stable at this radius, mainly because the temperature gradients are low there. Fig. 15 shows the result of the scan at $r/a = 0.7$. At this radius, the stabilizing effect due to density peaking would be reinforced by lower temperature gradients. In particular, we note that if the normalized ion temperature gradient was 50% lower, the density peaking increase at that radius ($r/a = 0.7$) would bring a complete ITG stabilization, in agreement with JETTO transport analysis.

V. CONCLUSION

FTU discharges exhibit a significant energy confinement improvement following pellet injection. We have carried out a numerical study of the growth rates of the drift wave modes in the prepellet and postpellet phases of these discharges. Both low wavelength modes such as ITG and TEM and high wave length modes such as ETG modes have been carefully analyzed. We have found that TEM are negligible due to lack of trapped electrons at these high collisionality while both ITG and ETG are stabilized by an increased density peaking. The impact of other potential important players to explain the energy confinement improvement have also been studied. The stabilization occurs with density peaking even if the accompanying $\alpha$ stabilization is neglected. No clear change neither of the magnetic shear nor of the $E \times B$ shearing rate has been found to bring a significant stabilization. FTU plasmas exhibit, already in the prepellet phase, a very stable core region (up to $r/a = 0.4$) therefore dominated.
by collisional transport. The anomalous transport arises in the region between \( r/a = 0.4 \) and \( r/a = 0.8 \) where both ITG and ETG are present. By taking the experimental profiles of shot 12 744 as validated with JETTO, the overall quantitative effect of density peaking and change in the temperature gradients and \( q \) profile is that of reducing of 50\% the growth rate of ITG and ETG at \( r/a = 0.75 \). Complete ITG suppression, as found in the transport analysis done with JETTO, would be reached by assuming a 50\% error in the estimate of the normalized ion temperature gradient (calculation done at \( r/a = 0.7 \)).

The stabilization due to the density peaking independently of \( s, E \times B \) and \( \alpha \), is not systematically expected with pellet injection. Indeed, the stability threshold in gyrokinetic simulations shows no density peaking stabilization when both ion and electron modes (ITG and TEM) are unstable. Results showing systematic stabilization due to density peaking are recovered only when ion modes only or electron modes only are unstable, so, at low wavelength, when trapped electron modes are stabilized due to high collisions for example. This is the case in FTU plasmas where the collisionality is high enough to detrapp most of the electrons. On the contrary, in JET, where the electron collisionality is not as high, the trapped electrons play a role in the microturbulence. In such cases, the improvement of the confinement triggered by pellet injection cannot be explained by a pure density peaking effect, but it is more likely due to the associate increase of \( \alpha \).{13}

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