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** See annex of J. Pamela et al, "Overview of Recent JET Results and Future Perspectives",*
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ABSTRACT

Investigation of electron Internal Transport Barriers (eITB) in experiments with dominant electron heating is a subject of detailed analysis on different tokamaks due to a possibility to use this plasma as a prototype of a reactor relevant condition with prevailing electron heating by alpha particles. A link between eITB dynamics and peculiarities of safety factor profile, q(r), is discussed in many recent papers (see, for example, [1-3] and references therein). However there is no common opinion about the role of the magnetic shear in eITB formation and evolution.

Previous JET results focused on eITB physics [4,5] have shown that electron ITB is located in reversed shear area just inside the qmin position. Turbulence stability analysis performed in [5] showed that magnetic shear value of s<-0.5 is a favourable condition for eITB formation due to Dissipative Trapped Electron mode stabilisation.

The goal of this paper is an investigation of q(r) profile influence on eITB formation and evolution in JET discharges with dominant electron heating. Magnetic shear effect in the eITB triggering will be emphasised.

1. EXPERIMENTAL CONDITIONS AND RESULTS

25 representative shots were chosen from the JET database. Typically Lower Hybrid (LH) heating and current drive was applied early on the current ramp-up phase to freeze reversed shear current profile. Electron ITB has been defined using the JET ρ^*_{Te} criteria [6] ($\rho^*_{Te} = \rho_S / L_{Te}$, where ρ_S - ion Larmor radius at the sound speed, $L_{Te} = -T_e/(\partial T_e/\partial R)$. In agreement with this criterion, the ITB is characterised by ρ^*_{Te} 0.014.

In typical cases with LH preheating, eITB was formed early on the initial stage of the discharge. Therefore it was difficult to determine the eITB trigger. However, it was clearly shown that negative central shear plays at least a facilitating role in the eITB formation. Figure 1 compares two shots which have the same plasma parameters (plasma current, plasma density, heating power value and timing), but their history of plasma breakdown is different. There was no eITB observed in Pulse No: 53448, where the q(r) profile became monotonous early at I_p ramp-up. In the Pulse No: 53454 a reversed shear region existed in the plasma core ($\rho \leq 0.3$) during the whole pre-heating phase, that led to an appearance of an eITB.

There is no clear correlation between the eITB position and the location of the rational magnetic surfaces in discharges under consideration.

2. LINEAR STABILITY ANALYSIS

Linear micro-turbulence analysis was made with an electrostatic linear gyrokinetic code KINEZERO [7]. It is shown that the eITB formation in the discharges under consideration is the result of a stabilising effect of both negative central magnetic shear and high normalised pressure gradient (α–stabilisation, where $\alpha = -4Rq^2 \times \nabla p / B_T^2$, R- major radius, p- plasma pressure, B_T – toroidal magnetic field). Long wavelength turbulence (ion temperature gradient, ITG, and trapped electron, TEM, modes) is suppressed mainly by negative central shear (Fig.2(a)), whereas both $s < 0$ and high value of α leads to the suppression of short wavelength instability (electron temperature gradient mode, ETG) (Fig.2(b)). It should be noted that lowest order ballooning approximation used in KINEZERO does not allow the stability analysis of flat q(r) configurations to be made. Test calculations with KINEZERO code show that the electron temperature gradient increases within the eITB region up to the level, which is close to the critical one for ETG destabilisation. Analysis presented on Fig.2 was made for Pulse No: 53454 at t = 5.3s, when maximal temperature gradient was located at $\rho = 0.25$ and was characterised by $\rho^*_{Te} = 0.014$, i.e. close to the threshold value for eITB identification.

3. POSSIBLE INFLUENCE OF A HEAT SOURCE PROFILE ON THE EITB STRENGTH.

Experimental data show the crucial role of the reversed magnetic shear configuration for eITB formation in experiments with dominant electron heating. However questions about a threshold power for eITB formation, its connection with producing of favourable magnetic configuration and localisation of heat source (see, for example, [8]) are still open. Test calculations were made using the JETTO transport code to mark out a possible effect of a heat source on eITB strength in regime with negative central shear. In these calculations, only thermal energy balance equations for ions and electrons were solved. For both species, an empirical transport model based on a combination of Bohm and Gyro-Bohm type of transport coefficients was chosen similar to [9]. Negative central shear is considered as being the triggering condition for eITB formation in the model. Magnetic configuration was fixed with strongly reversed central shear (Pulse No: 53454 on Fig.1(b)). In addition to LH power (2.5MW) identical to that required for formation of magnetic configuration in the experimental Pulse No: 53454, test source of electron heat (2MW) was applied to analyse the transport barrier properties depending on heat source width and location. Figure 3(a) represents a range of the test source distributions. LH heating is located at $\rho \sim 0.3$. Ohmic power was located mainly outside of q_{min}. It should be noted that in the case of $P_{test} = 0$ the calculated temperature profile agrees well with the experimental data for Pulse No: 53454, at t = 4.7s (see Fig.1). These test calculations show that broadening of the heating power profile can lead to a decrease of the temperature gradient at eITB location, in spite of the possible conservation of the q(r) profile.

CONCLUSIONS

It was shown that a negative central magnetic shear is at least a facilitating condition for eITB formation in JET discharges with dominant electron heating. Electron ITB formation in these discharges is the result of dual stabilising effect of reversed shear q(r) profile: long wavelength turbulence stabilisation mainly due to $s < 0$ and short wavelength turbulence stabilisation by both $s < 0$ and high α value. It was demonstrated that the value of electron temperature gradient in eITB is determined by achievement of value close to the critical one for ETG mode destabilisation. Heating power profile width apparently could be considered as an important factor determining the eITB strength in discharges with reversed shear q(r) profile.

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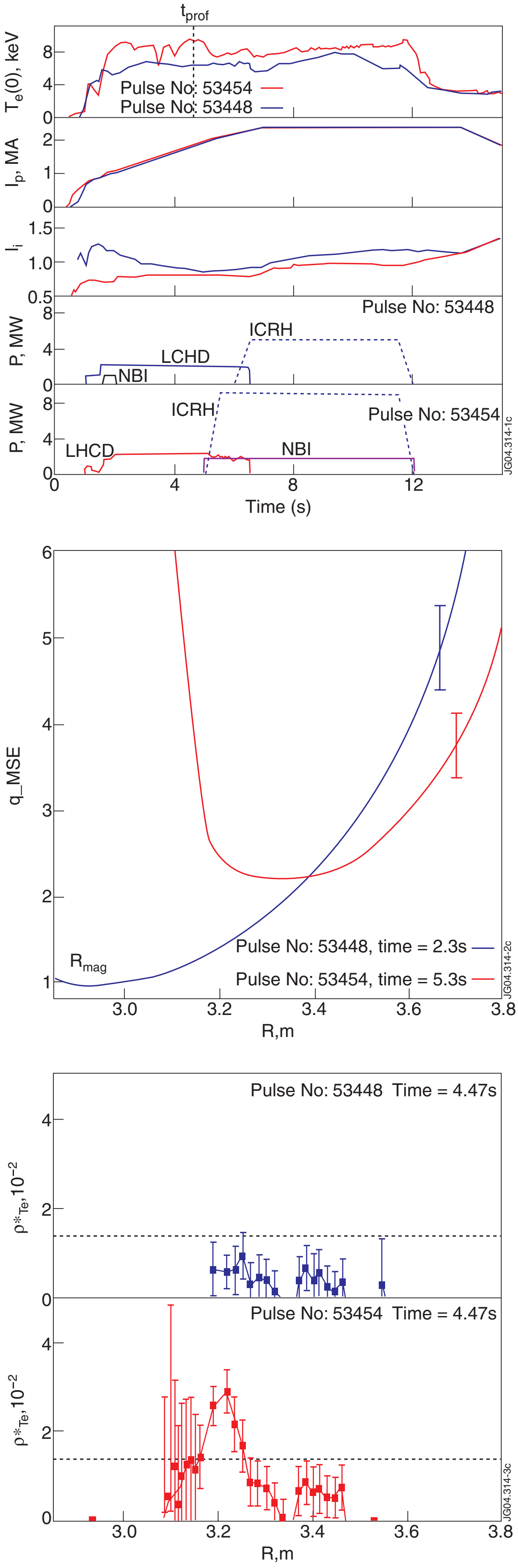

Figure 1: Comparison of two similar Pulse numbers with (53454) and without (53448) eITB formation: (a) temporal evolution of central electron temperature (T_e), internal inductance (l_i), and heating power; (b) differences in q profile behaviour measured by MSE diagnostic; c) ρ^*_{Te} profiles at the time marked as t_{prof} (Fig. 1(a)) in comparison with the critical value determining ITB existence (dashed lines).

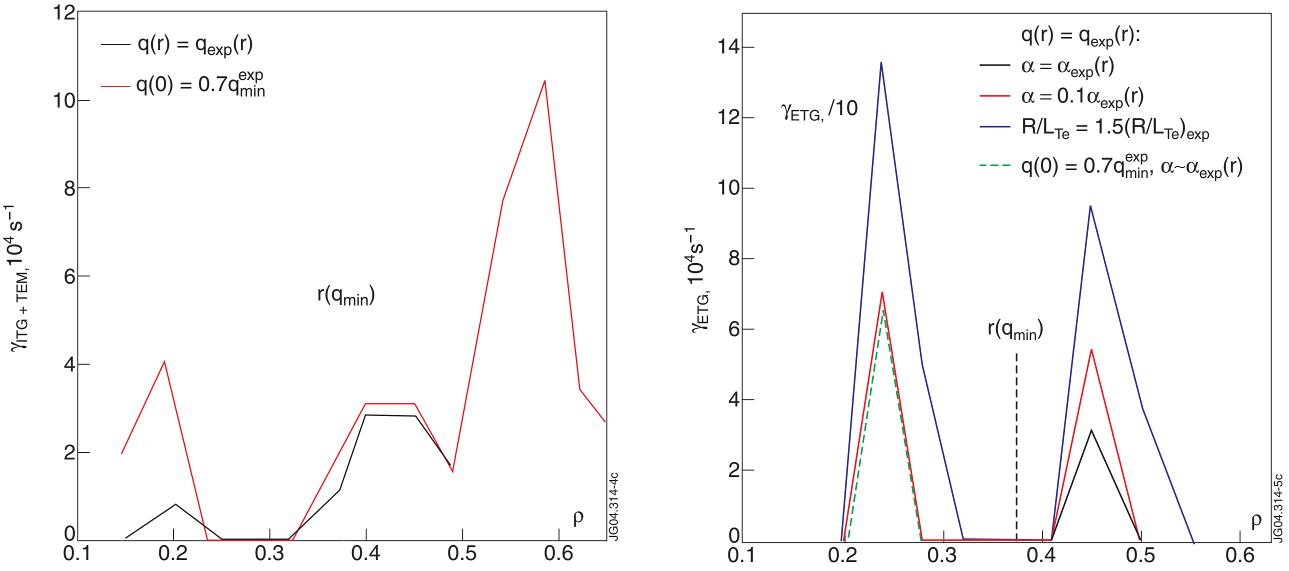

Figure 2: Stability of drift modes in test calculations in comparison with that obtained for experimental profiles: a) Growth rates for long wavelength turbulence (mainly ITG; note that TEM is more pronounced at $0.4<\rho<0.5$) at different $q(r)$ profiles. b) ETG mode growth rates for experimental profiles and in test calculations with decreased α parameter and with experimental α, but increased T_e gradient; changes of ITG/TEM stability inside of $r(q_{min})$ with decrease of α parameter or increase of T_e gradient are not so dramatical. q_{min} position for experimental $q(r)$ profile is shown.

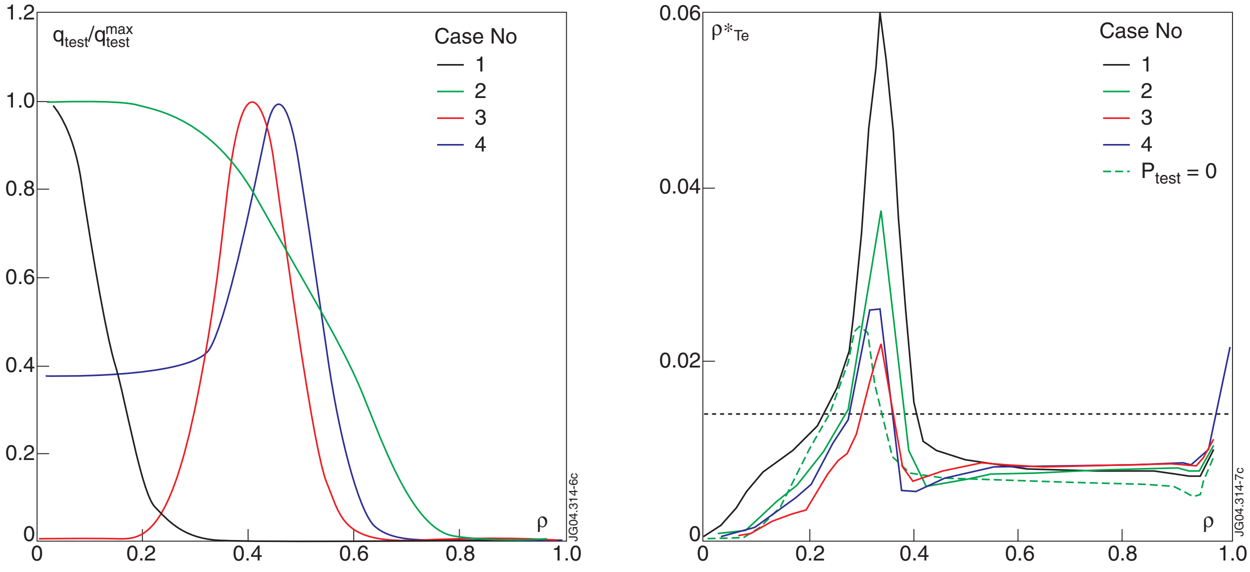

Figure 3: (a) Normalised profiles of test heating power, q_{test}; numbers are used as a markers of calculation run; b) ρ^*_{Te} values for calculated electron temperature profiles.