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**See Annex of J. Pamela et al., "Overview of Recent JET Results and FuturePerspectives", Fusion Energy 2000 (Proc. 18th Int. Conf. Sorrento, 2000), IAEA, Vienna (2001).*

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ABSTRACT.

In JET a new ITB scenario has been identified [1], which features high n_e and high j_{boot}. This paper addresses the questions: What is the role of the strong bootstrap current in the q-profile evolution? What are the micro-stability properties of these discharges?

1. DESCRIPTION OF SCENARIO FOR PULSE NO: 55860

The scenario for Pulse No: 55860 and the profile evolution for the first second in the main heating are described in detail in [1]. Directly at the start of the main heating phase (3.8s) the density profile is broad, with $n_e(0) = 6\times10^{19}$ m^{-3}. A pronounced gradient in $n_e(r)$ forms around r = 0.4. $n_e(0)$ decreases steadily but the ne-gradient is maintained throughout the high performance phase. Gradients also develop in the Ti and Te profiles around r = 0.4. At the end of the pellet gap, the MSE q-profile is flat, with q_0 ~2. The q-profile re-reverses during the NBI heating phase. The data suggest that current is being expelled from the plasma core.

2. JETTO INTERPRETATIVE RUN

We use JETTO to evolve the bootstrap current $j_{boot}(r)$, and the current density j(r) for the first second of the main heating of Pulse No: 55860. All profiles, except for j(r), are prescribed, and closely mimic the experimental data. Figure 1 shows the input profiles for T_e (from ECE and LIDAR), T_i (CXS), n_e (interferometry and Lidar). Z_{eff} is assumed flat. Figure 2 shows the bootstrap current evolution and the simulated total current density profile evolution. j_{boot} peaks at the barrier location, at r = 0. 4. The maximum bootstrap current density is $1MAm^{-2}$. The maximum bootstrap current is 25 % of the total current. Starting from a monotonic q-profile, JETTO finds an off-axis maximum in j(r) at r = 0.4. The development of this off-axis maximum is associated with a reduction of the current density just outside the bootstrap layer. The q-profile re-reverses but the simulations do not show a reduction of $j_{total}(0)$.

3. MICRO STABILITY ANALYSIS WITH KINEZERO

Kinezero (KZ) [2] is a local, linear electrostatic code in the collisionless limit, which takes both passing and trapped, electrons and ions into account. It calculates the linear growth rates as a function of radius and wave number. At the start of the main heating phase, the electron collision frequency and the vertical electron drift are of the same order, therefore the collisionless approximation in KZ is only marginally valid, while later in the discharge the temperatures increase making the collisionless approximation more applicable. 16 radii, with poloidal and toroidal wavenumbers in the range from 5-5000 are taken into account. In Fig. 3 the maximum growth rates in the ITG-TEM range, i.e. for $k_\theta\rho_i < 2$, are shown for t = 4.0, 4.2, 4.4 and 4.8s. Already at 4.2s, a significant reduction in the growth rates around r=0.4 is observed, while at t = 4.4s, the growth rates in the ITG-TEM range are reduced throughout the plasma, despite a steep increase of the temperature gradient. The micro turbulence simulated modes are stabilized early in the main heating phase, which is consistent with the experiment. At t = 4.8s, the ETG growth rates increase dramatically (not shown here).

4. PARAMETRIC SCANS WITH KINEZERO

From 4.0s to 4.4 s, the growth-rates are reduced at increasing inverse normalized temperature gradient length, $A_T = R/L_T$. To investigate this, A_T was varied numerically, while fixing the other profiles at their values of t=44.4 s. Initially, for reduced A_T, the growth rates decrease, and vanish for $A_T/2$ and $A_T/4$, indicating that we are close to the critical A_T. For $A_T/8$ however, we see an increase of the growth rates. This is a kinetic effect on trapped electron modes (TEM), which remain unstable even at very low A_T as long as the normalized density gradient An is not zero. But if the electron collisions are efficient, they de-trap the electron and this effect disappears. In the collisionless approximation, the stabilizing impact of density peaking is therefore under evaluated. First, we want to know if the density gradient, $A_n = -R\nabla n/n$, is stabilizing at 4.0s. We compare the real growth-rates with growth rates for $A_n/8$ with a consistently modified and $A_n/8$ with a as for $A_n/1$. The results are listed in table 1. We conclude that for ITG-TEM modes, a more peaked density profile is destabilizing. For ETG modes, the density peaking is stabilizing when consistently increased with α. We have to recall here that, in the collisionless approximation, the role of trapped electron modes is overestimated, therefore, the stabilizing impact of density peaking is underevaluated. But consistently with the experimental observation, the microstability analysis does not predict an improved confinement as soon as the density is peaked.

Real, An/1	1.6 10^5 s^{-1}
An/8, but α inconsistent	1.6 10^4 s^{-1}
An/8, α consistent	1.6 10^4 s^{-1} + strong ETG

JG03.581-3c

Table 1. Modification An with consistent and inconsistent a, for t = 4.4s.

To investigate why the growth rates are lower at 4.4 s despite increasing normalized temperature gradient, $A_T = -R\nabla T/T$, we take all profiles as at 4.4 s, and independently (and inconsistently) insert the profiles of s, α and q as at t = 4.0s. We test the impact of magnetic shear reversal at 4.4 s and the impact of $\alpha = -Rq^2 2\mu_0/B^2\, dP/dr$ increase through steeper temperature gradient. The results of our numerical experiment are listed in table 2.

t=4.4, with α as at 4.0s	Destabilizing
t=4.4, with q as at 4.0s	Not a strong effect
t=4.4, with q, s as at 4.0s	Not a strong effect

JG03.581-4c

Table 2. Modification of a, q and s for the profiles at 4.4 s.

We see only a small response if we change q and s to monotonic values at 4.0s, and a strong destabilization if we lower α as it was at 4.0s. This a stabilization is due to an increase of the pressure gradient through the adding impact of steep density and temperature profiles [4].

CONCLUSIONS.

JETTO analysis for Pulse No: 55860 shows that a bootstrap fraction of 25% is achieved at maximum performance. This localized effect explains the re-reversal of the q-profile. The simulations do not reproduce the rise in q_0. Micro stability analysis for this discharge was done with the gyrokinetic code Kinezero. KZ has reproduced the early, but not immediate reduction of growth rates in the ITG-TEM range. ETG-modes are destabilized at t = 4.8 s, roughly coinciding with the performance roll-over. Stabilization only occurs at increased normalized temperature gradient. This effect is due to an increase of a. The important role of a to maintain the ITB suggests that, at least from a transport point of view, barriers can be maintained at low momentum input.

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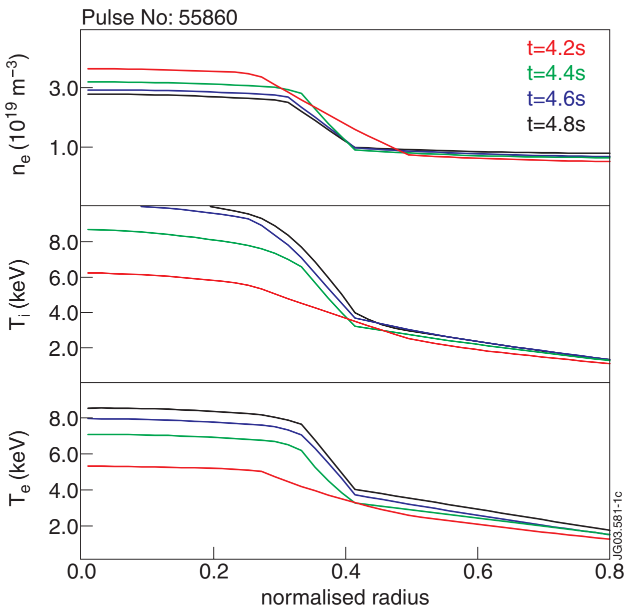

Figure 1: Input profiles for t = 4.2, 4.4, 4.6 and 4.8s (JETTO, KINEZERO)

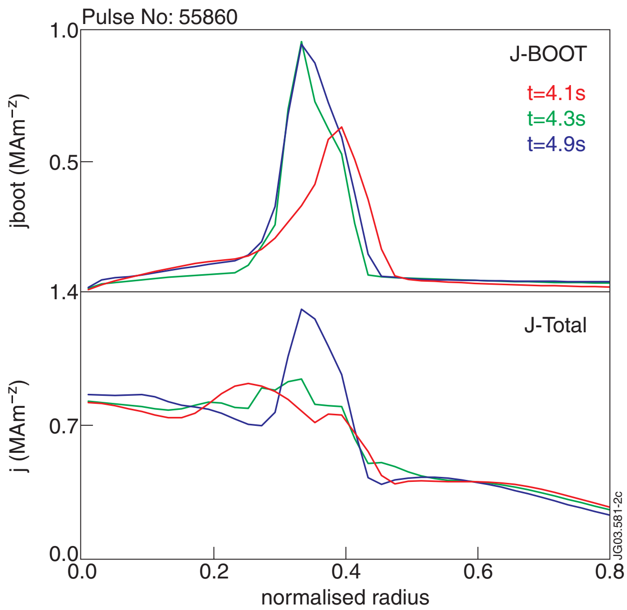

Figure 2: JETTO simulation: J_{Boot} is sufficient to re-reverse the q-profile. No current is expelled from the core in the simulation. 4.1s(red), 4.3s (green) and 4.9s (blue).

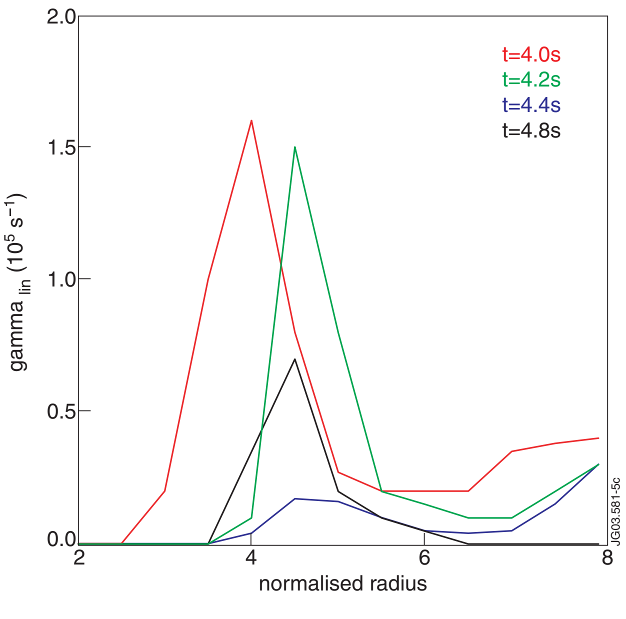

Figure 3: Maximum linear growth rates for the ITG-TEM branch. We observe an early, but not direct stabilization of the turbulence. At the end of the sequence strong ETG turbulence develops (not show here)