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Measurement and qualitative interpretation of the radial scale of turbulence in JET plasmas

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Introduction and Method

Turbulence generally dominates transport in tokamak plasmas [Doyle2007, Conway2008]. It is believed to play a central role in the formation of internal transport barriers (ITBs) and the edge transport barrier through the reduction of anomalous transport by sheared poloidal flow. In JET, there is ongoing work on the influence of rotational shear on ITB dynamics [Crombé2009], and recent studies on the radial electric field indicate that its increase does not necessarily precede the L-H transition [Andrew2008]. The experimental characterization of turbulence in JET is thus necessary to, for instance, complement such flow shear studies and contribute to the understanding of ITB and H-mode physics.

Here, measurements of the radial correlation length of density fluctuations made during different phases of JET plasmas are discussed in relation to *changes* in transport and confinement. Both correlation length L and coherent reflection G are directly calculated from raw radial correlation reflectometry data, which relies on the variation of coherence with the separation between the cutoff positions of two probing microwave beams [Figueiredo2008]. A spectral approach is used to calculate G and provide some sensitivity to variations of $\delta n/n$ without requiring the DC components of the reflectometer signals [Figueiredo2008], which are currently unavailable. Calculations use the magnetic field from reconstructed equilibria and electron density profiles from the high resolution Thomson scattering diagnostic.

Although realistic modelling of correlation reflectometry in JET will be required to obtain the actual turbulence correlation length $L_{\delta n}$ and level $\delta n/n$ from L and G [Kramer2003], it is possible to make a qualitative interpretation of *variations* in L and G based on published simulations [Kramer2003] and on the understanding of the interplay between turbulence level and reflectometer correlation length [Kramer2003, Gusakov2004]. In fact, a variation of L signifies more than just a variation of $L_{\delta n}$. For higher turbulence levels complicated interference patterns arise and the phase of the microwaves becomes increasingly chaotic and poorly localized [Mazzucato1996]. Consequently, coherence is lost between the reflectometry signals from the two probing beams, which leads to lower values of L. Simulations in [Kramer2003] show that if G does not change too much, as in the analyses presented here, to a variation of L corresponds a matching variation of $L_{\delta n}$ and an opposite variation of $\delta n/n$ —

[*]See the Appendix of F. Romanelli et al., Fusion Energy Conference 2008 (Proc. 22nd Int. FEC Geneva, 2008) IAEA, (2008)

unless G is very high, in which case $\delta n/n$ is low and practically unchanging, and the largest variations of L can take place. In the case of ITBs it must also be taken into account that flow shear reduces the turbulence correlation length $L_{\delta n}$ [Connor04] and consequently also L. Since $\delta n/n$ increases from core to edge [Conway2008], for variations in L to be attributed to sheared flow they must be observed at close enough cutoff positions to signify a local variation of $L_{\delta n}$. The possibility of a local variation in $\delta n/n$ producing the same effect on L must also be considered. Moreover, only L variations of the order of 100% will be considered significant. The energy confinement time τ and collisionality ν^* will be used to estimate confinement and collisional transport, respectively. It is expected that an increase in $\delta n/n$ in the core will correspond to an overall degradation of confinement [Durst1993, Conway2008].

Results and Discussion

Figure 1(a) shows that during the early H-mode phase of pulse #78022 (until 51 s) the reflectometer correlation length is $L \approx 1$ cm at $R \approx 3.6$ m, which is relatively low compared with later values. Confinement time does not change significantly with collisionality: τ remains stable as ν^* is growing.

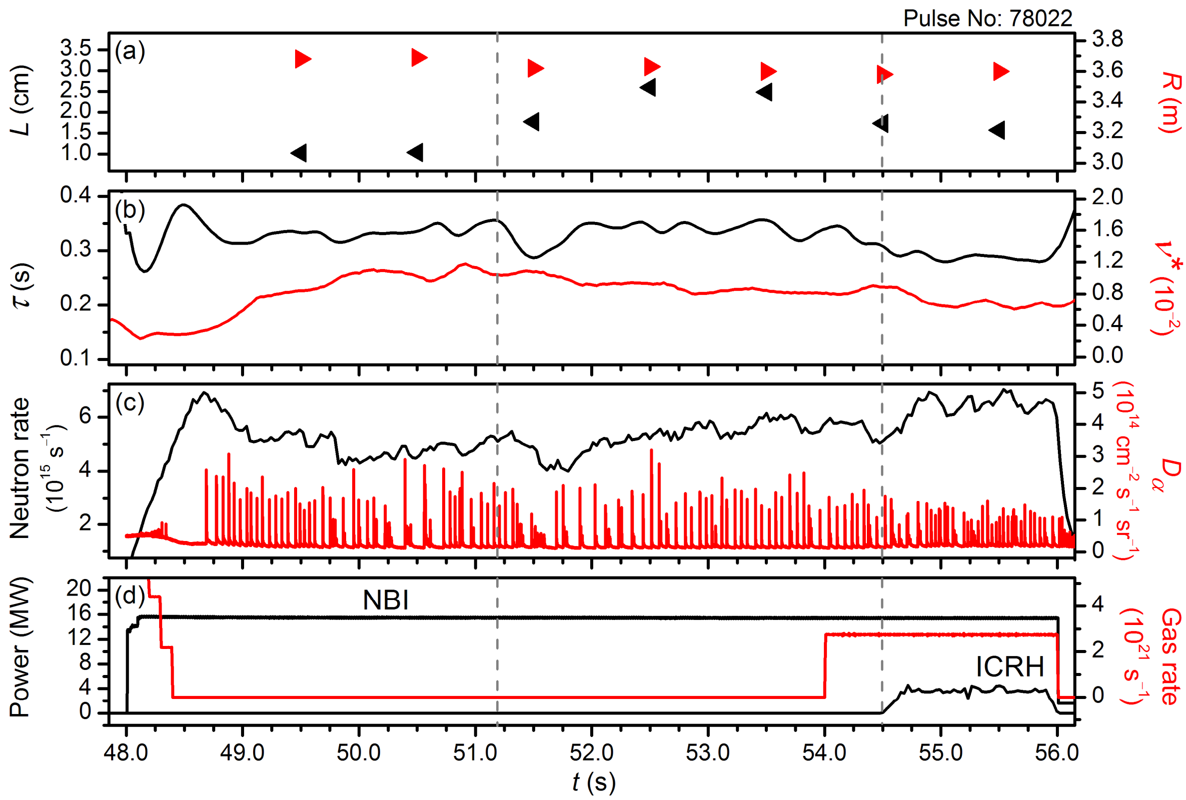

Figure 1. *For JET pulse #78022 (B=2.6 T, I_p=2.5 MA, n_e=6×10^{19} m^{-3}) it is shown (a) the reflectometer correlation length (left) and cutoff position (right), (b) the energy confinement time (left) and collisionality (right), (c) the neutron emission rate (left) and D_α emission (right), and (d) the heating power (left) and gas injection rate (right). The dashed lines mark a decrease of the neutron rate (51.2 s) and ICRH ramp up (54.5 s).*

Around 51.2 s there appears to be a well-correlated drop in the neutron rate and in τ, collisionality seems to start decreasing, and the reflectometer correlation length more than duplicates to $L \approx 2.5$ cm. After gas injection starts at 54 s and as 3.7 MW of ICRH are applied at 54.5 s, the reflectometer correlation length drops to $L \approx 1.5$ cm. A plausible interpretation based on the above discussion is that the turbulence level decreased at around 51 s and increased again around 54 s, which appears to be consistent with the evolution of τ. Confinement time seems to depend mostly on $\delta n/n$ rather than on ν^*.

In pulse #77895 a weak ITB is formed at 44.7 s between $R \approx 3.47$ m and $R \approx 3.58$ m [Tresset2002, deVries2009]. It is seen in Fig. 2(a) that as the ITB terminates at 48.3 s the correlation length inside the ITB foot increases from $L \approx 1$ cm to $L \approx 2.5$ cm, which is consistent with turbulence breakup by $\boldsymbol{E}\times\boldsymbol{B}$ shear [Connor2004, Figueiredo2007, Conway2000]. During the ITB the inboard turbulence level is lower [Conway2001] and by taking into account only the previously described simulations a decrease in L would be expected as $\delta n/n$ rises with ITB termination. Instead, the large *increase* observed in L demonstrates flow shear reduction, as happens also in pulse #77899 (ITB from 44.7 s to 47.2 s between 3.43 m and 3.58 m), with a reduced variation of the cutoff position.

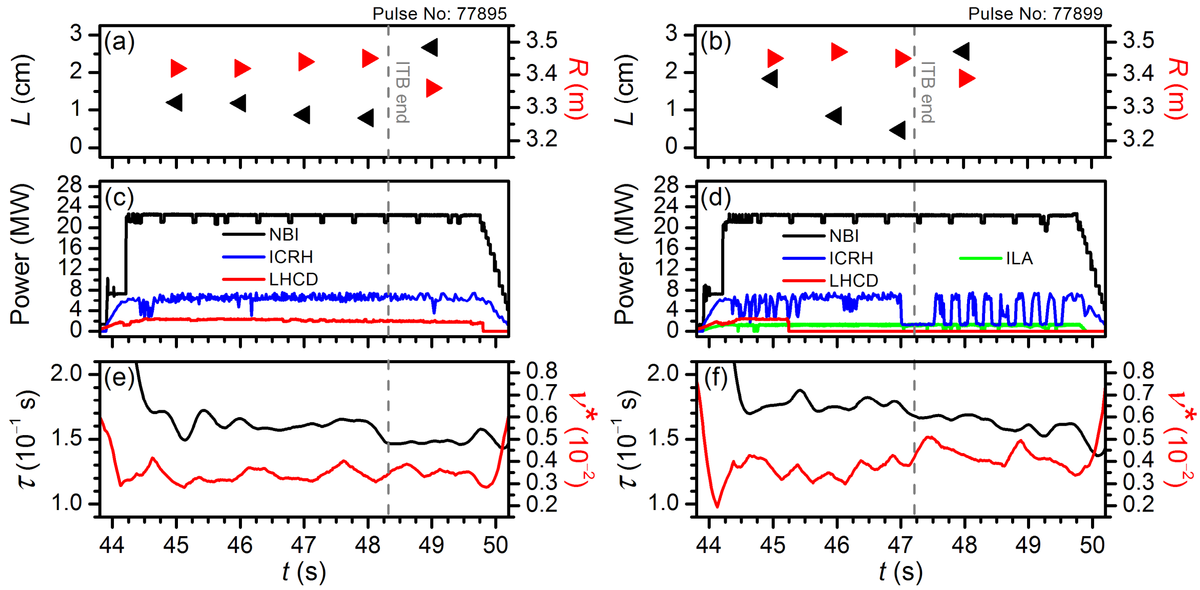

Figure 2. *For JET pulses (a,c,e) #77895 and (b,d,f) #77899 (B=2.7 T,* I_p*=1.8 MA,* $n_e=4\times10^{19}$ m^{-3}*) it is shown (a,b) the reflectometer correlation length (left) and cutoff position (right), (c,d) the heating power, and (e,f) the energy confinement time (left) and collisionality (right). The dashed lines mark ITB termination.*

As seen in Figs. 2(e) and 2(f), the decrease in τ is slower but greater in pulse #77899 for which ICRH power dropped along with ITB termination. This might be due to higher collisionality — which does not change in pulse #77895 —, since turbulence variations look similar for both pulses. Also in pulse #77899 LHCD power is stopped at 45.25 s when spectrogram analysis shows a strong burst of magnetic activity in the range 5–11 kHz and large losses of fast particles are detected by the scintillator probe. At that moment the ITB, which had become slightly stronger just before this event, instantly moves 0.1 m inwards and returns to its previous position in less than 200 ms. The reflectometer correlation length decreases from $L = 1.8$ cm at 45 s to $L = 0.8$ cm at 46 s, indicating that around 45 s (possibly until 45.25 s), the turbulence level was lower in this pulse than in pulse #77895. This significant variation of L is not seen in pulse #77895 for which there is no peaked magnetic activity, fast particle losses are smaller, and $L \approx 1$ cm until the ITB collapses. This difference in behaviour might be related to the extra ICRH from the ITER-like antenna (ILA).

Summary

Despite some existing limitations, it has been possible to perform measurements and a qualitative interpretation of the radial correlation reflectometer results that seems to be consistent with the changes observed in other plasma signals. Correlations have been observed between variations in confinement, measured by the energy confinement time; in the turbulence level — inferred from significant variations of the reflectometer correlation length at nearby radial positions —; and in collisionality. Correlation lengths correctly reflected confinement changes in presence of ITBs.

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References

[Doyle2007] E. J. Doyle *et al.*, Nucl. Fusion **47**, S18 (2007)

[Conway2008] G. D. Conway, Plasma Phys. Control. Fusion **50**, 124026 (2008)

[Crombé2009] K. Crombé *et al.*, “Influence of rotational shear on triggering and sustainment of internal transport barriers on JET”, to be presented at this conference

[Andrew2008] Y. Andrew *et al.*, EPL **83**, 15003 (2008)

[Figueiredo2008] A. C. A. Figueiredo, A. Fonseca, L. Meneses, JET-EFDA Contributors, Rev. Sci. Instrum. **79**, 10F107 (2008)

[Kramer2003] G. J. Kramer, R. Nazikian, and E. Valeo, Rev. Sci. Instrum. **74**, 1421 (2003)

[Gusakov2004] E. Z. Gusakov and A. Yu. Popov, Plasma Phys. Control. Fusion **46**, 1393 (2004)

[Mazzucato1996] E. Mazzucato *et al.*, Phys. Rev. Lett. **77**, 3145 (1996)

[Connor2004] J. W. Connor *et al.*, Nucl. Fusion **44**, R1 (2004)

[Durst1993] R. D. Durst *et al.*, Phys. Rev. Lett. **71**, 3135 (1993)

[Tresset2002] G. Tresset *et al.*, Nucl. Fusion **42**, 520 (2002)

[deVries2009] P. C. de Vries *et al.*, “Identity physics experiment on internal transport barriers in JT-60U and JET”, to be presented at this conference

[Figueiredo2007] A. C. A. Figueiredo *et al.*, 34th EPS Conference on Plasma Physics, Warsaw, Poland, 2007, ECA Vol. 31F, 2.149

[Conway2000] G. D. Conway *et al.*, Phys. Rev. Lett. **84**, 1463 (2000)

[Conway2001] G. D. Conway *et al.*, 28th EPS Conference on Contr. Fusion and Plasma Phys., Funchal, Portugal, 2001, ECA Vol. 25A, 545