Similar advanced tokamak experiments in JET and ASDEX-Upgrade

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1. Introduction

For the extrapolation to future large fusion devices, similar scenarios on different size tokamaks are essential to investigate the formation process, power threshold and steady state prospects of plasmas with Internal Transport Barriers (ITB). In the 2000 JET campaigns, dedicated experiments have attempted to reproduce the ASDEX- Upgrade stationary advanced scenario [1].

In addition to extending the domain of existence of ITBs in JET to the q=1 integer surface, the experimental similarities between ASDEX Upgrade and JET suggest that these advanced regimes may have the same underlying physics.

2. JET q=1 ITB scenario.

Experiments performed in ASDEX-upgrade (a=0.5; R=1.65) have achieved stationary regimes with high performance ($H_{ITER89-P}$=3.0; β_N=2.4; Ti(0)=10keV; T_e(0)=5keV) and q(0) in the vicinity of 1 [1]. This regime is accompanied by n=1, m=1 fishbone activity and an improved confinement, which at constant heating power becomes noticeable as a peaking of electron and ion temperature and density profiles, and is correlated with an increase of the neutron rate.

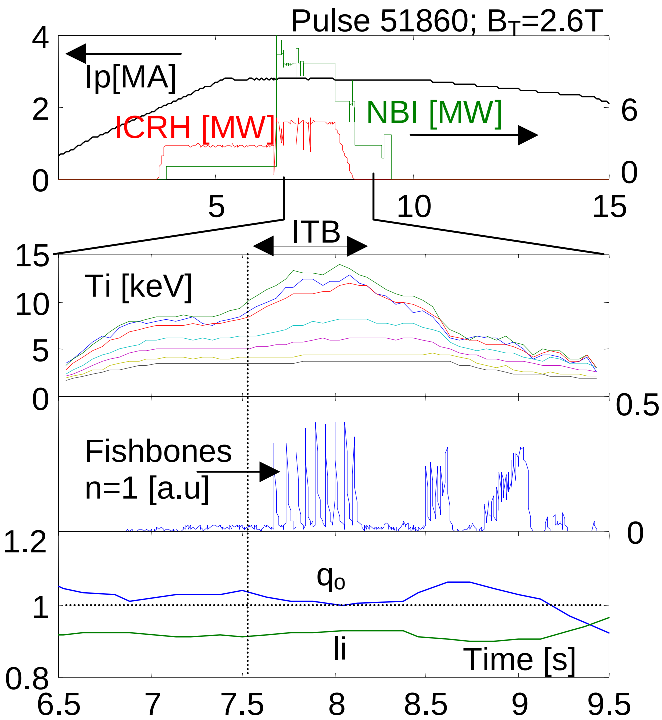


Figure 1. Typical q=1 ITB scenario in JET as oobserved on the ion temperature traces.

In JET (a=0.95; R=2.96), this regime has been reproduced and shows similar features tho those observed in ASDEX-Upgrade (fig 1). As qo reaches 1, n=1, m=1 fishbone activity is also triggered. In this phase the q profile evolution is consistent with the presence of a reconnection-like process. Simulations of the current diffusion with the JETTO code without a reconnection mechanism show a continuous drop of central q value. Reconnection is therefore necessary to explain that qo stays close to for more than 1 second, like the ASDEX-Upgrade scenario [1].

In comparison to the ASDEX-Upgrade scenario, the performance of the JET regime are rather modest ($H_{ITER89-P}$=2.0 and

β_N=1.4). However, in JET an ITB is formed in the main heating phase at 7.5s prior to the first fishbone (fig 1). During the ITB phase Ti(0) reaches 15keV and Te(0) 10keV for an average density (n_e=2.5 $10^{19}m^{-3}$) lower than in the ASDEX-Upgrade scenario (n_e=4.$10^{19}m^{-3}$). The ITB triggering appears to be correlated with the presence of the q=1 surface (r/a=0.35) as observed on ECE and soft X-ray measurements. This new experiment is a further indication that the role of integer q surfaces in the ITB triggering unveiled in previous works [2,3] is not limited to the q=2 or q=3 surfaces. This suggests that the role of integer q surfaces in the ITB triggering physics in JET is quite general.

3. Transport analysis and ITB identification.

To confirm the presence of a core transport barrier, a TRANSP analysis has been carried out for pulse 51860 using the equilibrium data from the EFIT code combined with Motional Stark Effect diagnostic (MSE). The ion temperature data were provided by the charge-exchange recombination spectrometer and electron temperature data from Thomson scattering. As illustrated (fig 2), the ion diffusion coefficient is strongly reduced when the barrier forms and gets near to its neo-classical value in the plasma core in a phase where the heat flux does not change significantly (from 6.5 to 8s).

The presence of the ITB in JET is also confirmed by the ITB quantitative criterion characterised by the parameter $\rho^*_T = \rho_s / L_T$ [4] (fig 3). This criterion compares the typical drift wave (such as ion temperature gradient instability: ITG [6]) scale length ρ_s with the local temperature gradient length L_T. When this quantity exceeds a threshold value of 0.014 in JET, the analysis shows that ITBs are formed, possibly as the result of the stabilisation of ITG by ExB rotational flow and magnetic shear effects.

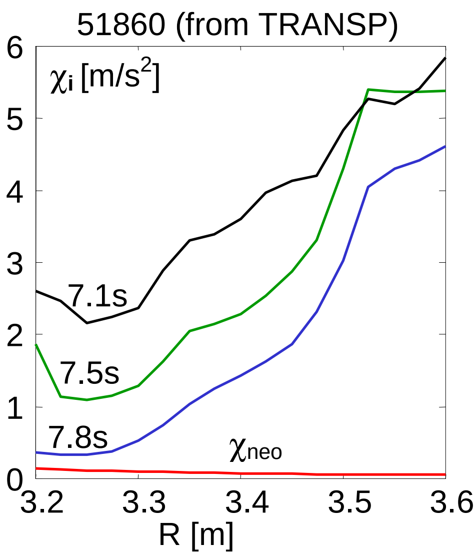


Figure 2. Evolution of the ion diffusivity profiles from TRANSP.

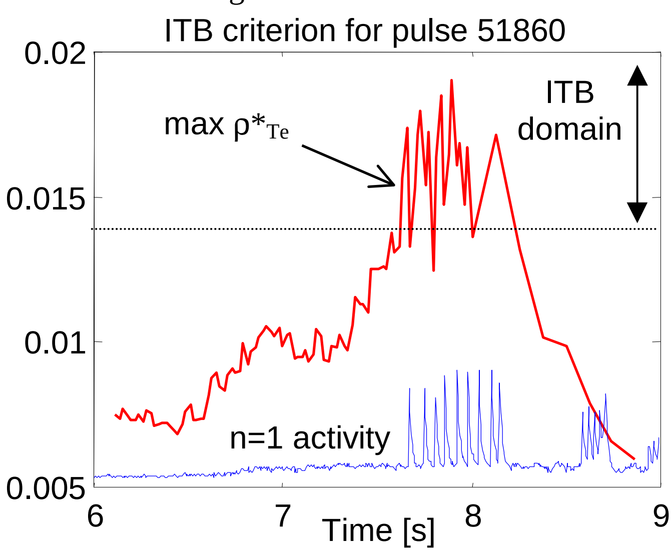


Figure 3. Time evolution of the maximum value of ITB criterion for electrons ρ^*_{Te} = ρ_s / L_{Te}. The fishbone n=1 activity is also shown.

In ASDEX-Upgrade, the temperature profiles of improved confinement H-mode are observed to be stiff [5] (i.e. one can scale the profiles at any time with a single multiplication factor). The profile stiffness is in qualitative agreement with the ion temperature gradient instability (ITG) models. For flat (or almost flat) density profiles the criterion for the ITG instability is reduced to a critical ion temperature gradient length (L_{Ti}). When this critical gradient is exceeded the profile clamps to the critical gradient length. For this to occur, R/L_{Ti} should be larger than 5 to 6. This feature has been used to identify the presence of ITB in the reversed shear scenario in ASDEX-Upgrade [6]. Indeed, in presence of strong ExB shearing rate the ITG turbulence could be stabilised and the ion temperature profile stiffness can be broken.

In the case of the ASDEX Upgrade q=1 improved confinement H-mode, the ion temperature has not been found to deviate significantly from the profile stiffness on the Ti(0) versus Ti(r/a=0.8) diagram. The same analysis has been made for JET using a large database of ELMy and Hot-Ion H-modes (fig 4). The data are showing a stiffness "trend" except at high temperature. The critical value of R/L_{Ti}=5.5 for JET is consistent with both the expected linear kinetic threshold for ITG [6] and the value of ASDEX-Upgrade (R/L_{Ti}=6.5) given its larger aspect ratio (3.3 for AUG and 2.9 for JET). On the diagram of figure 4, the time trajectories of two JET ITBs are also super-imposed. Discharge 51573 is a typical reversed shear ITB case with Lower Hybrid preheat [8] (B_T=2.6T;Ip=2.3MA;P_{IN}=15MW) associated with the q=2 surface. It is clearly drifting away from the observed profile stiffness trend. The JET q=1 ITB scenario (see figure 1) is also showing a bifurcation behaviour from the stiffness trend which confirms again that an ITB is formed for this type of scenario.

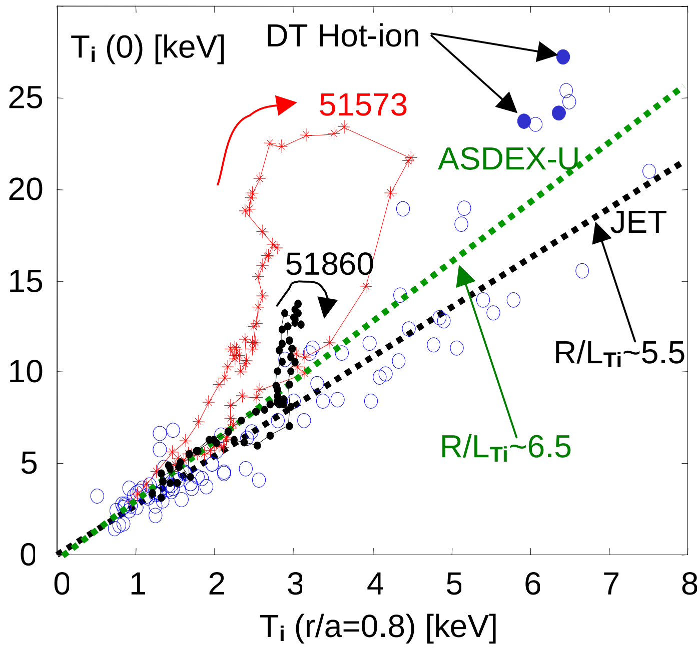


Figure 4. Ti(0) versus Ti(r/a=0.8) diagram for JET using ELMy and Hot-Ion H-mode data. A profile stiffness "trend" is observed on JET except at high temperature and for DT pulses. q=1 ITBs (pulse 51860) and q=2 ITBs (pulse 51573) are breaking the profile stiffness.

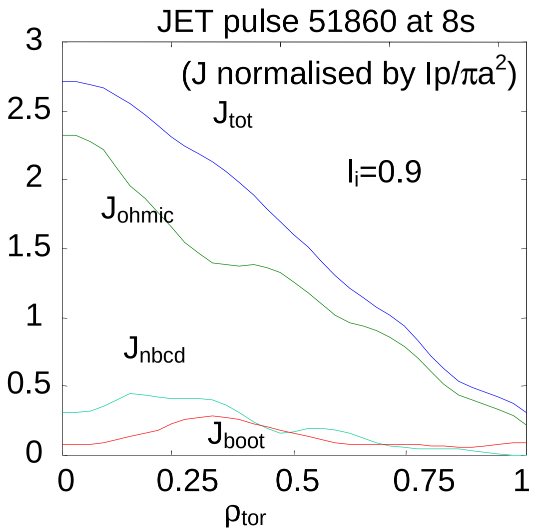
Using this type of comparative analysis, the physics understanding of ITB formation could benefit greatly of common experiments performed on two different size devices.

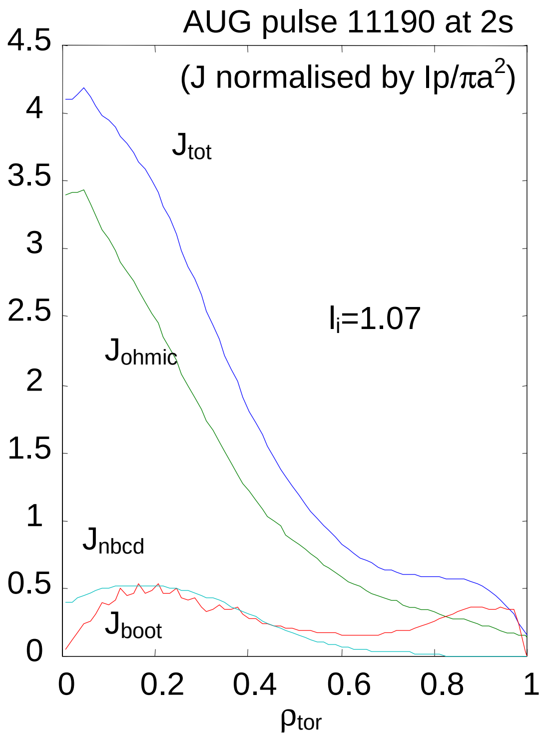
4. JET – ASDEX-Upgrade differences for ITB similar experiments.

From the TRANSP analysis, the non-inductive current contributions to the total current in JET are also compared with the equivalent analysis done by ASTRA in ASDEX-Upgrade in figure 5a and 5b. Although the q profile on both devices are close to 1 in the plasma core and at the edge (q_{95}=4.0 for ASDEX-Upgrade and 3.2 for JET), the ASDEX-Upgrade current density profile is clearly more peaked than the JET profile. This is also supported by the difference of internal inductance (0.9 for JET and 1.1 for AUG). This difference is most likely due to the difference in resistive skin time on the two machines due to their different plasma radius.

Since the current profile is recognised as one of the most important plasma parameter to produce ITBs, to get closer to actual ITB identity experiments on both machines, it is necessary to match the target q profiles (q_o, q_{min} and q_{95}) and the plasma configuration. This task is complicated by the different resistive skin times and

Figure 5a and 5b. Comparison of the current diffusion analysis from TRANSP (for JET; P_{NBI}=10MW) and ASTRA (for ASDEX-Upgrade P_{NBI}=5MW) for the q=1 scenario.





operational constraints. The q profile build-up depends strongly on the available heating schemes as well. Electron Cyclotron heating in ASDEX-Upgrade or Lower Hybrid in JET can play a key role in pre-forming the target q profile [8]. The neutral beams are also playing a key role in ITB production through the applied torque and particle fuelling. Their technical characteristics (orientation, power and energy) are therefore essential to achieve the similar ExB shearing and fuelling rate on both devices.

Identity experiments matching the normalised Larmor radius ρ* appear also possible provided that JET operates at low toroidal field (typically 1.7T) and ASDEX-Upgrade at 3.0T. However, this implies for JET a higher sensitivity to the ELM activity [9] which could affect the ITB existence.

5. Conclusions

JET and AUG common q=1 advanced scenario on JET and AUG are showing similar features (current profile behaviour around q=1, fishbone activity etc). In JET, a q=1 ITB has been produced and shows the same features as ITBs related to other integer q like q=2 and q=3 achieved in JET. On the basis of this q=1 scenario, and given their characteristics, JET and AUG do have the potential to study a large spectrum of identical current density profiles and configurations for overlapping range of ρ* to perform real identity ITB experiments.

6. References

[1]: R. C. Wolf et al., Plasma Phys. Control. Fusion **41** (1999) B93-B107.
[2]: C.D. Challis et al., in Control. Fusion and Plasma Physics (Proc. 26th European Conf. Maastricht, 1999), Vol. 23J, EPS, Geneva (1999) 69.
[3]: E. Joffrin et al., 'MHD Internal Transport Barrier triggering in low positive magnetic shear scenario in JET', submitted to Nuclear Fusion.
[4]: G. Tresset et al., EFDA-JET Report JET-EFDA-PR(00)09, submitted to Phys. Rev. Lett.
[5]: A.G. Peeters et al., 18th IAEA Fusion Energy Conf., Sorrento (2000) IAEA-CN-77- EXP5/06
[6]: R.E. Waltz et al., Phys. Plasma **4** (1997) 2482.
[7]: R.C. Wolf, S. Guenter et al., Phys. Plasma 7 (2000) 1839-1844 ; R.C. Wolf et al., this conference.
[8]: J. Mailloux et al., this conference.
[9]: M. Becoulet et al., this conference.