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Dimensionally Similar Studies of Confinement and H-mode Transition in ASDEX Upgrade and JET

F. Ryter, J. Stober, W. Suttrop, J. C. Fuchs, O. Gruber, H. Meister, H. D. Murmann, S. de Peña Hempel, H. Salzmann, J. Schweinzer and the ASDEX Upgrade Team

Max-Planck-Institut für Plasmaphysik, EURATOM-IPP Association, Garching and Berlin, Germany

J.P. Christiansen, G. Huysmans, P. Lomas, C. Lowry, B. Schunke, B. Tubbing and JET Team

JET Joint undertaking, Abingdon, OX 14 3EA England

Abstract

Joint experiments on confinement and L-H transition were performed in ASDEX Upgrade and JET. The confinement experiments suggest that the invariance principle is not always fulfilled at high density. For the L-H transition studies, the dimensionless variables taken at the plasma edge can be in general only made identical per pair, due to the condition imposed by the L-H transition. This new approach to investigate the L-H physics suggests a weak dependence of the L-H transition mechanism on collisionality.

1. INTRODUCTION

The H-Mode transition and confinement are key issues for future fusion devices. Comparisons between tokamaks are expected to bring insight into the physics mechanisms and to finally allow a reliable extrapolation to fusion reactors. A possible physical way to address this problem is to compare experiments performed in devices in which dimensionless parameters are made equal [1,2]. The experiments presented here are part of a collaboration between JET and Alcator C-Mod, ASDEX Upgrade and DIII-D, reported in a companion paper [3]. This dimensionally similar approach has already been applied to confinement studies, for instance in JET and DIII-D [4,5]. The experiments carried out between ASDEX Upgrade and JET, address not only confinement but also the L-H transition. A new approach had to be developed for the L-H transition case because it introduces an additional condition, as discussed in section 3.

2. IDENTITY CONFINEMENT EXPERIMENTS

In the "confinement identity experiments" the usual dimensionless variables $(\rho*, \nu*, \beta, q)$ as well as plasma geometry must be the same in the two devices. Phenomena occurring on the Debye length or related to atomic physics are assumed to be negligible. In addition the heating power deposition profiles must be similar. The identity of the dimensionless variables determines the size scaling (a = minor radius) of the controllable parameters, [1,2,5]: $B_T \sim a^{-5/4}$, $I_p \sim a^{-1/4}$, $\bar{n}_e \sim a^{-2}$, $P_{tot} \sim a^{-3/4}$, $T \sim a^{-1/2}$, leading to $B_T \times \tau_{th} = const.$ If energy transport is determined by plasma physics only, heat conductivity χ must scale as $a^{+3/4}$ between the two devices under such conditions. A important consequence of the above scaling is that JET must be operated at the lower boundary of its parameter range ($B_T = 1.1$T, $I_P = 1$ MA) whereas ASDEX Upgrade (AUG) was run close to its higher values($B_T = 2.3$ T, $I_P = 1.2$ MA).
A set of pulses has been performed initially in JET in which the plasma shape of ASDEX Upgrade

has been matched. It includes low density ($\bar{n}_{e,AUG} \approx 7 \times 10^{19} m^{-3}$, $\bar{n}_{e,JET} \approx 2.2 \times 10^{19} m^{-3}$) and high density cases ($\bar{n}_{e,AUG} \approx 10 \times 10^{19} m^{-3}$, $\bar{n}_{e,JET} \approx 3.3 \times 10^{19} m^{-3}$), at $q_{95} \approx 3$.

For the low density case, a good match of the global parameters and of the scaled profiles ($n_e a^2$, $T_e a^{1/2}$ and $T_i a^{1/2}$), as well as their gradient lengths, could be achieved by adjusting density and heating power in AUG (shot pair: AUG 11229, JET 43868). This results in a good profile agreement of the dimensionless parameters in the core ($\rho_{tor} \leq 0.75$), shown in Fig. 1.

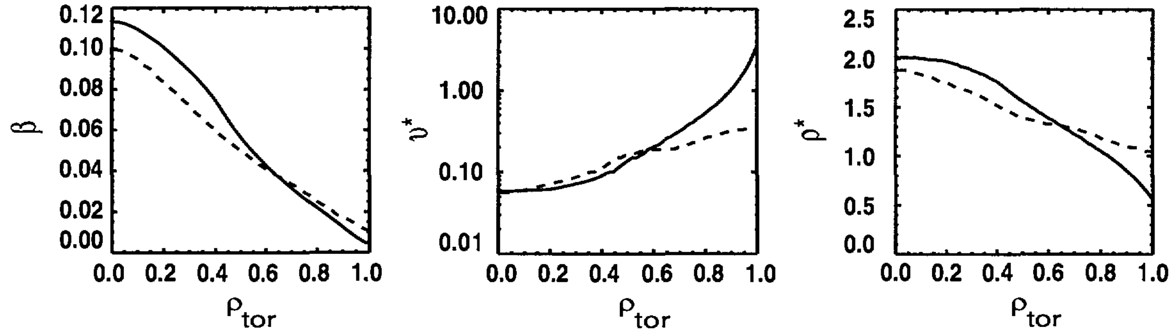

Figure 1: *Radial profile of $\rho*$, $\nu*$, and β for electrons in AUG (solid) and JET (dashed).*

For the pair 11229/43868, the $B_T \times \tau_{th}$ values agree within the uncertainties: 0.27 for AUG, 0.28 for JET. This is in agreement with the expectation from the invariance principle for the global analysis. However, the transport analysis of this matched pair reveals that the power deposition profiles in the 2 devices differ significantly: it is more peaked in JET than in AUG because the NBI acceleration voltage was not scaled. This leads to a difference in heat fluxes of about a factor of 2 between the two devices at mid-radius. The scaled profiles being well matched, transport analysis indicates that the scaled values of χ differ by about a factor of 2 at mid radius. The fact that the heat deposition profiles are not matched well enough does not allow to apply the invariance principle. It must be stressed, however, that the excellent profile agreement achieved under such conditions suggests that the reaction of profiles to changes in heat flux is much weaker than one would expect from a diffusive transport model.

The high density case was proposed to investigate the confinement degradation at high density. In this case the NBI heating deposition is strongly off-axis in AUG, whereas that of JET remained peaked. This effect was partly counterbalanced by providing a fraction of the required power with ICRH, yielding heat fluxes similar to that of the low density case. Three JET pulses at constant density with different heating power are available for the comparison and time slices from 15 AUG shots with different heating power at similar densities.

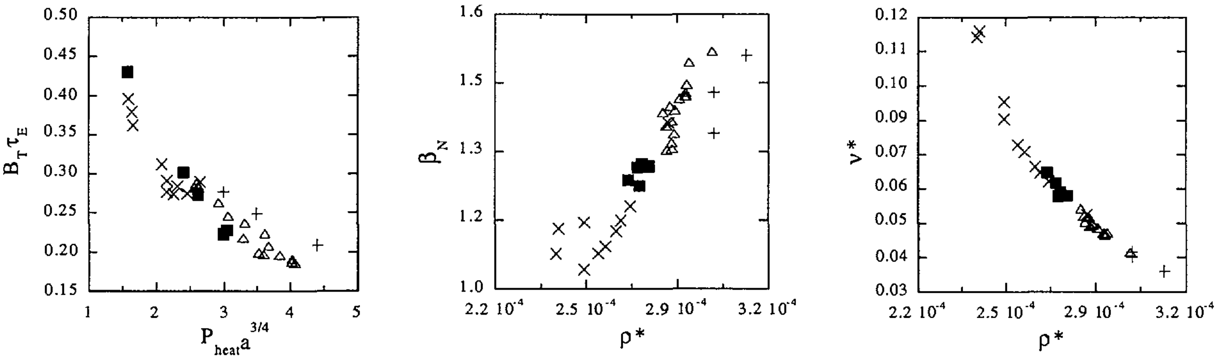

Figure 2: *High density dataset: normalised confinement versus scaled power(a); dimensionless parameters (b, c). + for JET, others for AUG (see text)*

The results are summarised in figures 2 a-c in which 3 classes of AUG points are presented: triangles $B_T \times \tau_{th}$ close to JET values, crosses far from JET values and squares spread over a large range of $B_T \times \tau_{th}$. Figure 2.a reflects the power degradation for both devices and also indicates that $B_T \times \tau_{th}$ is systematically higher in JET. This can be attributed to the effect of heating power mentioned above and/or to the somewhat higher triangularity in JET. The triangles have similar $\nu*, \rho*, \beta$ as in JET, whereas the crosses do not, as expected. Surprisingly the squares exhibit quite different $B_T \times \tau_{th}$ values but similar $\nu*, \rho*, \beta$. They demonstrate that $\nu*, \rho*, \beta$ and plasma energy can be identical at the same density for quite different heating powers, in contrast to the usual monotone increase of plasma energy with heating power (triangles and crosses). We verified that the squares also have very similar density and temperature profiles. They are taken from phases in the discharges during which the density can be kept at the required high value, but with less gas puffing. As gas puffing is experimentally observed to cause confinement degradation, less gas puffing allows for higher confinement. This effect can occur when heating power is reduced after a high density/high power phase. Following the reduction of heating power the ELM frequency decreases and less gas puffing is required to maintain the density. Thus, after an initial decrease caused by the reduction of the heating power, plasma energy increases in relation with the reduced gas puffing. This evolution can reaches a quasi-stationary state. Finally the same density and plasma energy are reached than previously but with weaker particle fuelling and at lower power. This behaviour only appears in the high density shots, little gas puffing being required at low density. It is so far not clear whether such a phenomenon can be observed in JET.

This observation sheds new light on transport and identity experiments at high density: the relation between transport degradation and power can be broken and transport can be different for the same local values of $\nu*, \rho*, \beta$. This suggests several interpretations: i) a strong variation of transport for very small variation of at least one on the parameters $\nu*, \rho*, \beta$, in this region of operational space; ii) the evolution described above reflects a change of plasma state for identical $\rho*$, $\nu*$ and β; iii) edge particle balance has a strong influence on transport. An additional parameter is perhaps required to characterise the plasma and determine the corresponding pairs in the two devices. These high density experiments also provide examples of very similar temperature profiles obtained with quite different heating profiles, observation known as profile resilience and widely observed in the tokamaks. This also implies that for very similar local values of $\nu*, \rho*$ and β heat diffusivity can be different.

3. DIMENSIONNALY SIMILAR L-H TRANSITION EXPERIMENTS

Experiments in which dimensionless variables at the plasma edge are equal may contribute to a better understanding of L-H physics. The situation is different from confinement studies because data are taken at the time of the L-H transition, introducing an additional condition: the heating power is not free. More details on this work are to be found in [6]. It was experimentally observed that the edge temperature has a critical value at the L-H transition [7,8]. Therefore it is in general not possible to make $\rho*, \nu*$ and β respectively equal in two devices at the L-H transition but only one of the 3 possible pairs $(\rho*, \nu*)$, $(\beta, \nu*)$ or $(\rho*, \beta)$. The required scaling of the global parameters has been calculated using the experimental knowledge about the critical temperature [7,8], yielding the following scaling for the edge data: $(\beta, \nu*)$ matching: $B_T \propto a^{-1/2}$ $T^{3/2}$, $\bar{n}_e \propto a\ T^2$; $(\beta, \rho*)$ matching: $B_T \propto a^{-1}$ $T^{1/2}$, $\bar{n}_e \propto a^2$; $(\rho*, \nu*)$ matching: $B_T \propto a^{-1}$ $T^{1/2}$, $\bar{n}_e \propto a^{-1}$ T^2.

Thirteen pulses have been first done in JET followed by 22 in ASDEX Upgrade in an iterative way to match the edge parameters by varying density. In these discharges the heating power was slowly increased across the L-H transition. The measurements allow only the comparison of electron parameters, but in ASDEX Upgrade analyses of available ion temperatures indicate that the results are qualitatively valid for ions too. The dataset shown in Fig. 3 provides a variation of $\rho*$, $\nu*$, β and scaled temperature $T_e a^{1/2}$, at 95% of the poloidal flux, for $q_{95} \approx 3$ and $q_{95} \approx 4$. The range in $\rho*$ is moderate within each q_{95} value but $\nu*$ and β vary by ≈ 3.

In Fig. 3 different symbols indicate matched pairs of shots. For the circles the 3 dimensionless parameters are quite similar which is a particular situation for the L-H transition as explained above. In this case, the scaled electron temperatures are similar as well. The heating powers at the L-H transition in this case scale as $a^{-1/3}$, somewhat weaker than $a^{-3/4}$ (previous section) but in clear disagreement with a^{+1} required for divertor similarity in which the identity

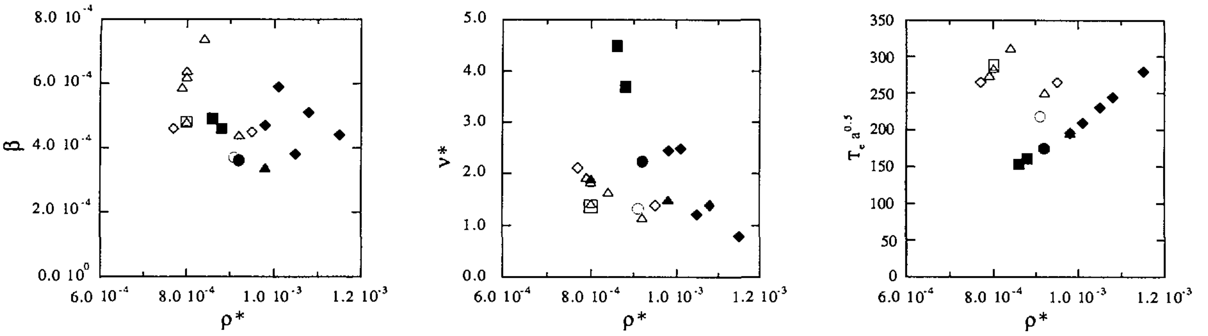

Figure 3: *Edge data at L-H transition: closed symbols for AUG, open for JET; circles good match and squares no match of $\nu*$ (see text), triangles $q_{95} \approx 3$, diamonds $q_{95} \approx 4$*

in β is replaced by that in temperature [9]. Squares highlight matched $(\beta, \rho*)$ which differ in $\nu*$ by a factor of ≈ 3 and in scaled temperature by ≈ 2. The complete analysis of the dataset shows that β and $\rho*$ can be matched simultaneously within the experimental errors, dominated by the uncertainty on edge temperature ($\approx$ 10%), while $\nu*$ varies in one machine by 50% or more. We conclude that $\rho*$ and β are critical parameters for the L-H transition physics which however depends weakly on $\nu*$, as observed previously in ASDEX Upgrade [7]. The variation of q_{95} yields similar $\rho*$ and β values, indicating a weak q_{95} dependence of the L-H threshold. Finally, in a plasma shape variation in JET the L-H transition occurred at the same values of the dimensionless parameters.

4. CONCLUSION

The common work between JET and ASDEX Upgrade shows that "dimensionless similarity experiments" are quite fruitful in investigating both confinement and L-H transition physics. The imperfections on plasma shape and heat profiles of this first set of discharges should be minimised in future campaigns. In-vessel modifications in ASDEX Upgrade will allow higher triangularity, which is expected to change the situation at high density in particular. The increase of the beam acceleration in ASDEX Upgrade from 60 kV to 100 kV and operation of the NBI in JET at lower voltage should allow a better match of the heat profiles. The reaction of confinement to power changes at high density in both devices should be compared in "behaviour similarity experiments". The results of the new approach to study the L-H transition with dimensionless parameters at the plasma edge, which suggest that the Kadomtsev constraints are valid in this case, should be pursued and the extension to other devices is highly recommended.

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References

[1] CONNOR, J. W. et al., Nucl. Fusion **17** (1977) 1047.

[2] LACKNER, K., Comments Plasma Phys. Controlled Fusion **13** (1990) 163.

[3] CHRISTIANSEN, J. et al., this conf. paper EXP2/02 (R) .

[4] PETTY, C. C. et al., Phys. Plasmas **2** (1995) 2342.

[5] CORDEY, J. et al., Plasma Phys. Controlled Fusion **38** (1996) A67 .

[6] SUTTROP, W. et al., *H-Mode Threshold Edge Parameter Similarity Discharges in JET and ASDEX Upgrade*, Proc. of 25th EPS Conf. Contr. Fus. Plasma Phys., Prague, 1998, to be published .

[7] SUTTROP, W. et al., Plasma Phys. Controlled Fusion **39** (1997) 2051 .

[8] RIGHI, E. et al., Plasma Phys. Controlled Fusion **40** (1998) 721 .

[9] LACKNER, K., Comments Plasma Phys. Controlled Fusion **15** (1994) 359.