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E. Asp, J. Weiland, X. Garbet, P. Mantica, V. Parail, W. Suttrop
and JET EFDA Contributors

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E. Asp[1], J. Weiland[2], X. Garbet[3], P. Mantica[4], V. Parail[5], W. Suttrop[6]
and JET EFDA Contributors

[1]Dept. of Astronomy and Space Physics, Uppsala University, Sweden (EURATOM-VR)
[2]Dept. of Electromagnetics, Chalmers University of Technology, Sweden (EURATOM-VR)
[3]Association Euratom-CEA, CEA Cadarache, St Paul-lez-Durance Cedex, France
[4]Istituto di Fisica del Plasma, EURATOM-ENEA-CNR Association, Milan, Italy
[5]Euratom/UKAEA Fusion Association, Culham Science Centre, Abingdon, OXON, UK
[6]Max-Plank-Institut für Plasmaphysik, IPP-EURATOM association, Garching, Germany
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INTRODUCTION

In typical JET shots the NBI heating leads to a plasma with the ion temperature (T_i) equal or higher than the electron temperature (T_e). With the prospect of ignited plasmas an interest of hot-electron scenarios has emerged, since the a-particles created as a by-product of the fusion reaction mainly heats the electrons. A better understanding of the transport properties for $T_e>T_i$ is thus needed. The plasma response to different heating schemes is also related to the stiffness of the plasma. A stiff plasma exhibits a critical steepness of its temperature profiles and whenever the applied heating tries to push the temperature profiles beyond this critical value, the plasma responds by amplifying the heat diffusivities. As a consequence the profiles remain unchanged. From a theoretical view point, the Weiland model predicts that this critical steepness and the magnitude of the diffusivities depend on the temperature ratio T_e/T_i. To validate this claim and gain an improved knowledge of plasma transport properties it is important to further clarify the plasma response to increasing heating, ion or electron.

1. CONFINEMENT TIME STUDY

A series of shots at JET dedicated to the issue of dominant electron heating [1], was analysed to better comprehend how the temperature ratio, Te/Ti influences the plasma confinement. Simulations performed with JETTO utilising the Weiland model, seems, at first glance, to point towards little or no dependence on Te/Ti (see Fig.1). The energy confinement times in Fig.1 have been normalised with respect to total heating power and plasma density in order to eliminate dependencies which are not temperature relevant. In the experiments the plasma current was almost constant and thus required no normalisation. Experimental values for the energy confinement time were calculated using the heating power and thermal energy content. The lack of any evident trend of the confinement times in Fig.1 might be due to the short interval of Te/Ti in conjunction with the almost constant applied heating power. Expecting the diffusivities to rise with more heating disregarding the source (see stiffness analysis Figs 3a), c) and e)), may imply that in the current interval of Te/Ti the effects of varying the ion/electron heating fractions cancels out.

2. STIFFNESS ANALYSIS

The stiffness of the Weiland model has been carefully examined through monotonously increasing the applied heating power of the ions or electrons and monitoring the resulting heat fluxes and diffusivities. In these simulations only the temperature of the heated channel and the plasma current were allowed to change and the result was evaluated at a specific radius, in a direct attempt to minimize the influence of all other plasma parameters. Previous studies of stiffness have concluded that the Weiland model is, at the most, moderately stiff [2,3]. To better understand the trend of the generated heat fluxes, we assume that the ions are dominated by the pure ion temperature gradient (ITG) mode and the electrons by the pure trapped electron (TE) mode. From the uncoupled ion an electron fluid equations we may then extract the following temperature dependencies of the growth rates. Hence for the ITG mode,

$$\gamma_i \sim \sqrt{T_e T_i\,(\eta_i \sim \eta_{i,th})}, \text{ where } \eta_i = \frac{L_n^{-1}}{L_{Ti}},\ L_n = \frac{1}{n}\frac{dn}{dr},\ L_{Ti}^{-1} = -\frac{1}{T_i}\frac{dT_i}{dr} \text{ and } \eta_{ith} = \frac{2}{3} + \frac{10}{9T_i/T_i}\,\varepsilon_n.$$

The TE mode, which does not depend on the ion temperature, yields

$$\gamma_i \sim \sqrt{T_e T_i\,(\eta_i \sim \eta_{i,th})}, \text{ where } \eta_{eth}\,(T_e) = \text{const.}$$

In the following analysis we examine the response to increasing heating in JETTO simulations of JET Pulse No: 50628. By increasing the applied power in multiples of the experimental profiles, in either the ion or the electron channel, the stiffness of the plasma was evaluated. The total input powers at the experimental level are about 7 and 5.5MW for the ions and electrons, respectively. In the simulations we let the ion heating to increase up to 98MW and the electron heating up to 66MW. As we keep the temperature of the unheated channel fixed, some of this heating is lost through resistive equilibration. The effective heating is thus somewhat less than the figures above. The experimental power profiles have a marked peak at mid radius and hence we choose to study the response at $\rho = 0.41$ and $\rho = 0.61$.

To get an overview of the stiffness and Te/Ti dependence of the confinement we plot in Fig.3 the diffusivities and heat fluxes arising in Fig.2. The heat fluxes in Fig.3d) and f) show indications of stiffness. As expected, we can see from Figures 3a), c) and e) that the diffusivities grow with more applied power (increased ion power reduces Te/Ti), but in 3a) we get close enough to the ITG threshold to obtain a suppressing effect for small Te/Ti. The difference in response of the electrons to the ion heating and vice versa, has its origin in the asymmetry of the ITG and TE modes, see equations on the previous page. For the ITG mode we see that it depends on both Te and Ti whereas the TE mode depends only on Te. So, when Te rises it simultaneously drives both the ion and electron diffusivities (Fig.3e)), while higher Ti only affects the pure ITG mode (Fig.3a) and c)). Hence, the increase of the electron diffusivity in Fig.3c) is most likely due to a weak coupling of the ITG and TE modes which introduces a Te/Ti dependence into the TE mode.

To get a better grasp of the influences on the growth rates of the ITG and TE modes shown in the previous page, we summarise the parametric dependencies in Tables A and B. As we can see from the Table A, for the ion heating at $\rho = 0.41$, the higher ITG threshold for rising Ti have a suppressing effect on the ITG growth rate. The steeper Ti profiles can not fully counteract this as it does at $\rho = 0.61$. For the electron heating in Table B, the higher Te with steeper profiles enhances both the ITG and TE growth rates. The stiffer than expected response in Figures 3d) and e) might be due to permitting the temperature as well as its gradient to respond to the higher power depositions, in contrast to earlier investigations [2, 3] which made scans of one gradient at the time at fixed temperatures.

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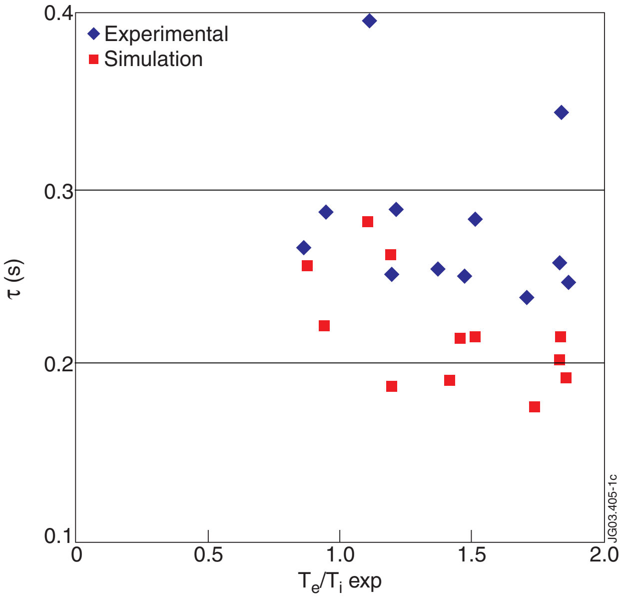

Figure 1: A comparison of simulated and experimental confinement times, normalised with respect to density and applied power, plotted against the experimental temperature ratio. Values at the same Te/Ti correspond to the same shot.

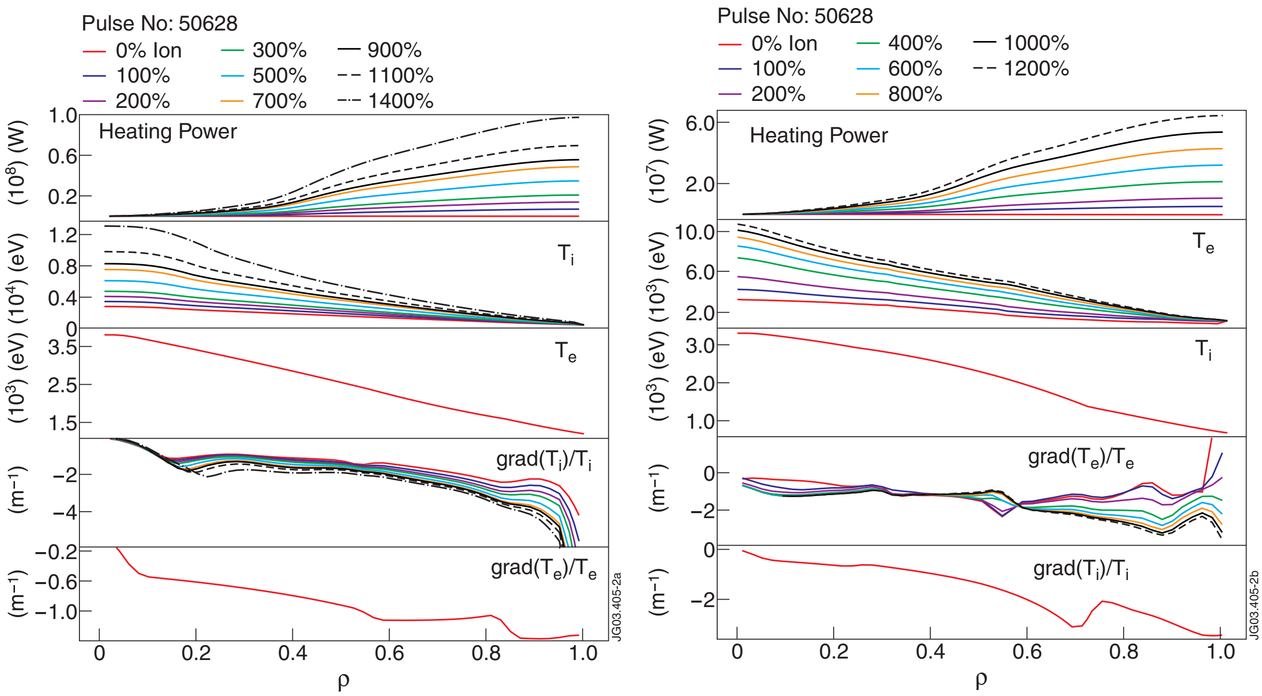

Figure 2: Profile changes of Pulse No: 50628 at t = 50s with rising ion heating at constant T_e (left) and electron heating at constant T_i (right). The higher core temperatures w.r.t. the constant edge temperatures are most likely due to the non-stiff gyro-Bohm model used in the edge. For truly stiff plasma the core temperature would not change if the edge temperature was constant.

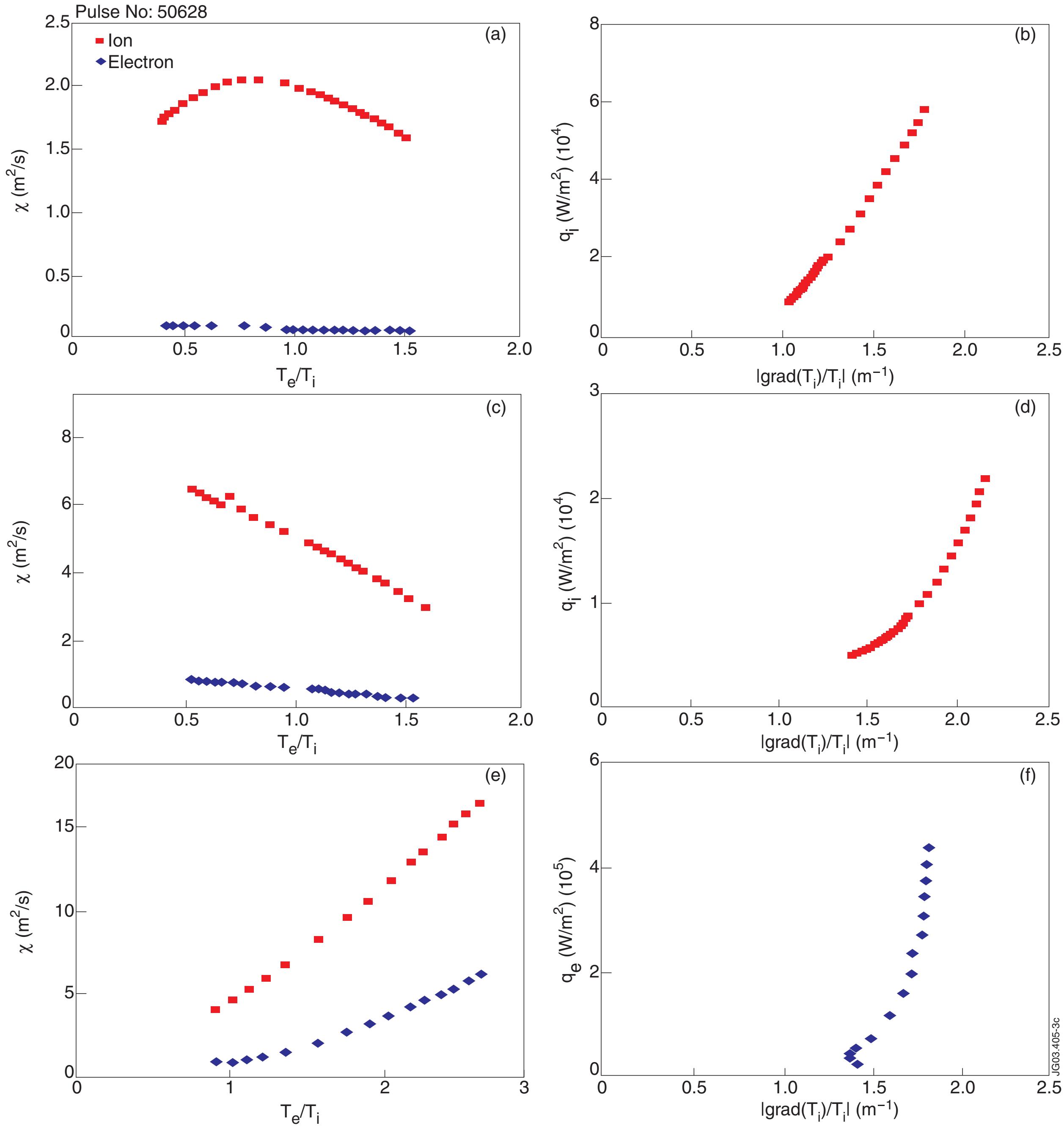

Figure 3: Pulse No: 50628 at t=50s. The effects of increasing ion heating at Te=const is evaluated at r=0.41 in a)-b) and at r=0.61 in c)-d). Influences of the electron heating at Ti=const in e)-f) Note that Te/Ti decreases for increasing ion heating in a) and c).

ρ	Ion Heating	T_i	T_i/T_e	$1/L_{Ti}$	η_i	η_{ith}	$\eta_i - \eta_{ith}$	γ_i
0.41	↗	↗	↗	↗	↗	↗	↘	↗ ↘
0.61	↗	↗	↗	↗	↗	↗	→	↗

Table A: Schematic response of the ITG and TE modes to increasing ion heating in Fig 3a)-d).Two arrows in one box indicates a change in the trend of the parameter in question.

Electron Heating	T_e	T_i/T_e	$1/L_{Te}$	γ_e	η_{ith}	$\eta_i - \eta_{ith}$	γ_i
↗	↗	↘	↗	↗	↘	↗	↗

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Table B: Schematic response of the ITG and TE modes to increasing electron heating in Fig 3e)-f).