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** See annex of F. Romanelli et al, "Overview of JET Results",*
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INTRODUCTION

It is currently assumed that a reliable control technique for Edge Localised Modes (ELMs) is mandatory for the success of ITER. Gaining information about the process of inducing ELMs by pellets and reaching some level of understanding is desirable for the design of next step fusion devices and the preparation of successful operation of those. Experiments at ASDEX Upgrade have shown that deuterium ice pellets when reaching the pedestal top instantly induce ELMs up to frequencies twice the natural ELM frequency [1].

It is widely assumed that the instability associated with spontaneous type-I ELMs has a peeling ballooning character [2]. Pellet injection is done at one fixed toroidal position both in JET and ASDEX Upgrade. This raises the question, if the spatial structure of the perturbation associated with pellet induced ELMs features a corresponding asymmetry. In this work we show experimental evidence of a signicant asymmetry of the Scrape Of Layer (SOL) heat transport in presence of pellet induced ELMs and its absence (in line with [3, 4]) for spontaneous ELMs. We further link these results to recent simulations from JOREK indicating that pellet induced ELMs retain this externally forced structure peaking in toroidal direction around one location [5].

1. EXPERIMENTAL RESULTS AND ANALYSIS BY FIELD LINE TRACING

Divertor InfraRed tomography (IR) in combination with magnetic field line tracing has previously been employed to investigate the filamentary structure of spontaneous ELMs [4]. We apply this method in conjunction with a ramp of the toroidal magnetic field in order to manipulate the position of the divertor imprint of a (transiently) toroidally localised lament. An optimised JET H-mode discharge employs a ramp in toroidal magnetic field from 2.2T to 2.8T at fixed IP and hence decreasing both q_{95} from 4.8 to 3.6 and the SOL connection length. The main discharge parameters are: IP = 20MA, $P_{NBI} \approx 8$MW and $\delta = 0.27$ (low triangularity). Pellets of a nominal particle number of 2 1021 have been injected perpendicularly from the outer low field side midplane at 4Hz with velocities between 170m/s and 200m/s.

Figure 1 displays the evolution of the heat load profiles on the outer divertor target throughout the BT -ramp. The profiles for the spontaneous ELMs (figure 1 a) all have one main peak with a steep left (towards the private flux region) and at right shoulder (towards the far SOL). The radial location of the peak does not change with B_T and lies close to the pre-ELM heat flux maximum. Profiles for other spontaneous ELMs (e.g. the ELMs succeeding the pellet induced ELMs) are identical and not shown here. In clear contrast, the profiles for pellet induced ELMs (figure 1 b) are accompanied by additional dominant peaks located at a variety of radial positions in the SOL region. We identify a trend of such pellet induced additional peaks moving outwards with B_T.

An inverted toroidal magnetic field ramp (3.3T-2.1T) has been carried out in order to verify the radial movement of the pellet induced peak heat flux due to the change of the toroidal magnetic field only. Indeed, for this discharge the pellet associated peaks move towards lower radii with decreasing B_T.

In order to investigate the question of the origin of the B_T-depended peaks observed exclusively in conjunction with pellet induced ELMs SOL field line tracing has been employed. We traced field lines starting from the pellet injection location at the outer MidPlane (MP) at the vertical and toroidal coordinates Z_{MP} and ϕ_{MP}. The radial coordinate R_{MP} varies from the value of the pellet entrance in the far SOL to the separatrix at otherwise fixed coordinates. Magnetic field lines obtained via the equilibrium reconstruction have been followed from (R_{MP}, Z_{MP}, ϕ_{MP}) until they hit the outer target defining the coordinates (R_{DIV} , Z_{DIV} , ϕ_{MP}). In such a mapping of intrinsic 3D SOL field lines both R_{DIV} and ϕ_{MP} are functions of *RMP*. The target end points of this field lines for a continuous variation of RMP build a spiral on the target [6, 7]. As pointed out earlier, changing B_T at constant plasma current leads to a rotation of this spiral. A rotation of the spiral in return leads to a radial movement of the observed heat fluxes pattern by IR in line with the observed effects by applying the B_T-ramp.

Figure 2 shows the result of this previously explained mapping function applied to such times, at which pellet triggered ELMs are observed. For each time, hence the pellet trajectory is mapped onto the outer divertor target observed by IR (black squares). Figure 2 shows additionally the radial target position of the largest peaks by defining a threshold criterion versus B_T values. The threshold criterion is fulfilled when the local heat flux density exceeds 85% of the maximum heat flux density within the profile during an investigated period of $\approx 200-300\mu s$ while ELM power flux itself is maximum in time. Again the different peaking behaviour for spontaneous and pellet induced ELMs is clearly visible. One can see in figure 2 that the radial peak locations on the target, which are expected on the basis of field line tracing, are in very good agreement with the experimentally observed peak locations for the pellet induced ELMs with a slight systematic deviation towards higher radii. This allows the conclusion that the pellet induced ELM energy transport in the SOL is not distributed fully toroidally symmetric but mainly concentrated along the SOL field lines intersecting the pellet trajectory. It should be finally noted that the pellet associated additional peak in the heat flux profiles does not show a significant delay when compared to the spatially integrated heat fluxes giving the ELM power flux ($<200\mu s$).

3. CODE PREDICTIONS FOR PELLET INDUCED ELMS AT JET

The code JOREK is evolving non-linearly a set of reduced MHD-equations [5]. The plasma is represented in X-point geometry and the calculation domain extends beyond the separatrix into the SOL. JOREK simulations of spontaneous ELMs have reproduced various ELM features like filaments [5], which previously have been observed experimentally. For the simulation of pellet induced ELMs a JET-like plasma has been chosen with an edge pressure gradient such that the plasma without pellet perturbation is stable to ballooning modes. To describe an injected pellet an adiabatic density perturbation with an amplitude of 25 times the central density, which extends over 8% of the minor radius and which has in the toroidal direction a full width half maximum of about 16% of the circumference, has been superimposed to the unperturbed plasma.

The pressure increases within a few μ*s* to a value 6 times the pressure on axis in a region slightly larger than the size of the original pellet perturbation. The extent of the magnetic perturbation is large enough to ergodize the flux surfaces, where the density has been initially enhanced. As shown in Figure 3 ≈ 50μ*s* after the initial density perturbation a field aligned helical perturbation has evolved. This perturbation peaks at one location in toroidal direction, which is defined by the pellet injection location. The regions of peak density are aligned with the same field line.

DISCUSSION

We have measured the ELM induced divertor heat flux for spontaneous and pellet induced ELMs. We have found notably that the divertor heat flux footprints due to pellet triggered ELMs do show a dominant additional peak.

First we conclude that the observed additional structure can not be a consequence of material ablated by the pellet during its flight through the SOL and convected to the divertor since such particles should be low energetic and hence have a much larger parallel transport time. Thus at some location along the field line, which we have traced to the pellet specific imprints on the target, there has to be a strongly enhanced radial transport across the separatrix. The results from JOREK and in particular extent and location of the peak pressure and field line ergodisation support the hypothesis of such a high radial transport in the vicinity of the pellet injection location only a μ*s* after the deposition of the material. This is in line with visible camera observations of hot spots on limiters in the vicinity on the pellet injection location [8]. In this study for pellet induced ELMs no delay to the magnetic ELM onset has been found, while for spontaneous ELMs a distribution of delays up to 100μ*s* has been measured.

In summary we have given experimental evidence that the SOL heat transport associated with a pellet induced ELM concentrates in the main chamber in one filamentary structure. From our observation we infer that spontaneous ELMs are not associated with such a strong asymmetry.

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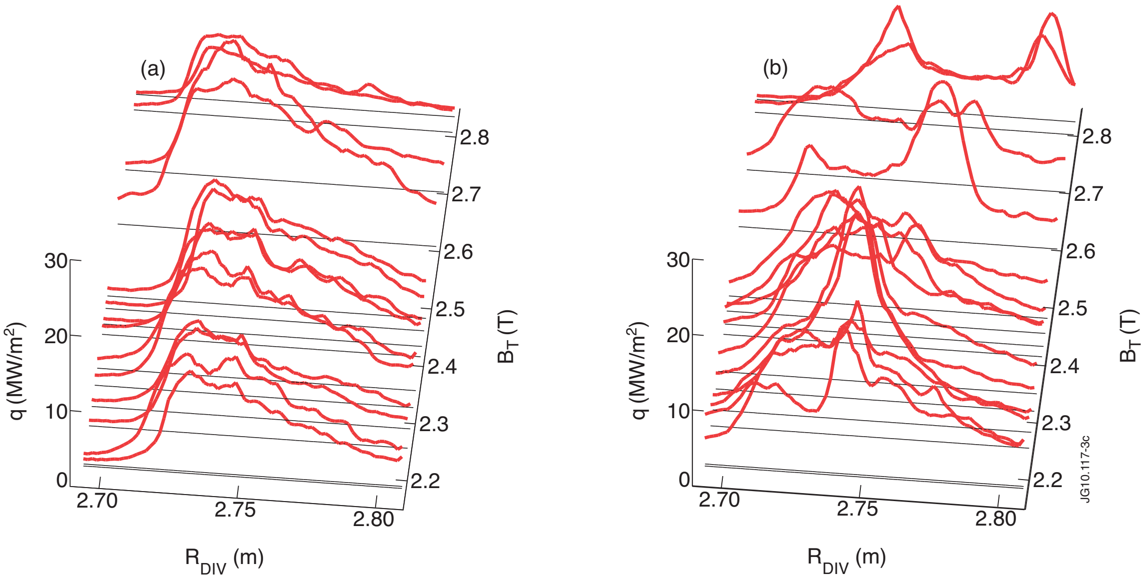

Figure 1: Evolution of the deposition profiles on the outer target: a) ELMs preceding pellet induced ELMs and b) pellet induced ELMs. The heat flux densities are averaged over a period of 0.4µs starting at the time of the peak power deposition. Horizontal lines are to support the allocation with telm.

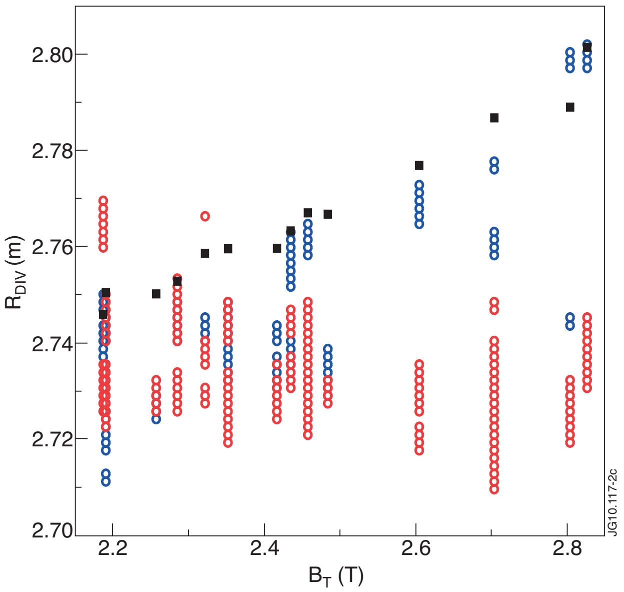

Figure 2: Evolution of experimentally observed peak positions for pellet induced ELMs (blue dots) and spontaneous ELMs (red dots) and predicted peak positions on the basis of eld line tracing (black squares).

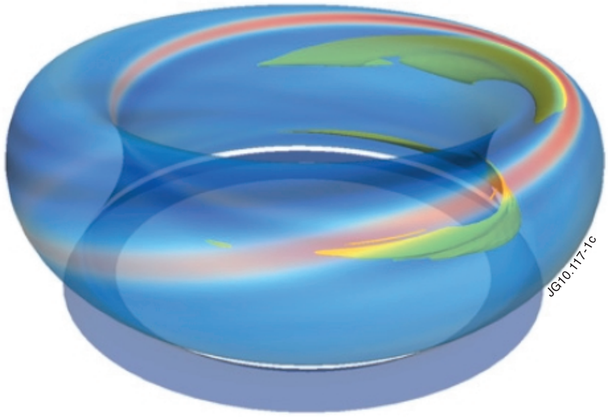

Figure 3: JOREK simulation of a pellet induced ELM about 50µs after the initial density perturbation: Temperature on a flux surface just inside the separatrix is illustrated from blue (low T) to red (high T). The density contour of twice the central density is shown in yellow. The initial density perturbation was superimposed in the pedestal on the left-hand side. (Figure taken from [5] - courtesy IOP)