30th EPS Conference on Contr. Fusion and Plasma Phys., St. Petersburg, 7-11 July 2003 ECA Vol. ***27A**, P-1.126*

Type-I ELM mode structure observed by divertor thermography in ASDEX Upgrade

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Abstract In the ASDEX Upgrade tokamak, power deposition structures on the outer divertor target surfaces during type-I Edge Localised Modes (ELMs) have been discovered by infra red thermography. These structures are radially and toroidally separated non-axisymmetric spirals. They are most obvious about 80 mm away from the toroidal symmetric strike zone on the target plates. The spiral structure of the power load is caused by a toroidally structured energy release in the outer midplane during the non-linear phase of a type-I ELM cycle as shown by basic field line tracing. The resulting structures correspond to values around $n \approx 12$ and $m \approx 50$ (for $q_{95} \approx 4$).

Introduction and Experimental Setup The type-I ELMy H-Mode [1] is regarded as the standard scenario for a power producing tokamak. This high confinement operation mode is accompanied by the repeated release of large power bursts due to ELMs [2]. Although the sudden release of power from the edge region of the magnetically confined plasma is of no harm for plasma performance in the core, such high heat fluxes are likely to cause ablation of the first wall and particularly of the divertor target materials. ELMs are therefore one of the major concerns for a next step fusion device. The standard experimental approach to investigate the power deposition charcteristics is the observation of the divertor target plates by infra-red thermography. Usually, the experimental studies for type-I ELMs are guided by the search for those quantities which determine the material ablation limit. These are the (i) energy deposition duration, (ii) the spatial profile and (iii) the fraction of released energy arriving at the inner/outer target. However, for an extrapolation to ITER an understanding of the physics is needed to obtain a more reliable result within smaller error bars than the currently available data [3].

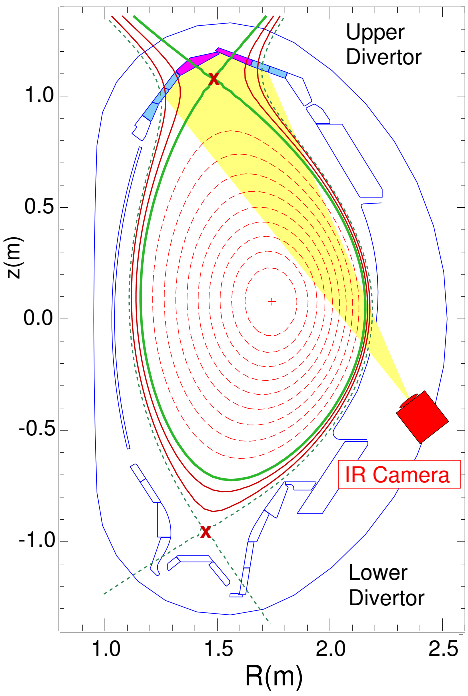

Figure 1: *Poloidal cross section of ASDEX Upgrade with Upper Single Null magnetic equilibrium configuration (#16724).*

Therefore, on ASDEX Upgrade, a new infra-red thermography system has been installed, combining a high data acquisition speed, with camera shutter speeds down to $4\mu s$ and with a fairly large survey area of $40cm$ in toroidal as well as poloidal directions with a spatial resolution of $3.5mm \times 3.5mm$ per pixel on the target surface. This system has been applied to the easily accessible upper divertor with its flat and open target geometry, as illustrated in figure 1. Furthermore, in order to increase the sensitivity of the measurements, carbon tiles with different surface properties particulary in respect to their heat conductivities are used. At the separatrix position, where the largest power load on the target plates is expected, newly installed target tiles with virgin surface and therefore best possible heat conductivity are positioned (inner dark tiles in figure 1 and in centre of figure 3). In the area remote from the separatrix, the surfaces of the installed target tiles have been exposed to the plasma over a period of 10 years operation. Therefore, high temperature increases are measured, even when exposed to low heat fluxes [4]. This experimental set-up is well within the requirements for detailed estimation of the heat flux evolution, particularly during fast events like type-I ELMs in H-Mode discharges, over ultra short time scales. Recent experiments have been run using the Upper Single Null (USN) magnetic field geometry restricting the plasma-wall interaction nearly exclusively to the upper divertor target tiles, which lie in the visual field of the new IR camera system.

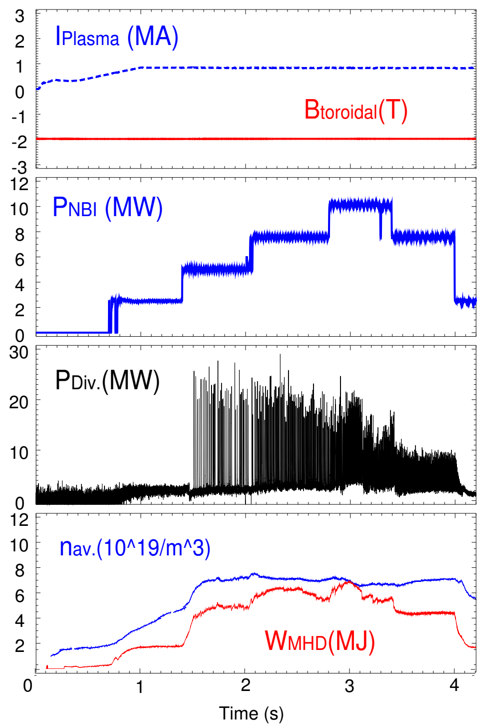

Figure 2: *Temporal evolution of some discharge parameters in the Upper Single Null (USN) discharge (#16724) in ASDEX Upgrade.*

Observation of non-axisymmetric power deposition pattern With this set-up, type-I ELMy H-Mode discharges display a multi-facetted heat flux pattern upon the outer divertor target plates during the type-I ELM power deposition phase. Figure 3 shows the temperature distribution on the target surface during a type-I ELM in discharge #16713, which is identical to # 16724 (Fig.1), but with different settings for the IR system. In #16713, largest possible frame sizes have been chosen (as displayed in figure 3) resulting in a frame rate of 315Hz ($= 3.17ms$), whereas in #16724 smaller frame sizes are used with a frame rate of 7350Hz ($= 136\mu s$). In addition to the usual axisymmetric strike point line, about 3-5 narrow, non-axisymmetric and slightly inclined stripes are routinely observed in a region between 80mm to 160mm radially outwards from the strike point line (the maximum of the heat flux profile).

Less than 3% of the deposited energy is contained in the stripe's pattern on the remote tile surface.

Until now, no evidence for a corresponding structure has been identified on the inboard target plates.

From the evolution of the temperature profiles in # 16724 (recorded with frame rates able to resolve the ELM power deposition) the heat flux evolution is calculated [5] (presented in figure 2 as the deposited power onto the divertor target plates $P_{Div.}$). In the type-I ELM phase from 1.6s to 2.7s, peak power values of $20-30MW$ are measured. The ELM power deposition time is around 350μs with an ELM frequency of about 80Hz.

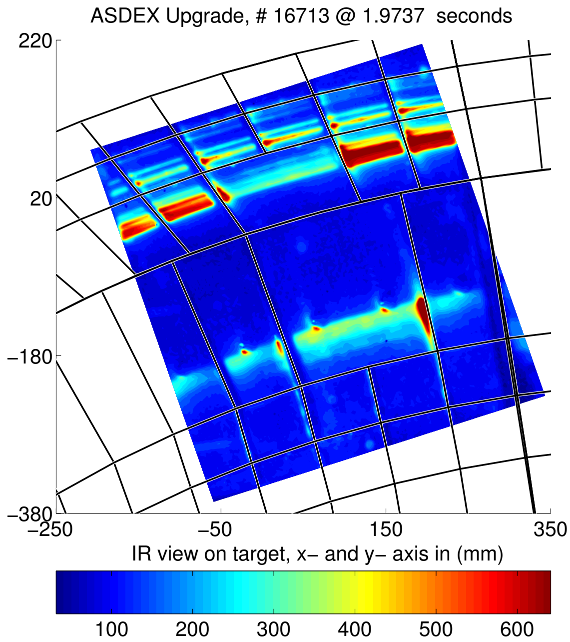

Figure 3:*The power deposition pattern during this type-I ELM event shows a characteristic non-axisymmetric structures most prominent in the remote area of the outboard strike line (# 16713). Temperature in ^oC*

Estimation of a quasi toroidal mode numbers during type-I ELMs This pattern may be qualitatively understood in terms of the edge field line topology of poloidal divertor equilibria. Let us consider a narrow helical flux bundle in the main chamber low field side Scrape-Off-Layer (SOL), loaded by plasma expelled from the pedestal region during the non-linear phase of an unstable high-(n,m) mode as expected during ELMs [6].

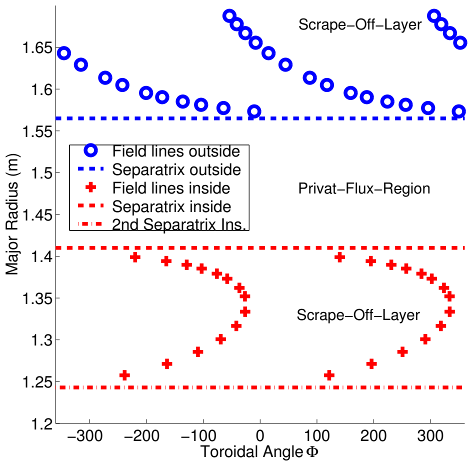

Figure 4: *Intersection of field lines originating at a fixed toroidal and poloidal major radius line.*

Our choice of field line starting at the low field side is based on the experience that the ELM energy loss comes predominantly from this bad curvature side. This is shown in ASDEX Upgrade double null discharges [7] in which the power is dominantly deposited on the upper and lower outer divertor legs. When this flux bundle is mapped along field lines to the upper outer divertor target, it is distorted by the strong upper x-point shear. The key mechanism behind is that the closer a field line passes by the x-point, the higher the connection lengths gets and the more it is displaced in toroidal direction, when arriving at the target. This leads to a characteristic relation between the distance and the toroidal angle of the intersecting point of the helical flux bundle on the target plates, namely a spiral on a $R-\Phi$ map representing the upper divertor target tile surface (figure 4, top). The intersection structure on the inner target plates is more complex, since, on the way around the plasma bottom, field lines between first and second separatrix (see figure 1) are influenced first by the lower and then by the upper x-point (figure 4, bottom). Assuming that, energy is transported strictly along field lines and identifiying the inclined stripes, seen by thermography, with the spiral arms in figure 4, this interpretation explains the basic features seen on the outer target. Because of the $R-\Phi$ relation in figure 4, the toroidal wave number n can in principle be derived from the toroidal as well as poloidal variation of the target pattern.

Given the actual observation area, however, the poloidal variation allows to investigate much lower n values in the following manner: From the radial distance between each spiral and separatrix we can derive the corresponding toroidal intersection angle in the midplane according to the $R-\Phi$ map. As we see several displaced stripes appear simultaneously, we identify them as a subset of several toroidally displaced origins of energy release in the midplane. From these we may define a quasi toroidal mode number n, given by 2π divided by the toroidal displacement between two neighbouring origins in the midplane. The resulting distribution of n-values is presented in figure 5 for # 16724 for $t = 1.6s$ to $t = 2.7s$. Here, the values for n are largely varying around $n = 12$. It should be noted, that this result is only preliminary and possibly higher order effects due to drifts, particle diffusion, ergodisation etc. have to be taken into account.

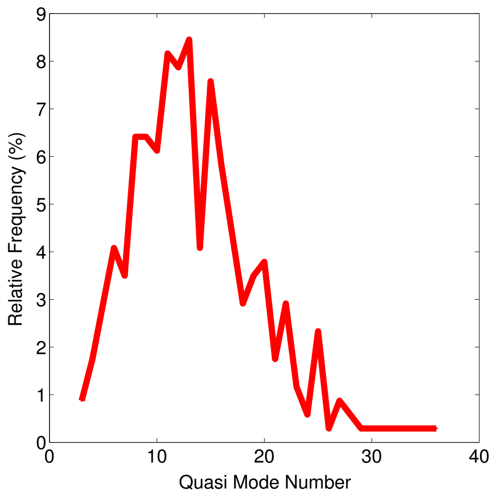

Figure 5: *Distribution of the derived quasi mode numbers (# 16724).*

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