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ABSTRACT.
Abstract. In recent JET experiments, Lower Hybrid (LH) power losses in the Scrape-Off Layer (SOL) were characterized using Infra-Red (IR) thermography. Hot spots were observed on objects intercepting the field lines passing in front of the LH launcher, i.e. on poloidal limiters and on dumplates located at the top of the tokamak; their locations being in good agreement with magnetic field line tracing using the EFIT equilibrium code. The dumplate temperature was monitored while scanning the launcher position so that the radial distance between field lines intercepting the hot spots and the launcher was increased up to 3.5cm. The dissipation layer in front of the launcher was estimated to be at least 3.5cm wide, in agreement with recent measurements on Tore-Supra, but not with simple models that predict a dissipation layer in the mm range.

1. INTRODUCTION
Most of the experimental observations of localised hot spots precisely located on tokamak components magnetically connected to the launcher [1] (with in some cases connection length of few tens of m) can be explained by Electron Landau Damping (ELD) of the waves with high $N_{||}$ components ($|N_{||}|$ > 15) directly in front of the grill, generating fast electrons in co and counter current directions with energies up to few keV [2]. However, simple wave propagation models taking into account ELD predict that these high $|N_{||}|$ waves are being absorbed within few mm [3], while recent measurements on Tore-Supra (TS) have provided evidence of fast electrons 40-50mm in front of the grill [4]. A good knowledge of the radial extent of the LW wave dissipation in the SOL is key for the understanding of this phenomena and to estimate the amount of LH power lost through this channel. This paper describes JET experiments in which the radial extent of the LH wave dissipation layer in front of the grill was measured. The JET LH launcher [5] is made of 12 rows of 32 reduced rectangular waveguides, fed by 6 modules of Klystrons (A-F). Depending of the plasma configuration, and LH grill position, LH hot spots can be observed at (see Fig.1): the septum of ICRF antenna B and A respectively (locations 1 and 4 respectively). the protection limiters of the ICRF Iter-Like Antenna (ILA, 2 and 3). the poloidal limiter (5). the dumplates located on top of the tokamak (6). The inner divertor aprons (7). The outer divertor aprons (8). The hot spots on locations 1 to 7 correspond to electrons accelerated in the co-current direction, while location 8 intercepts electrons accelerated in the counter-current direction. Hot spots at locations 1-5 are generally observed if the bottom rows of the grill are powered. This can be understood from Fig.2. Fast electrons travelling in the co-current direction, and generated a few centimetres in front of the bottom rows of the grill, get closer to the poloidal protections and eventually hit them when travelling from Z<0 to Z>0. Hot spots are observed on the dumplates (6), only for plasma configurations with a pseudo X point on top of the machine. In these cases hot-spots 7 are generally not seen, and vice-versa.

2. WIDTH OF THE DISSIPATION LAYER
A series of JET pulses were performed to measure the radial extent of the LH wave dissipation layer in front of the grill. The plasma parameters were the following: Lmode plasma; B_T = 2.95T;

$I_P = 1.75$ MA; $q_{95} = 5$; the separatrix-grill distance was approximately 9cm, and was changed in steps of 1cm (see Fig.5). Gas injection close to the grill was used (6×10^{21} el/s) to improve antenna coupling. The LH hot spots could be observed on the dumplates, and real time plasma shape control (XSC) was used to ensure uniform magnetic connection between the launcher and the dumplates throughout the LH phase. The connection length between the grill and the hot spots was ~20m. We now discuss in more details Pulse No 77393, for which 1.95MW of LH power was launched from the top rows of the grill (modules A&B) and 1.05MW from the bottom rows (module E). The LH power density at the grill was ~24MW/m^2. On Fig.3, magnetic field lines are traced for this pulse at t = 8s. Power dissipated in front of each row of the grill is expected to generate hot-spots on a line (each singular hot spot corresponding to protuberating surfaces), the electrons accelerated further away from the grill being intercepted further away toroidally by the dumplates, as they are closer to the pseudo X point. Also, the hot spot lines from the top and bottom rows are two separate lines with the hot spots from the bottom row being further away toroidally. This agrees well with the IR camera view on Fig.4. Also seen on Fig. 4 is the reference '0' of the bottom row (power dissipated directly in front of the grill, corresponding to point '0' of bottom row hot spot line on Fig.3). We can therefore conclude (see Fig.3) that during the 6-8s phase of the pulse, the top row hot spots (encircled in Fig.4) corresponds to LH power dissipated 1.5cm in front of the grill (which also explains their inward position relative to the bottom row hot spots). From this point, we have retracted the grill in 1 cm steps, as shown on Fig.5. Fitting the top row hot spots temperature evolution with a semi infinite model (for graphite at 200^{o}C, k = 9000 Wm^{-2}K^{-1}s$^{1/2}$), the heat flux on the dumplates was estimated as a function of the radial distance between magnetic field lines intercepting the analyzed hot-spots and the grill (Fig.6). The heat flux only decreases by 20% when the grill is retracted by 2cm, corresponding to a 'probing' position located 3.5cm away from the grill.

CONCLUSIONS

The width of the LH power dissipation layer in front of the grill was evaluated on JET, for ρ_{LH} = 24MW/m^2 close to the ITER target, and it was found to be at least 3.5cm. This result, and the recent TS observations [4], are a puzzle for theory [6,7], as linear Landau damping of LH waves in front of the grill predicts interaction layer in the mm range. The maximum heat flux along the field lines was estimated to be ~ 10MW/m^2, this estimate will be described in more details in an extended publication.

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REFERENCES

[1]. Goniche M. et al., Nucl. Fusion 38 (6), p. 919 (1998) - Rantamäki K. et al., Plasma Phys. Contr. Fusion **47** pp1101-1108 (2005).

[2]. Fuchs V. et al., Physics of Plasmas **11** p. 4023 (1996).

[3]. Rantamäki K. et al., Nucl. Fusion **40** p.1477 (2000).

[4]. Gunn J. et al., J. Nucl. Mat. **390-391**, p.904 (2009).

[5]. Dobbing J.A. et al., Proc. 17th Symp. Fusion Technology, Rome, Italy, Vol.1 p. 472, Elsevier Science, the Netherlands (1992).

[6]. Fuchs V. et al., 'Landau damping of the lower hybrid grill spectrum by tokamak edge electrons', these proceedings.

[7]. Petrzilka V. et al.,''Fast electrons generation by LH waves scattered on ponderomotive density modulations in front of LH grill', poster contribution at 2009 EPS conference.

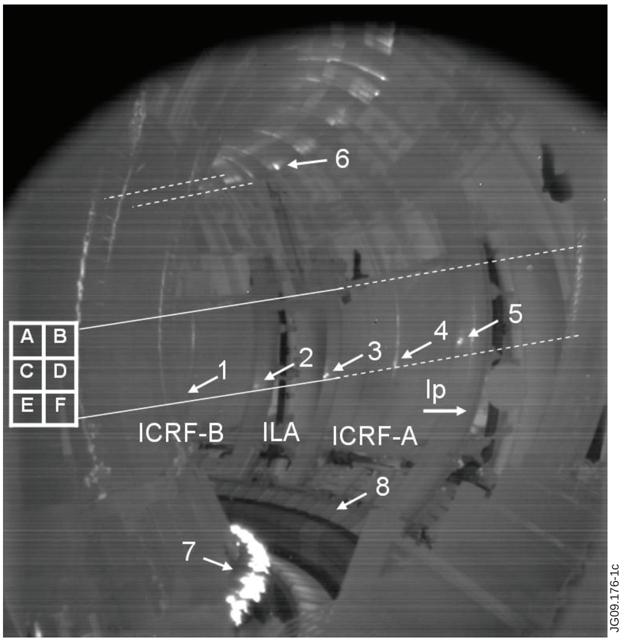

Figure 1: JET Pulse No: 69582 t=11.3s, IR frame showing locations where LH hot spots are observed. Also shown is the location of the LH launcher and of ICRF antennae A, B and ILA. In this example LH hot spots can be seen on 2, 3, 4, 5 and 6.

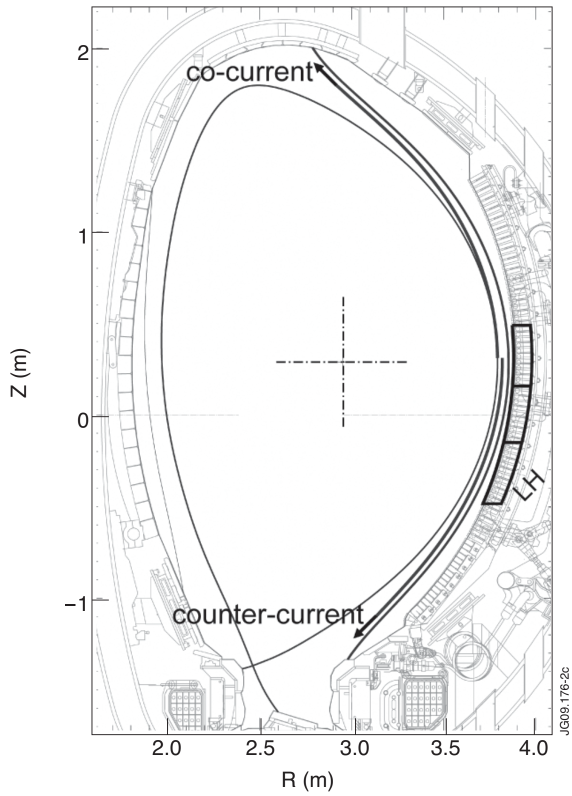

Figure 2: Cross section of plasma, from EFIT equilibrium code, JET Pulse No: 69582 t=11.3s.

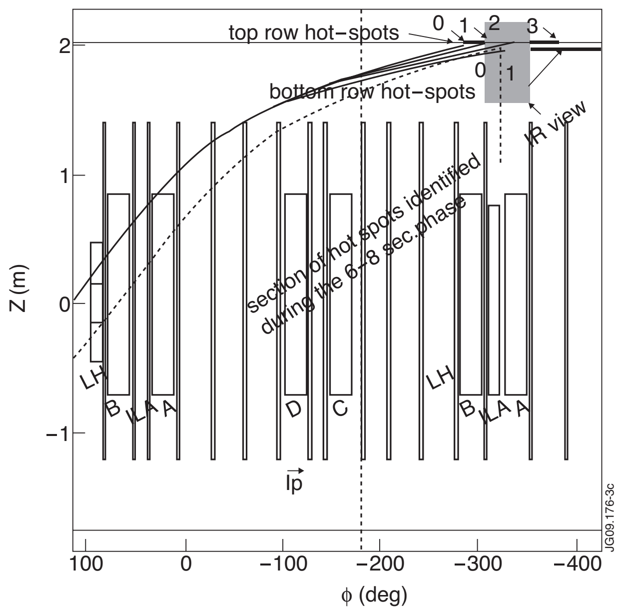

Figure 3: JET Pulse No: 77393 t=8s, magnetic field lines passing in front of the grill, tracing started on a 1cm grid, from the main poloidal limiter toward the plasma, in front of the top and the bottom rows of the grill. '0' refers to lines started directly in front of the limiter, '3' refers to lines started 3 cm toward the plasma.

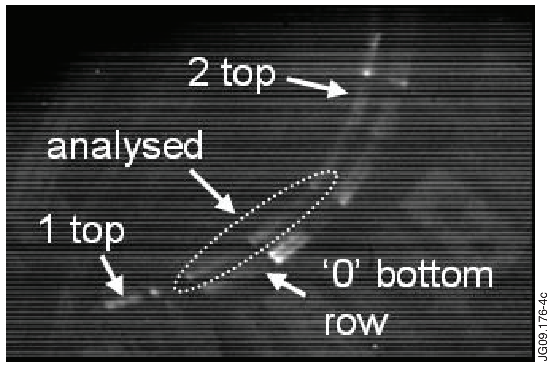

Figure 4: JET Pulse No: 77393 t=8s. IR view showing LH hot spots on dumplates, generated from LH grill top rows (A&B) and bottom rows (E). Encircled with dotted lines are the points used for temperature analysis in Fig.5 and Fig.6.

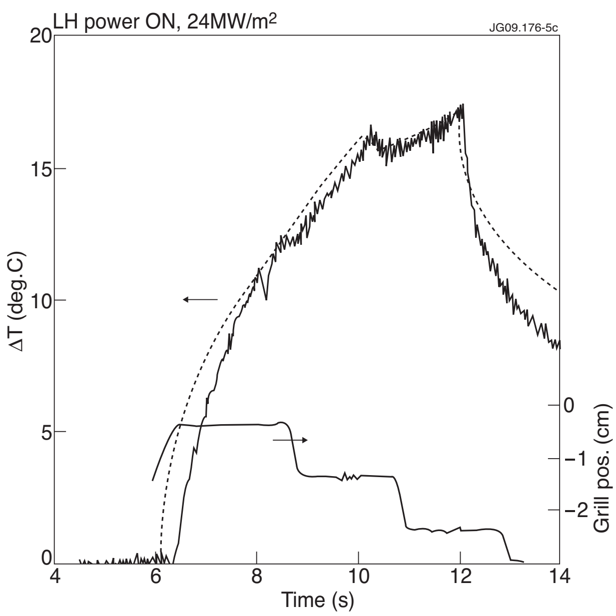

Figure 5: JET Pulse No: 77393. (a) Temperature evolution, top row hot spots on dumplates (averaged over 7 points encircled in Fig. 4) and (dotted line) fit with semi-infinite model. On right y axis, grill position.

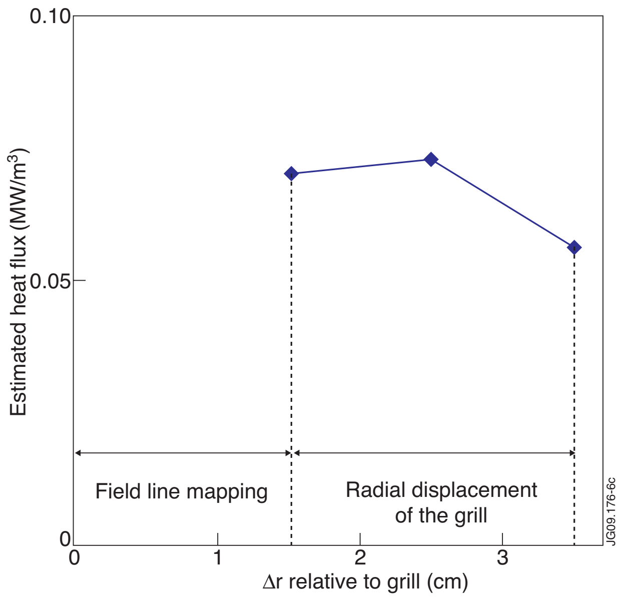

Figure 6: Estimated heat flux on dumplates, $Q_\perp$, as a function of radial distance between field lines intercepting the analyzed top row hot-spots and the grill.