Non-linear MHD simulations of pellet triggered ELMs in JET

S. Futatani[1,2], S. Pamela[3], L. Garzotti[3], G.T.A. Huijsmans[4], M. Hoelzl[5], D. Frigione[6],
M. Lennholm[3], the JOREK Team[7], and JET Contributors[8]

[1] *Universitat Politècnica de Catalunya, Barcelona, Spain*
[2] *EUROfusion Consortium, JET, Culham Science Centre, Abingdon, OX14 3DB, UK*
[3] *EURATOM/CCFE, Fusion Association, Culham Science Centre, Abingdon, Oxon OX14 3DB, UK*
[4] *CEA, IRFM, F-13108, St-Paul-Lez-Durance, France*
[5] *Max-Planck-Institute for Plasmaphysics, EURATOM Association, Boltzmanstr. 2, 85748 Garching, Germany*
[6] *ENEA, C.R. Frascati, Roma, Italy*
[7] *See* `https://www.jorek.eu` *team members*
[8] *See the author list of "Overview of the JET preparation for Deuterium-Tritium Operation" by E. Joffrin et al. to be published in Nuclear Fusion Special issue: overview and summary reports from the 27th Fusion Energy Conference (Ahmedabad, India, 22-27October 2018).*

Introduction

ITER operation is based on the H-mode regime with controlled ELMs (i.e. ELM power losses which do not cause excessive erosion of plasma facing components (PFCs)). One of the methods which is foreseen to control ELMs in ITER is based on the active controlled increase of the ELM frequency by injection of small pellets. As a contribution to a better understanding of the pellet ELM triggering, non-linear MHD modelling of pellet injection has been performed for a type I ELMy H-mode plasma in JET with the JOREK code [1, 2, 3]. The JOREK code solves previously implemented neutral gas shielding (NGS) model [4, 3]. The aim of the work is to estimate and to validate the power flux onto the divertor target. The validation of the simulations has been carried out with the comparison to JET data. The amplitude of the peak of the heat flux is similar in between the spontaneous ELM and the pellet triggered ELM which is consistent with existing experimental observations [6].

JOREK simulations of spontaneous and pellet triggered ELMs

The simulations are based on an equilibrium reconstruction for JET discharge 84690 (q_{95}= 3.3, I_p=2.0 MA, B_T=2.1 T) [6]. The target plasma was a baseline H-mode scenario with NBI heating power $P_{NBI} = 11$ MW and low triangularity $\delta_{LOW/UP} = 0.35/0.18$.

The JOREK simulations to study the non-linear growth of MHD activity leading to the spontaneous and triggering of ELMs by pellet injection have been carried out. The simulations are performed for spontaneous ELM (without pellet injection) and two pellet sizes, 0.5×10^{20} and 2.0×10^{20} particles contained in the pellet (1.1 mm and 1.7 mm of the diameter of cylindrical pellet, respectively) injected from Low Field Side, outer-midplane (LFS-MP) of the JET plasma

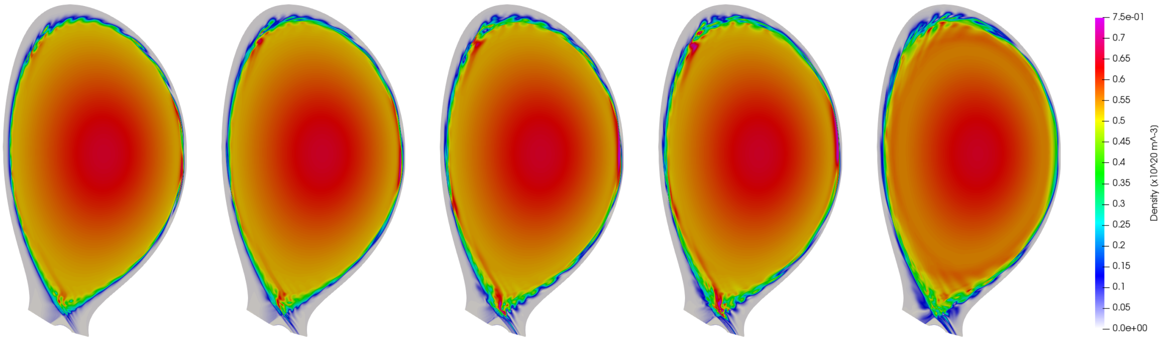

Figure 1: Plasma density contours for pellets injected at the LFS-MP of JET plasma with the injection of $2.0 \times 10^{20} D$ pellet for $t = 4249.9\mu$s, 4316.9μs, 4376.2μs, 4411.3μs, and 4926.6μs. The formation of ballooning mode structures in the density contours is indicative of the triggering of an ELM.

(see [6] for the detail information).They are the minimum and the maximum of the pellet size capability for the pellet injector of JET. The simulations of the study have been carried out using the toroidal harmonics n=0-10. Figure 1 shows the snapshots of the density contour during the pellet triggered ELM obtained by JOREK simulation. The clear structures of the ballooning modes are observed at the low field side and the X-point region of the plasma.

Figure 2 shows the time evolution of the heat flux on the outer/inner divertor target by spontaneous ELM and pellet triggered ELM. The movement of the filaments which appears in spontaneous ELM indicates that the plasma rotates during the ELM activity (plasma rotation induced by the ELM itself due to Maxwell stress). It is important to note that the heat flux on the divertor target shows small toroidal variations during the natural ELM. In the case of the pellet triggered ELM, the filamentary structures of the heat flux are not observed. This is due to the spectrum of the toroidal modes; the spontaneous ELM is dominated by high toroidal mode ($\sim n = 10$), but the pellet triggered ELM is contributed by lower toroidal modes.

Comparison with the experiment

The analysis of divertor heat load footprint of pellet-triggered and natural ELMs on the outer divertor target plate for the JET shot 84690 is reported in [6]. This analysis was performed with the aid of a fast resolution infra-red (IR) camera. The time resolution of this instrument was $100 - 300$ μs, depending on the view area. The IR camera is located at a toroidal angle of 90° from the pellet injection system (the angle coordination is defined as the clockwise direction from the top view of the tokamak). There is an additional IR in JET, located at a toroidal angle of 270°, but for this particular experiment the data quality was not good enough for this analysis. Additional analysis using both cameras will be included in future works. In the experiment

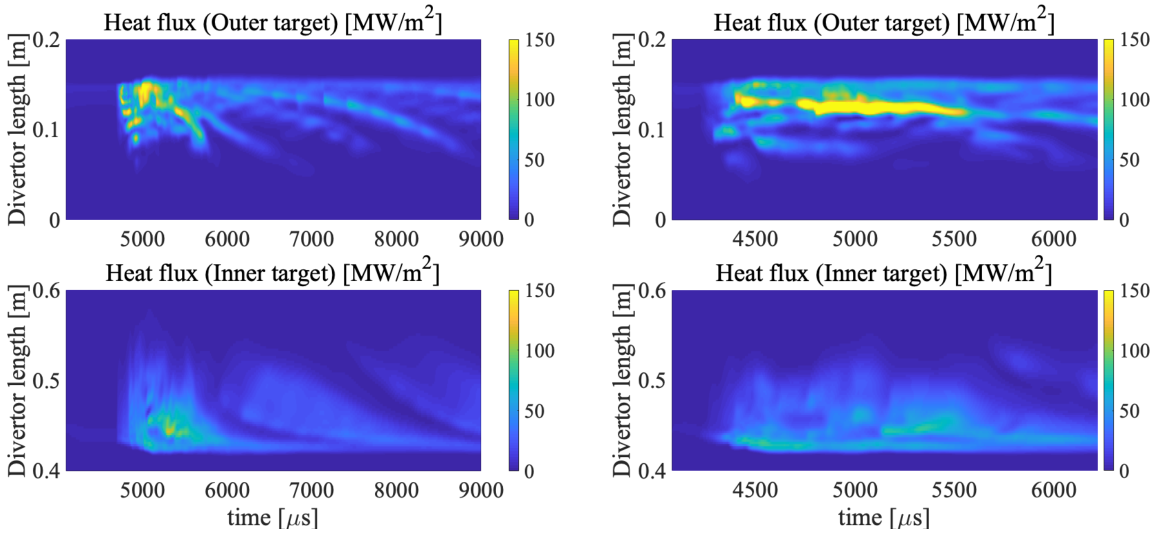

Figure 2: The time evolution of the heat flux on the outer/inner divertor target of the toroidal angle 0°. Left panel is the case of spontaneous ELM and right panel is the case of triggered ELM by 2.0×10^{20} pellet. The strike point at the outer divertor is L=0.145 [m] (R=2.70 [m]), and the inner divertor target is L=0.43 [m] (R=2.44 [m]).

analysis, the power flux is plotted as a function of major radius and time-averaged heat flux during the ELM event. Validation of the JOREK simulations is obtained by comparing the results against the divertor heat flux profile obtained from IR camera data as shown in Fig. 3. The JOREK simulations show the radial position of the strike point of the outer target is R=2.70 [m]. The time-averaged heat flux over the ELM events of the pellet triggered ELM (0.5×10^{20} pellet) and the spontaneous ELM is shown in Fig. 3 at the same toroidal location as the experiment IR camera. Both of the ELMs show the similar heat flux onto the PFC, ~ 60 MW/m^2 which is consistent with the experiment observation [6].

Conclusion

The JOREK simulations show the good agreement with the experiment observation [6] in terms of the similar heat flux onto the PFC, ~ 60 MW/m^2. The order of the peak of the heat flux are similar in between the spontaneous ELM and the pellet triggered ELM. This is consistent with the observation of the experiment. The next important step is to investigate the pellet triggered ELM in the presence of realistic plasma flows including diamagnetic drift, neoclassical effects, and toroidal rotation which had been neglected in previous studies.

Acknowledgement The work of S.F. is supported by a Ramón y Cajal grant from the Spanish Ministry of Economy and Competitiveness (RYC-2014-15206). This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the

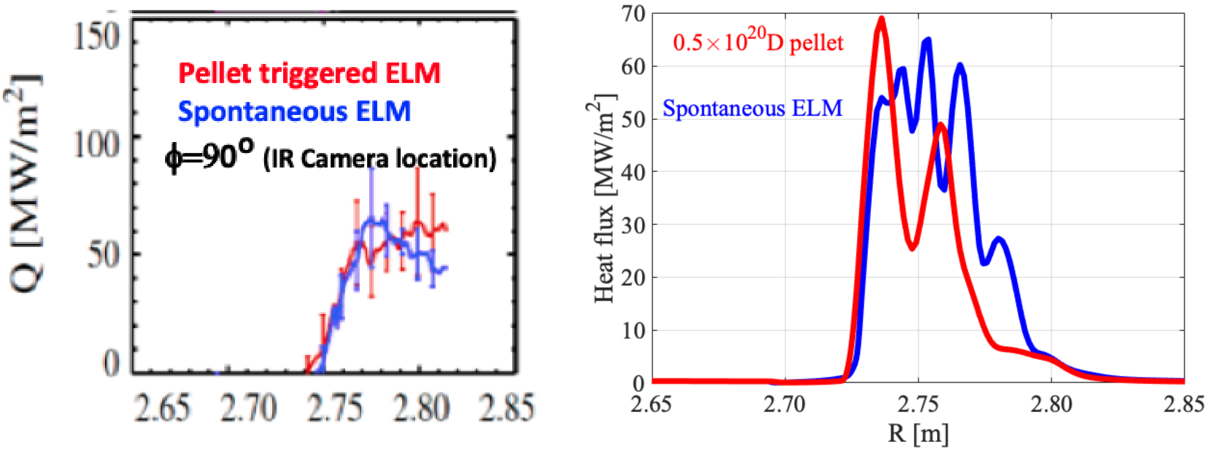

Figure 3: The heat flux profiles onto the outer divertor target of (left panel) the experiment and (right panel) JOREK simulation. The heat flux profile is averaged over the ELM event. Red lines show the pellet triggered ELMs and the blue lines show the spontaneous ELMs. Figure is quoted from Fig. 5 of [6].

Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect either those of the European Commission. The author thankfully acknowledges the computer resources of PRACE (Partnership for Advanced Computing in Europe) and RES (Spanish Supercomputing Network) at MareNostrum and the technical support provided by Barcelona Supercomputing Center, and the support from Marconi-Fusion, the High Performance Computer at the CINECA headquarters in Bologna (Italy) for its provision of supercomputer resources.

References

[1] Huysmans GTA and Czarny O, Nuclear Fusion **47** 659 (2007)
[2] Czarny O and Huysmans G, JCP **227**, 7423 (2008)
[3] Futatani et al., Nuclear Fusion **54**, 073008 (2014)
[4] Gal, K., et al., Nucl. Fusion **48** (2008) 085005.
[5] Wenninger, R.P, et al., Plasma Phys. Control. Fusion **53** (2011) 105002.
[6] D. Frigione et al., Journal of Nuclear Materials **463**, 714 (2015).