

SOL profile and fluctuations in different divertor recycling conditions in H-Mode plasmas

N. Vianello¹, N. Walkden², M. Dunne³, B. Lomanowski⁴, E. Wolfrum³, C. Tsui^{5,6}, M. Griener³, B. Tal³, D. Refy⁷, D. Brida³, I. Cziegler⁸, O. Février⁵, H. De Oliveira⁵, M. Agostini¹, S. Aleiferis⁹, M. Bernert³, J. Boedo⁶, M. Brix², D. Carralero¹⁰, I. Carvalho^{2,15}, C. Giroud², A. Hakola¹¹, A. Huber¹², J. Karhunen¹³, A. Karpushov⁵, B. Labit⁵, A. Meigs², V. Naulin¹⁴, T. Pereira¹⁵, H. Reimerdes⁵, C. Theiler⁵, the ASDEX-Upgrade Team, the TCV-Team, the EUROfusion MST1 Team* and JET Contributors**

¹Consorzio RFX, Padova, Italy, ²CCFE, Culham, UK, ³Max-Planck-Institut für Plasmaphysik, Garching, Germany, ⁴Oak Ridge National Laboratory, ⁵EPFL-SPC, Switzerland, ⁶UCSD, La Jolla, USA, ⁷Wigner Research Centre for Physics, ⁸York Plasma Institute, University of York, UK, ⁹NCSR Athens GR, ¹⁰CIEMAT Laboratorio Nacional de Fusión, Madrid, Spain, ¹¹VTT, Espoo, Finland, ¹²Forschungszentrum Julich, ¹³Aalto University, Espoo, Finland, ¹⁴DTU, Copenhagen, Denmark, ¹⁵IST/IPFN, Lisbon, Portugal *See the author list B. Labit et al 2019 Nucl. Fusion 59 086020, **See the authors list E. Joffrin et al 2019 Nucl. Fusion 59 112021

Corresponding Author: nicola.vianello@igi.cnr.it

Plasma Exhaust and Plasma Wall Interaction are subjects of intense studies in the context of fusion energy research for the understanding of the amount of heat loads and the lifetime of different Plasma Facing Components. In order to ensure reliable predictive edge modeling in this context, it is mandatory to determine the transport properties of the Scrape Off Layer (SOL), a region which is largely influenced by the presence of turbulent filaments which contribute to particle and energy losses in both L and H mode. From the ITER divertor perspective, to keep the power fluxes acceptable for target material, high neutral pressure and partial detachment are needed to ensure maximum tolerable loads [1].

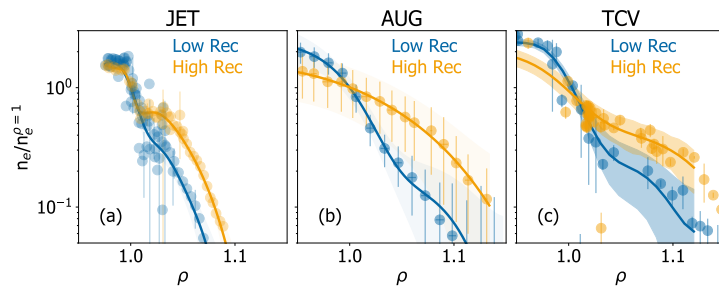


Figure 1: Upstream profiles, normalized with respect to values at the separatrix in different recycling conditions for JET (a), AUG (b) and TCV (c). In all the cases symbols represent raw data whereas the solid line represent a Gaussian Process Regression fit

Thus experimental investigation of SOL transport needs to be extended to these regimes. In present experiments the regimes matching the ITER divertor operational point are obtained with high gas throughput leading to high density regimes. In L-Mode these operational conditions are associated with the appearance of a *density shoulder* i.e. progressive flattening of the density scrape off layer profile at high density [2–4]. It has been shown that density shoulder appear starting from high-recycling regimes and become broader after target density rollover [5], even though differences have been observed depending on divertor geometry [6], or if high recycling conditions are achieved through impurity seeding rather than high fuelling [6, 7]. The density shoulder is actually accompanied by an increase of the filamentary activity [4, 5, 7], together with an increase of their associated convective transport [4]. Preliminary investigations suggested that similar inter-ELM SOL density profile broadening is observed in H-mode as well [4, 5, 8], with a stronger dependence on the neutral pressure [5]. The possible increase of convective heat and particle fluxes to the wall poses serious issues in terms of acceptable sputtering yield of the first wall. In H-mode, in case of highly dissipative divertor with high gas throughput, the plasma changes its stability properties moving towards a small-ELM regime [9] where a clear increase of the SOL density decay length is observed. Despite

the large experimental effort, a comprehensive understanding of the mechanism leading to an H-mode shoulder formation is presently lacking and this motivated a joint experimental effort within the Eurofusion framework. The present contribution will show an unique comparison of H-Mode SOL density shoulder properties across 3 different devices, JET, ASDEX-Upgrade (AUG) and TCV focusing on the SOL profile evolution in different divertor recycling states, correlating the observed profile modification with different turbulent SOL plasma transport.

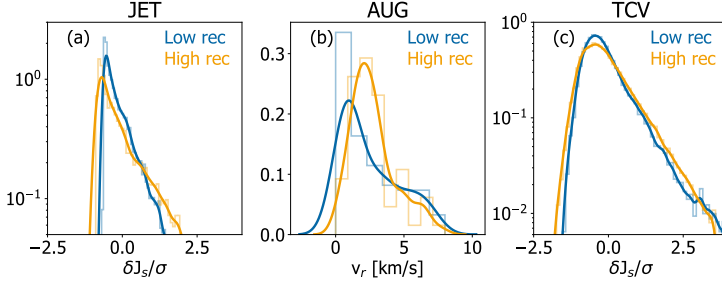


Figure 2: Fluctuation properties in different recycling states for the 3 devices: (a) PDF of J_{sat} fluctuations at the wall on JET (b) inter-ELM filament velocity in the far SOL from THB diagnostic (c) PDF of J_{sat} fluctuations at the wall on TCV

range of divertor parameters and recycling states. Finally on TCV high- δ low current (0.18 MA) discharges were investigated with an additional 1 MW of NBI heating with different fueling levels and locations. In all the devices we have been able to identify conditions where inter-ELM density profiles at different recycling states exhibit a clear profile broadening as shown in figure 1. In order to access the contribution of SOL turbulence induced convective transport in modifying the SOL profile, fluctuations in the main SOL and at the wall have been investigated using different diagnostics in the various machines as shown in 2. On AUG, filaments velocities of inter-ELM filaments have been determined using the Thermal Helium Beam diagnostic [11] and compared with the fluctuations observed in high-recycling state during the small-ELM regime. The comparison of the Probability Distribution Function (PDF) of these velocities is shown in 2 (b) and a clear increase of the filament velocity during high recycling state is observed. For TCV and JET we show the PDF of the ion saturation current density J_s as measured at the wall by mean of embedded langmuir probes respectively in panels (a) and (c) of figure 2. In high density/high recycling state more skewed PDFs are observed for both the machines suggesting an increase of the fluctuation induced convective transport towards the first wall. These experimental results form an excellent basis to benchmark SOL modelling under various conditions in differently sized machines, providing a more complete characterization of the explored conditions in terms of divertor properties, upstream profiles, SOL fluctuation and pedestal evolution. These observations consequently will strongly contribute to improve the understanding of SOL transport in conditions relevant for the ITER divertor operation.

Acknowledgment

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the 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 those of the European Commission.

1. Pitts, R. *et al. Nucl. Mater. Energy*, 100696 (2019).
2. Asakura, N *et al. J. Nucl. Mater.* **241-243**, 559–563 (1997).
3. LaBombard, B *et al. Phys. Plasmas* **8**, 2107 (2001).
4. Carralero, D *et al. Nucl. Fusion* **57**, 056044 (2017).
5. Vianello, N *et al. Nucl. Fusion* **60**, 016001 (2019).
6. Wynn, A *et al. Nucl. Fusion* **58**, 056001 (2018).
7. Kuang, A. *et al. Nucl. Mater. Energy* **19**, 295–299 (2019).
8. Müller, H. W. *et al. Journ Nucl. Mater.* **463**, 739–743 (2015).
9. Harrer, G. F. *et al. Nucl. Fusion* **58**, 112001 (2018).
10. Tamain, P. *et al. J. Nucl. Mater.* **463**, 450–454 (2015).
11. Griener, M *et al. Rev. Sci. Instruments* **89**, 10D102.