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Predicting Scrape-Off Layer profiles and filamentary transport for reactor relevant devices

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This paper discusses a statistical framework that relates the fundamental physics of Scrape-Off Layer (SOL) L-mode and inter-ELM filaments with the profiles they generate in magnetic confinement devices. This work reviews the theoretical and numerical work recently carried out at CCFE in support of the statistical framework and compares it with experimental measurements obtained with innovative techniques on MAST and JET. The emphasis will be on extrapolating the knowledge gained to future machines like ITER and to advanced divertor solutions. With a semi-analytic treatment using minimal computational resources, the framework predicts and interprets the experimental profiles and of the turbulence statistics on the basis of simple properties of the filaments, such as their radial motion and their draining towards the divertor. Filaments are described as independent events and modelled with a wave function of amplitude and width statistically distributed according to experimental observations and evolving according to fluid equations. The framework predicts that radially accelerating filaments, less efficient parallel exhaust (e.g. due to interaction with neutrals) and also a statistical distribution of the radial velocities can contribute to induce flatter profiles in the far SOL and therefore enhance plasma-wall interactions. It also suggests that profile broadening at high fueling rates, potentially harmful for ITER, can be caused by interactions with neutrals in the divertor or at the wall or by a significant radial acceleration of the filaments. The results of the framework are backed up by systematic experimental comparison with measurements taken on JET and MAST using Langmuir probes and fast visual cameras. Advanced machine learning algorithms were developed and deployed, including Bayesian analsysis of time traces and convolutional neural networks applied to filament identification in images. In all the cases treated, the theoretical prediction matched the experimental data within errorbars. In addition, 3D simulation in realistic geometry were performed with the 3D SOL turbulence code STORM, with the aim of assessing the validity of the framework assumptions. The mechanisms governing the interaction of pairs of filaments and the dynamics of high beta, inter-ELM like, filaments were investigated and employed to improve the statistical framework.

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