

# Understanding density decay lengths and particle exhaust in tokamaks from a theoretical and an experimental perspective.

*Fulvio Militello*

*CCFE, Culham Science Centre, Abingdon, OX14 3DB, UK*

As magnetic fusion research progresses towards reactor relevant conditions, it is becoming clearer and clearer that the plasma exhaust and its consequent surface interaction will strongly constrain the operational space and determine whether the next generation machines will be successful. The level of interaction of the plasma with the solid structures surrounding it is largely determined by the properties of the Scrape-Off Layer (SOL) and in particular by the decay lengths of relevant thermodynamic quantities such as density and temperature. Understanding the physical mechanisms determining the SOL profiles is therefore essential to predict and control the heat loads on the divertor plate and the heat and particle flux to the walls, which cause erosion and release impurities.

One important experimental observation in this respect is the formation of a flatter region in the density profile far from the separatrix (far SOL) as fuelling is increased. While the presence of this feature leads to enhanced plasma wall interactions, with harmful consequences to the material structures, a high core density is desirable from a performance point of view. Over the years, several theories were developed to explain this puzzling phenomenon, attributing its cause to enhanced wall recycling, divertor detachment or modifications of the parallel and perpendicular transport.

In this paper, all these theories are reviewed and compared with experimental findings from several machines. Particular focus will be given to recent MAST results that have shed some light on this problem, by falsifying the explanations involving wall recycling and divertor detachment as the SOL flattening was shown not correlate with the former and occur in the absence of the latter. While these theories might still explain part of the phenomenon and be relevant in particular conditions, and hence are interesting to study, they were proven to lack the generality of the transport based approach.

This approach is based on the physics of SOL filaments, which are coherent nonlinear density and temperature structures that erupt from the confined plasma and travel along field lines towards the solid surfaces of the machine. Their mechanics, still a field of active investigation, will be reviewed in the context of the interaction between fluctuations (the filaments) and profile formation (the decay lengths discussed above). The modelling of the intermittent, non-diffusive transport associated with the filaments, analysed with state of the art numerical simulations performed with the BOUT++ framework and with the ESEL code as well as with theoretical scaling laws, will also be discussed. It will be shown that even in the absence of divertor physics, simple filamentary transport models can explain the shoulder formation in the far SOL.

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