From L-mode to the L-H transition, experiments on ASDEX Upgrade, gyrokinetic simulations and full-radius transport modeling

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The edge of tokamak L-mode plasmas is characterized by a state of strong turbulence, which plays a critical role in determining the confinement properties and the accessibility to improved confinement regimes. In the present study, dedicated experiments in ASDEX Upgrade (AUG) are analyzed in combination with related local nonlinear gyrokinetic (GK) simulations with the GENE code [1]. Moreover, following recent results [2] on the prediction of the whole AUG L-mode plasma profile with the TGLF-sat2 [3] model using the ASTRA [4] transport code, the TGLF-sat2 ability of predicting the L-mode edge turbulent transport up to the L-H transition has been tested against the experiment and the GENE simulations.

Experimentally we focus on discharges in deuterium and hydrogen with scans in the input power [5-7] from L- moving to H-mode. The evolution of the edge plasma parameters, and in particular of the edge normalized logarithmic gradients (R/L_{Ti}, R/L_{Te}, R/L_n) and of the radial electric field (E_r) and their correlation are studied and used as inputs for the simulations.

The GK simulations are able to explain the strong isotope effect found for the edge turbulent transport and indicate different roles of R/L_{Te} , R/L_{Ti} and R/L_n for the edge turbulence. While R/L_{Ti} drives low k_y turbulence destabilized by β_e and strongly suppressed by the external ExB shear (γ_{ExB}), R/L_n drives strong intermediate k_y turbulence only mildly affected by γ_{ExB} and β_e [7]. The simulations clearly indicates the fundamental roles of β_e and γ_{ExB} for the evolution of the edge turbulence towards the L-H transition: when all the plasma parameters are considered consistently, local GK is able to reproduce the experimental heat fluxes behavior over an entire power ramp-up moving from L-mode up to conditions just prior the L-H transition. The simulations agree with the experimentally observed effects of the main ion mass on the plasma confinement, through the ion-mass-dependent impact of kinetic passing electrons, and support the observed importance of the T_i evolution in determining E_r and for the L-H power threshold.

The ASTRA-TGLF simulations, performed with boundaries at the separatrix and using only engineering parameters as inputs, reproduce quite well the experimental behaviors and are able to predict the formation of pedestal-like structures in temperature and densities. A route leading to the formation of these structures is identified and it is characterized by conditions which develop a sufficiently deep and localized E_r well with sufficiently large γ_{ExB}. This is found to be very sensitive to little variations of the plasma parameters that can affect the edge E_r profile. The validity of the quasi-linear approximation for the turbulent fluxes is also tested against the GK nonlinear simulations. Agreement is found in general trends, but also quantitative disagreement in some cases, motivating further development of the reduced models.

With these results, for the first time, nonlinear gyrokinetic simulations and full-radius integrated transport modeling are shown to reproduce the transport levels and to provide realistic predictions of the profiles over the entire evolution from L-mode to the L-H transition. The achieved theoretical understanding sheds light on the properties of L-mode edge turbulence, on the access to improved confinement regimes, as well as on the applicability and improvement of reduced models for full-radius time dependent simulations of discharges in present and future tokamaks.

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