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On the beneficial role of fast ions on microturbulence: from current experiments towards ITER

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Understanding and controlling the turbulent transport in tokamaks is of crucial importance towards the success of the magnetically confined fusion as a reliable energy source, since it is one of the main factors limiting the performance of the present devices. Some promising insights have been offered by the supra-thermal component of the fusion plasma, the so-called fast ions. Indeed, a significant improvement of the ion thermal confinement in the presence of a substantial population of externally-generated fast ions in the order of ~100 keV has been observed in several devices in the last decade (see, e.g., [1-4]). The exhaustive gyrokinetic numerical analyses established the beneficial role of the fast ions in reducing the turbulent transport[5]. However, these earlier studies were performed for plasma conditions far from the ones expected in future fusion reactors, such as in ITER. Thus, it is essential to develop experimental scenarios mimicking burning plasmas conditions in order to assess the role of the fusion-born alpha particles (3.5 MeV) on the turbulent transport before drawing any definitive conclusion.

Recent experiments at the JET tokamak[6] have provided novel details on the effect of MeV-range fast ions (FI), mimicking the alpha particles, on the turbulent transport and plasma confinement in ITER-relevant conditions. Despite a strong Alfvénic activity was observed experimentally, the ion thermal confinement was surprisingly improved[7]. Cutting-edge numerical gyrokinetic analyses with the GENE code[8] have revealed, for the first time in a validation study, that the ion-scale transport in the plasma core is totally suppressed in the presence of MeV-ions[9]. Supported by experimental validating analyses, fully destabilized FI-driven Toroidal Alfvén Eigenmodes (TAE) are demonstrated to play a fundamental role in the ion-scale turbulence suppression by nonlinearly triggering the beneficial zonal flow shearing activity. Zonal flows are well-known to reduce the ion-driven turbulence, by shearing and decorrelating the radially-outward propagating turbulent eddies. Advanced multi-mode analyses also prove the clear nonlinear coupling between the zonal fluctuations of both electrostatic and magnetic fields and the TAE spatio-temporal scale[10,11]. Thus, the capacity of FI-driven Alfvénic modes to trigger strong zonal flows is a determinant factor in such a complex mechanism of turbulence suppression and opens the intriguing possibility of profiting from it in future fusion burning plasma operations, accelerating therefore the exploitation of the nuclear fusion as an efficient energy source.

In conclusion, we will give a thorough overview of the electromagnetic effect of the fast ions on the ion-scale turbulent transport in tokamak plasmas in this contribution, tracing back to the first studies on this topic, and then reporting some recent insights on the fast-ion complex mechanism in different turbulence regimes and devices.

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