MF1-I20 AAPPS-DPP2020

4th Asia-Pacific Conference on Plasma Physics, 26-31Oct, 2020, Remote e-conference

Supra-thermal ions as an effective way to suppress turbulence in modern stellarators like W7-X

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With the reduction of neoclassical transport in modern, optimized stellarators like Wendelstein 7-X (W7-X), the magnetic confinement is expected to be controlled by microturbulence. This has recently been confirmed by the results of the first experimental campaigns of W7-X, which showed that ion-temperature gradient (ITG) driven turbulence clearly exceeds its neoclassical counterpart and controls the behavior of the temperature profiles by holding them close to the critical gradients for ITG onset [1]. Therefore, it is of great importance to identify mechanisms able to control and/or suppress turbulence transport in modern stellarators.

In this contribution, we present a novel method to strongly suppress turbulence in optimized stellarators, namely the resonant wave-particle interaction of supra-thermal (fast) ions with ITG modes [2]. This is demonstrated via a combination of analytical theory and state-of-the-art gyrokinetic turbulence simulations for W7-X. In particular, as shown in Figure 1, a turbulence reduction of up to 65 % can be achieved in W7-X via this mechanism if the generated fast particle population simultaneously fulfill the following conditions: (i) steep ion temperature and flat density profiles, (ii) fast ion temperature around an order of magnitude larger than the thermal ions. Such conditions can be achieved by ion-cyclotron-resonance-frequency (ICRF) heating schemes. However, due to the subdominant role played by the anomalous transport in previous stellarator experiments, no evidence of turbulence suppression by ICRF heating has been documented in such devices, only in tokamaks [3]. For this reason, these findings are attractive for steady-state stellarator devices, particularly for W7-X, whose ICRF system is under construction [4], providing an external tool – such as supra-thermal particles – to continuously reduce turbulent transport.

We also present novel results about the key differences between tokamak and stellarator devices in the dynamics of this resonance effect, identifying a new stellarator specific-feature. We show that each individual field-line is optimally stabilized by a different fast ion temperature, since each field-line is characterized by a distinct normal curvature. Finally, we explore the magnetic geometry flexibility, available for stellarator devices. We identify a particular configuration able to enhanced the fast particle turbulence suppression strongly and suggest new pathways for stellarator optimization in the presence of fast particles.

References

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Figure 1: Nonlinear main ion heat fluxes for different energetic particle temperatures for the full flux-surface (red) and flux-tube (blue) W7-X simulations. The horizontal dashed lines denotes the fluxes obtained without fast ions.