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Tokamak devices aim for magnetically confined burning plasmas in order to reach steady state operations and produce economically exploitable fusion energy. One of the main issues are the strong levels of transport due to the highly nonlinear turbulent plasma behaviour, which causes an increment of heat fluxes with respect to neoclassical theory. It is believed that microturbulence, characterized by small-scale and local resonant excited instabilities, is one of the principal drivers for the confinement degradation. Therefore, controlling and reducing the microturbulent transport is of paramount interest towards the exploitation of future devices.

A possible mechanism for such reduction could be identified in the fast ion population which is generated by neutral beam injection (NBI) and ion cyclotron resonance frequency heating systems in present day tokamaks. Recently, an enhancement of the thermal confinement with respect to the IPB98(y,2) scaling law has been experimentally detected in several devices, such as JET, ASDEX-Upgrade (AUG) and JT-60U, among others, in the presence of a significant amount of fast ions. Later, extensive dedicated gyrokinetic analyses demonstrated that fast ions beneficially impact on the ion-temperature gradient (ITG)-driven transport, reducing and partially suppressing the main ion heat fluxes [**1,2**]. The suprathermal species account for both stabilization of the linear growth rate and for an extra reduction of the nonlinear heat transport. Linearly, a wave-particle resonant effect - between the frequency of the instability and the magnetic drift frequency of the energetic species - has been established to be the major mechanism for the reduction of the ITG growth rate in JET L-mode scenario studies [**3**]. Subsequently, a complex multi-phase interaction between the ITG-scale turbulent transport and the zonal flow generation has been shown to affect beneficially the intensity of the heat transport [**4**]. The same nonlinear positive effect is found also in JET, DIII-D and AUG H-modes [**5**] and advanced scenarios, all of them being dominated by the ITG instability. In addition, a combination of NB-injected fast ions and α particles have been shown also in ITER predictive hybrid scenario to reduce the nonlinear saturated ion heat fluxes [**6**]. The latter results is significantly relevant since in ITER the $E \times B$ shearing turbulence reduction mechanism is expected to be weak; thus, fast ions could provide a valid alternative for such reduction.

Nevertheless, previous dedicated studies lack of generality, since multiple turbulence regimes, or even alternative ones, can usually be dominant in plasmas beyond the ITG paradigm. As a matter of fact, another relevant source of core microturbulence is represented by the trapped electron mode (TEM), often excited by the efficient electron heating systems or high density peaking, which can be subdominant to ITG modes.

In this paper, extensive gyrokinetic numerical studies have been performed with the local version of the GENE code [**7**] for a NBI-heated JT-60U hybrid scenario [**8**], previously identified with TEM dominated core turbulence by linear analyses [**10**], which share common characteristics with the already analysed JET hybrid scenario [**2**]. The multi-species simulations also include collisions, magnetic fluctuations (both in the parallel and perpendicular directions), and plasma magnetic equilibrium computed by the HELENA module [**10**] of the CRONOS integrated modelling suite of codes [**11**].

Spectra from linear analyses reveal the destabilization of dominant fast-ion-driven beta alfvénic eigenmodes (FI-BAEs) at low binormal wavenumbers k_y, for the case labelled *standard* which is set with nominal input parameters computed by CRONOS. Subsequent nonlinear simulations for the same case show that significant electromagnetic fluctuations (identified through the value of the electron-β) drive even more unstable the FI-BAEs, leading to a drastic increase of the thermal and fast ion energy transport with respect to experimental range of values – as it is displayed in ***Figure 2*** for the thermal Deuterium heat diffusivity. Hence, in order to evaluate the fast ion impact on dominant TEM-induced transport, FI-BAEs had to be stabilized. As a result, tuning both the thermal and suprathermal input physical parameters (principally the density and temperature gradients of the main and fast ion species, and also the electron-β), a stabilization of the fast-ion-driven mode has been achieved. Eventually, in this new configuration, the TEM has been found to be the dominant driver of the nonlinear saturated transport. Thus, it is shown that fast ions do not affect the TEM-induced turbulent transport [**12**], demonstrating that the turbulence suppression due to fast ion presence is not universal – in ***Figure 3***, the heat flux time-traces are shown for comparison between the with and the without fast ions cases. This lack of impact is established up to the definitive excitation of fast-ion-driven modes that leads to a complex scenario in which strong electromagnetic effects, fast ion pressure gradient and thermal turbulent transport are intimately related. Therefore, in contrast to what occurs for ITG-dominated systems, the fast ions do not affect the TEM-induced heat fluxes in this JT-60U hybrid scenario.

A possible explanation for the different impact of fast ions on ITG and on TEM is related to the different saturation mechanism. Indeed, for the ITG instability, zonal flows (ZFs) are well-established to play a significant role in the saturation and also, as already stated, in the beneficial interplay among fast ions. On the other hand, dissipative TEMs, driven mainly by the strong electron temperature gradient, do not saturate through ZFs [**13**]. Deeper analyses performed for the same JT-60U discharge highlight that no energy exchange occurs between the TEM wavenumber and the zonal component of the flux, even when fast ions are introduced as an active species in the simulations. Furthermore, a local conservation relation for the particle toroidal momentum is derived and then applied to the GENE code in order to study the main physical parameters underlying the ZF excitation in the presence of fast ions, for which a competition among neoclassical damping and turbulent Reynolds-Maxwell stress effects is undergoing.

The results achieved opens the way to a more detailed physical view about the fast-ion effect on the microturbulence saturation process. In this sense, the universal physical mechanism governing the interaction among fast ion pressure gradient, electromagnetic fluctuations and microinstability-induced transport could be unveiled, leading to a better tailoring of the fast-ion species through the control of the external heating systems.

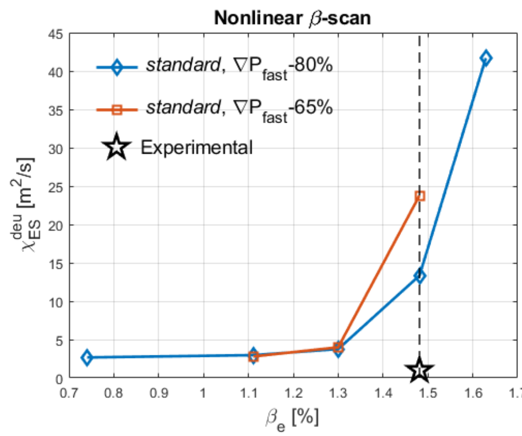

Figure 1. *Deuterium heat diffusivity for two different fast ion pressure gradient cases scanned over the electron-β parameter. 'Standard' input parameters case is displayed here. The dashed vertical line represents the nominal value of β* [**12**].

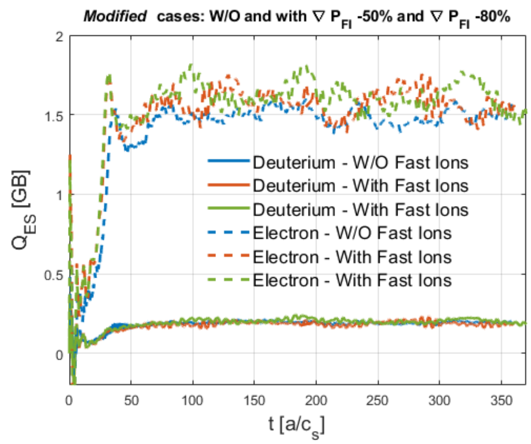

Figure 2. *Time trace comparison between the electrostatic heat fluxes with and without fast ions of electron and thermal deuterium species for the 'modified' case* [**12**].

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