Recognizing the hallmarks of the turbulent transport reduction by fast ions

S. Mazzi[1,2,3], J. Garcia[2], D. Zarzoso[1], Y. Kazakov[4], J. Ongena[4], M. Nocente[5], M. Dreval[6], C. Piron[7], JET contributors[a] and the TCV team[b]

[1] *Aix-Marseille Université, CNRS PIIM, UMR 7345 Marseille, France*
[2] *CEA, IRFM, F-13108 Saint-Paul-lez-Durance, France*
[3] *Ecole Polytechnique Fédérale de Lausanne (EPFL), Swiss Plasma Center (SPC), CH-1015 Lausanne, Switzerland*
[4] *Laboratory for Plasma Physics, LPP-ERM/KMS, TEC Partner, Brussels, Belgium*
[5] *Dipartimento di Fisica "G. Occhialini", Università di Milano-Bicocca, Milan, Italy*
[6] *National Science Center Institute of Physics and Technology, Kharkiv 61108, Ukraine*
[7] *ENEA, Fusion and Nuclear Safety Department, C. R. Frascati, Roma, Italy*
[a] *See the author list of 'Overview of JET results for optimizing ITER operation' by J. Mailloux et al., Nuclear Fusion (2022)*
[b] *See the author list of S. Coda et al. 2019 Nucl. Fusion 59 112023*

In burning plasmas of next-generation tokamak devices, such as ITER, the fusion-born alpha particles may lead to unexpected turbulence and transport regimes. As this issue has not been extensively studied in detailed in the present-day tokamaks, the development of experimental conditions mimicking burning plasmas is a clear priority.

This study is focused on analyzing a recently developed JET scenario [1], in which the three-ion scheme [2] is efficiently applied to generate a substantial population of ions in the MeV energy range, mimicking thereby the alpha particle's energy. Extensive and complex gyrokinetic studies were performed in order to analyze the underlying causes for the ion thermal confinement improvement, surprisingly obtained in the presence of dominant electron heating in the core and strongly unstable Alfvén Eigenmodes (AEs), both induced by the presence of the MeV ions [1]. The state-of-the-art gyrokinetic GENE code [3] is employed to self-consistently solve the MeV- and bulk-ion-scale turbulence dynamics and their interplay for the first time in a validated framework. The role of the unstable fast-ion-driven Toroidal AEs (TAEs) is demonstrated to be fundamental in the complex mechanism leading to the suppression of the ITG-driven turbulent transport [4]. TAE-induced fluctuations are shown, by means of multi-mode analyses, to nonlinearly couple to the zonal component of the electrostatic potential, triggering thereby a strong zonal flow activity. Thus, such shearing zonal activity effectively suppresses the ion-scale transport, leading to an optimum ion confinement. This turbulent transport reduction finds a noteworthy agreement with the experimental outputs, accurately matching also the power balances. The implications of these analyses for alpha-heated plasmas are discussed, showing that this mechanism might be effective in ITER, where fusion-born alpha particles are expected to excite TAEs [5]. Further numerical studies, inspired from a TEM-dominated TCV experimental scenario [6], identify the fingerprints for the possible reproducibility of this beneficial mechanism in different devices and turbulent regimes. This study, in conclusion, opens the way towards tailored and optimized experiments with highly energetic ions in future burning plasma conditions.

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