Energetic particles and multi-scale dynamics in fusion plasmas*

F. Zonca[1,2] and L. Chen[2,3]

[1]*ENEA C.R. Frascati, Via E. Fermi 45 – C.P. 65, 00044 Frascati, Italy*

[2]*Institute for Fusion Theory and Simulation and Department of Physics, Zhejiang University, Hangzhou, 310027 P.R. China*

[3]*Dept. of Physics and Astronomy, University of California, Irvine CA 92697-4575, U.S.A.*

The role of energetic particles (EPs) in fusion plasmas is unique as they could act as mediators of cross-scale couplings. More specifically, EPs can drive instabilities on the macro- and meso-scales; intermediate between the microscopic thermal ion Larmor radius and the macroscopic plasma equilibrium scale lengths. On one hand, EP driven shear Alfvén waves (SAW) could provide a nonlinear feedback onto the macro-scale system via the interplay of plasma equilibrium and fusion reactivity profiles. On the other hand, EP-driven instabilities could also excite singular radial mode structures at SAW continuum resonances, which by mode conversion yield microscopic fluctuations that may propagate and be absorbed elsewhere inducing nonlocal behaviors. The above observations thus suggest that the theoretical approach based on an extended inertial range becomes dubious for burning fusion plasmas and call for more advanced kinetic treatment of both EPs and thermal plasma. Energetic particles, furthermore, may linearly and nonlinearly excite zonal structures, thereby acting as generators of nonlinear equilibria that generally evolve on the same time scale of the underlying fluctuations. These issues will be presented within a general theoretical framework, discussing evidences from both numerical simulation results and experimental observations. Analogies of fusion plasmas dynamics with problems in condensed matter physics, nonlinear dynamics and accelerator physics will also be emphasized.

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