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Nonlinear radial envelope evolution equations and energetic particle transport in tokamak plasmas

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The role of energetic particles (EPs) in fusion plasmas is unique as they could act as mediators of cross-scale couplings [1,2]. Energetic particle driven shear Alfvén waves (SAWs), on one hand, could provide a nonlinear feedback onto the macro-scale system via the interplay of plasma equilibrium and fusion reactivity profiles. Meanwhile, 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 that require a global analysis.

Energetic particle transport must be described in phase space because of the underlying kinetic nature of wave-particle interactions and fluctuation excitations. The proper structures to describe such transport processes are phase space zonal structures (PSZS) [3]. Energetic particles, furthermore, may linearly and nonlinearly excite zonal field structures (ZFS), acting, thereby, as generators of nonlinear equilibria, or zonal states (ZS) that generally evolve on the same time scale of the underlying fluctuations. These issues are presented within a general theoretical framework. In particular, we present the nonlinear envelope equations that are needed to solve for the self-consistent evolution of the SAW fluctuation spectrum driven by EPs; and the PSZS transport equations, which determine the renormalized response of EPs including fluctuation induced transport [4].

References

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