ENERGETIC PARTICLES TRANSPORT IN THE PRESENCE OF GYROKINETIC TURBULENCE AND ALFVÉN ACTIVITY

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Energetic particles (EP) transport plays a key role in controlled nuclear fusion. In burning plasmas EP need to be confined long enough to ensure the transfer of energy to the thermal plasma to achieve self-sustained fusion reactions. This is a challenging problem because pervasive micro- and macro-instabilities and turbulence can dramatically reduce EP confinement and limit the performance of future devices including ITER and fusion pilot plans. Motivated by the pressing need to address this problem, we present a numerical study of EP transport in the presence of electromagnetic perturbations resulting from ITG-gyrokinetic turbulence and Alfvén activity.

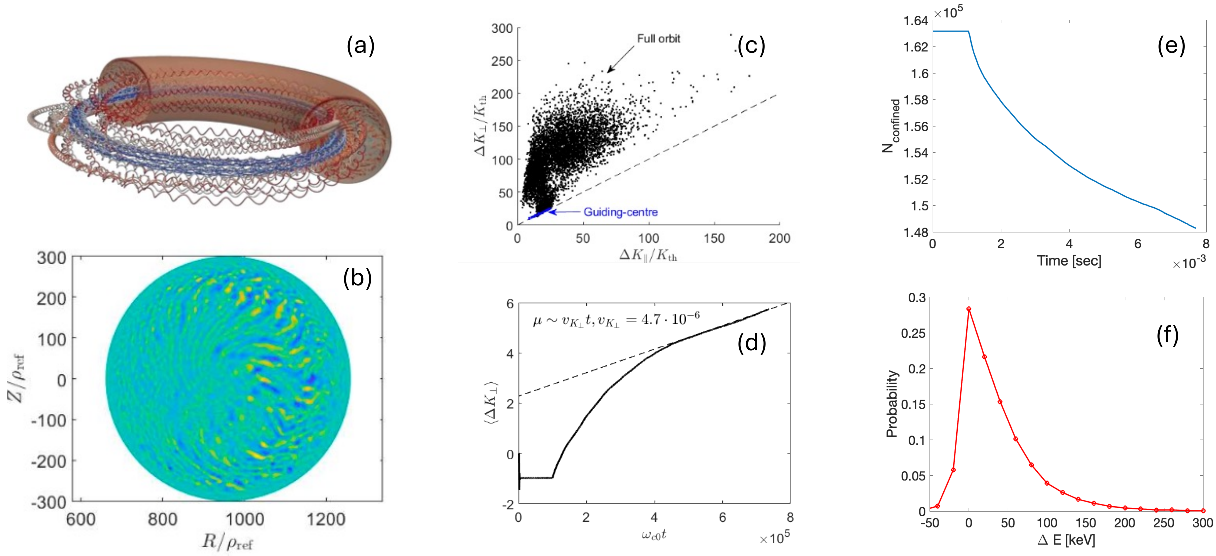

Figure 1. Energetic particle transport in ITG-driven gyrokinetic turbulence. (a) Sample full-orbit trajectories computed with TAPAS; (b) Poloidal cross-section of ITG-turbulent fluctuations; (c) Change in perpendicular energy with respect to parallel according to full-orbit and guiding centre models; (d) Growth in time of ensemble averaged perpendicular energy; (e) Confinement loss as function of time; (f) Probability distribution of energy change of lost particles.

Our study is based on the state-of-the-art, high-performance GPU-enabled, particle tracking code TAPAS [1,2], which for given electromagnetic fields, computes the trajectories of large ensembles of tracers using full-orbit or guiding-center models, including collisions. The ITG turbulence is computed using the code GYSELA and the Alfvén activity is computed using the gyro-fluid code FAR3d [3] which has been recently coupled to TAPAS [2]. Complementing these tools we also use recently developed Machine Learning (ML) methods including Convolutional Variational Autoencoders to accelerate turbulence computations [4] and Normalizing Flows to accelerate particle tracking computations [5,6]. The main objective is to quantify the dependence of confinement on the type, intensity, and spatiotemporal characteristic of electromagnetic perturbations and the properties of the EP distribution function.

Figure 1(a) shows a sample of EP trajectories computed with TAPAS in the presence of ITG-driven gyrokinetic turbulence, Fig.1(b). A distinctive novel feature of the computations presented in this work is that, as shown in Fig.1(c)-(d), ITG turbulence can lead to an increase of the perpendicular energy only captured when using a full-orbit description. The resulting loss of confinement is documented in Fig.1(e) along with the probability distribution of the energy change of the exiting EP in Fig.(f).

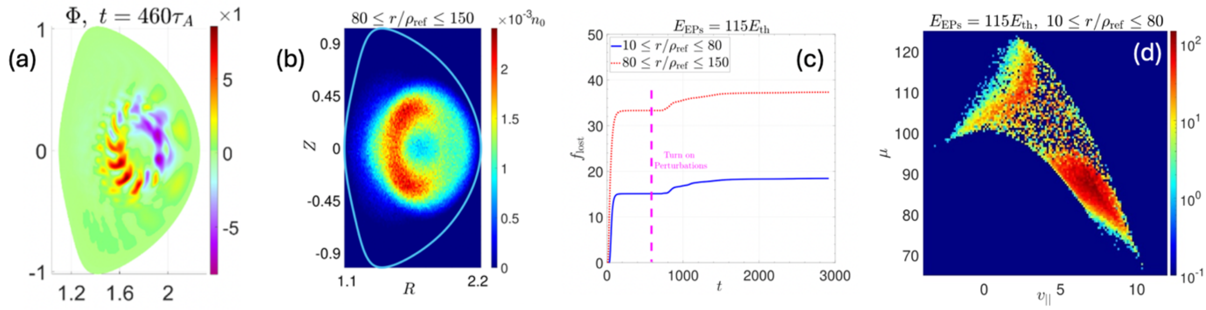

Figure 2. Energetic particle transport in the presence of Alfvén activity. (a) Poloidal cross-section of electrostatic fluctuations computed with FAR3d; (b) Number density of confined EP in the presence of Alfvén activity computed with FAR3d-TAPAS; (c) Confinement loss as function of time; (d) Distribution of number of lost particles in velocity phase space.

Figure 2 presents recent results on EP transport in the presence of Alfvén activity in DIII-D plasma discharge *#159243* using the TAPAS-FAR3d coupled model. Panel (a) shows the electrostatic potential fluctuations on a poloidal cross section at the early stage of the nonlinear saturation phase computed with FAR3d for a VMEC magnetic equilibrium. Panel (b) shows the effects of AE (Alfvén eigenmodes) on the spatial distribution of particles in the poloidal plane, with larger density values on the high field. The time evolution of the confinement loss is shown in panel (c). Significant prompt losses are observed before the introduction of the electromagnetic perturbations (vertical dashed line), followed by a smaller rate of particle losses in the presence of perturbations. Further insights on the dependence on the initial condition can be gained from panel (d) showing that for tracers closer to the magnetic axis the main contribution to the losses correspond to trapped ($v_{||} \leqslant 5$) and co-passing ($v_{||} \geqslant 5$) particles. Further results in this presentation include comparisons between simulations and diagnostic measurements of AE activity and EP fluxes in DIII-D [7] and JET [8,9]. In addition, progress on ML surrogates of turbulence and EP transport will be reported.

ACKNOWLEDGEMENTS

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