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Chirping Alfvén Eigenmodes Drive Convective and Diffusive Transport

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A major concern in burning plasmas is that high energy ions can excite plasma instabilities in the frequency range of Alfvén eigenmodes, which significantly enhance their transport. We focus on the Toroidal Alfvén Eigenmode (TAE). In many TAE experiments, the mode frequency is observed to split into two branches that sweep upwardly and downwardly. This nonlinear frequency sweeping (chirping) is due to the dynamics of phase-space structures, known as holes. Holes are vortex-like (BGK-like) structures in phase-space, with a depletion of density. Holes are formed by electrostatic self-trapping. Simulations of the Berk-Breizman extension of the bump-on-tail model reproduce many features of chirping TAEs, in a regime of quasi-periodically repetitive bursts.

In this paper, we analyse data of TAE experiments on MAST based on simulations of the Berk-Breizman model. We report on the impacts of phase-space structures on particle transport. We show that this nonlinearity induces collective transport, which exceeds the quasilinear estimate in unstable plasmas, and a new convective (drag) term. It is well known that the conventional wave-coherent response yields diffusive transport. In contrast, phase-space structures are wave-incoherent, and introduce convective transport. Indeed, trapped particles are convected along with phase-space structures. The flux-gradient relation confirms the existence of a strong convective flux.

Phase-space structures also contribute to diffusive transport. This is despite the absence of turbulence, since we consider a single mode. In other words, the observed transport contradicts quasi-linear theory, which predicts no transport at all. Phase-space structure-driven transport thus dominates for isolated single modes. In addition, our simulations suggest the possibility of strong turbulent flux (energy exchange) in linearly-stable plasmas.

These results impact resonance-driven modes in general, and TAE-driven transport in tokamaks with strong neutral beam injection in particular.

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Author: Prof. LESUR, Maxime (Kyushu University)

Co-authors: Prof. ITOH, Kimitaka (NIFS); Prof. DIAMOND, Patrick H. (NFRI, UCSD); Prof. ITOH, Sanae (Research Institute for Applied Mechanics, Kyushu University); Prof. KOSUGA, Yusuke (Kyushu University)

Presenter: Prof. LESUR, Maxime (Kyushu University)

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