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Modulated heat pulse propagation and partial transport barriers in 3-dimensional chaotic magnetic fields

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The quantitative understanding of the role of magnetic field stochasticity on transport is critical for the confinement of fusion plasmas. Specific problems of interest include the control of ELMs by resonant magnetic perturbations and the assessment of heat fluxes at the divertor. Here we present direct numerical simulations of the time dependent parallel heat transport equation modeling heat pulses driven by power modulation in 3-D chaotic magnetic fields. Understanding this problem is important because effective diffusivities, advection velocities, and damping rates are often inferred from local measurements of the amplitude and the phase of the propagation of harmonic temperature perturbations. Heat pulse propagation has also been recently used to study the connection between transport and magnetic field bifurcations in modulated electron cyclotron heating perturbative experiments in LHD and DIII-D. The numerical results presented here provide conclusive evidence that even in the absence of magnetic flux surfaces, chaotic magnetic field configurations exhibit partial barriers to modulated heat transport. In particular, it is shown that high-order islands and remnants of destroyed flux surfaces (Cantori) act as partial "leaky"barriers that slow down or even stop the inward propagation of heat waves where the connection length exhibits a strong gradient. Motivated by recent experimental studies in LHD and DIII-D we also present preliminary results on modulated heat pulse propagation across magnetic islands. The geometry used in this calculation is toroidal and the magnetic field was obtained using the MHD equilibrium code SIESTA. It is shown that magnetic islands, in particular the elliptic (O) and the hyperbolic (X) points, have a direct impact on the spatio-temporal dependence of modulated heat pulses. The main computational challenge in the work presented here stems from the strong asymmetry between the parallel and perpendicular conductivities. To address this problem, we use a Lagrangian Greene's function (LG) method that bypasses known limitations of grid-based methods. To deal with time periodic sources, we present a novel reformulation of the LG method in Fourier space that is significantly more efficient than the original real space version of the method.

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