DPP11-2011-000876

Abstract for an Invited Paper
for the DPP11 Meeting of
the American Physical Society

Local and Nonlocal Parallel Heat Transport in General Magnetic Fields[1]

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Transport in magnetized plasmas is a topic of fundamental interest in controlled fusion, space plasmas, and astrophysics. Three issues make this problem particularly challenging: (i) The *extreme anisotropy* between the parallel (i.e., along the magnetic field), $\chi_{\|}$, and the perpendicular, $\chi_{\perp}$, conductivities; (ii) Magnetic *field lines chaos* which may preclude the use of magnetic coordinates; and (iii) *Nonlocal parallel transport* in the limit of small collisionality. As a result of these challenges, standard finite-difference and finite-element numerical methods face significant limitations. Motivated by the strong anisotropy typically encountered in magnetized plasmas ($\chi_{\perp}/\chi_{\|}$ may be less than 10^{-10} in fusion plasmas) we consider heat transport in the extreme anisotropic regime, $\chi_{\perp} = 0$. To overcome the limitations of previous approaches, we present a novel Lagrangian Green's function method that bypasses the need to discretize and invert the transport operators on a grid.[2] The method allows the integration of the parallel transport equation without perpendicular pollution, preserving the positivity of the temperature field at all times. The method is applicable to local (i.e., diffusive) and non-local (e.g., free streaming) heat flux closures in integrable or chaotic magnetic fields. The method is applied to study: (i) Local and non-local parallel temperature mixing and flattening inside magnetic islands; (ii) Fractal structure of the Devil's staircase temperature profile in the previously inaccessible $\chi_{\perp} = 0$ regime in weakly chaotic fields; (iii) Transport in fully chaotic fields. For the last problem it is shown that, for local and non-local parallel closures, transport is incompatible with the quasilinear diffusion model. In particular, flux-gradient plots show clear evidence of non-diffusive, non-local effective radial transport.

[1]Supported by U.S. DOE Contract DE-AC05-00OR22725.

[2]D. del-Castillo-Negrete and L. Chacon, Phys. Rev. Lett. **106** 195004 (2011).