Modeling (mis)adventures with the extremely anisotropic heat transport equation in fusion-grade magnetized plasmas

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Transport in magnetized plasmas is of fundamental interest in controlled fusion and astrophysics research. Three challenges make this problem particularly difficult to study: (i) The *extreme anisotropy* between the parallel (i.e., along the magnetic field), $\chi_\parallel$, and the perpendicular, $\chi_\perp$, diffusivities ($\chi_\parallel/\chi_\perp$ may exceed 10^{10} in thermonuclear magnetized fusion plasmas); (ii) *magnetic field-line stochasticity,* which in general precludes the construction of magnetic field line coordinates; and (iii) *nonlocal parallel transport* in the limit of small collisionality. These issues make the accurate numerical treatment of the parallel electron transport operator extremely challenging. In fact, finding a suitable numerical approach that simultaneously possesses high-order accuracy (to avoid numerical pollution of the perpendicular dynamics), robust positivity-preservation (i.e., with a maximum principle), and algorithmic scalability (i.e., amenable to modern iterative methods) is remarkably challenging. In this talk, I will describe our history solving this stubborn equation over the last 15 years using both semi-Lagrangian [1-5] and Eulerian [6] approaches, culminating with recent magnetohydrodynamics simulations of disruptions in the ITER tokamak fusion reactor [6,7].

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