Eliminating the CFL timestep constraint in nonlinear gyrokinetics

Robert Davies[1], Jason Parisi[2], Michael Barnes[3]

[1]York Plasma Institute, University of York

[2]UK Atomic Energy Authority

[3]Rudolf Peierls Centre for Theoretical Physics, University of Oxfird

Abstract

Gyrokinetics is a powerful theoretical framework used to study transport in MCF plasmas, and has been widely employed both to explore the physical mechanisms underlying plasma turbulence and to make quantitative estimates of turbulent transport. Usually, the model equations (which are five-dimensional and nonlinear) must be solved numerically, and thus considerable effort has been spent developing methods which maximise the accuracy whilst minimising the computational cost of gyrokinetic simulations.

A particular numerical difficulty in local gyrokinetics arises in electromagnetic simulations in which the nonlinear term is included. The nonlinear term (the advection of the perturbed plasma distribution function by an electromagnetic drift) is typically calculated using an explicit numerical scheme, and this gives rise to a Courant-Friedrichs-Lewy (CFL) timestep constraint, which becomes prohibitive as the plasma β (the ratio of thermal to magnetic pressure) becomes moderate. Since fusion devices are steadily achieving (or expecting to achieve) higher β values, it is highly desirable that nonlinear electromagnetic simulations can routinely be performed.

In this work, we present a scheme which avoids the CFL condition altogether, by calculating the nonlinearity using an interpolation-free semi-Lagrangian approach. This scheme is numerically stable for arbitrary simulation timestep, and thus permits the timestep to be selected based on the physics of interest, rather than by the spatial resolution of the simulation. The implementation of this scheme in the local, operator-split, Eulerian code `stella` is described, and we examine the computational savings this offers over a range of parameter space.