Novel algorithms for the accurate and fast solution of the two-fluid plasma equations

X. Ke Lin, S.T. Millmore, N. Nikiforakis

Laboratory for Scientific Computing, Department of Physics, University of Cambridge

The disparate time- and length-scales associated with the physics of magnetically confined fusion necessitate the deployment of a variety of simulation strategies, ranging from magnetohydrodynamic (MHD) to kinetic (or gyrokinetics) based models. Single-fluid MHD, though computationally efficient, is invalid in regimes with small length and time scales, whilst kinetic methods are computationally expensive in simulations of full-domain phenomena, due to their high dimensionality. Two-fluid plasma models offer an attractive compromise between the two approaches, by significantly reducing the dimensionality of the problem, but retaining important physics lost by standard MHD models. This work is concerned with the numerical solution of the two-fluid model by means of a finite volume approach and this work presents new innovations to improve the simulation efficiency. Divergence-free techniques are used and the cost of the calculation is reduced by relaxing the time step restrictions from the speed of light constraint with an implicit Maxwell solver (with finite-difference time-domain) or sub-cycling the Maxwell equations (with finite-volume time-domain). Further improvement of the efficiency of the solution is achieved by using a locally implicit treatment of the stiff source terms and using of projection methods to reduce divergence errors introduced by this source treatment. The algorithms are implemented in a highly parallelized software framework, and are validated against benchmarks from the open literature. It is shown that the new algorithms considerably reduce the computational times compared to traditional fully explicit methods.

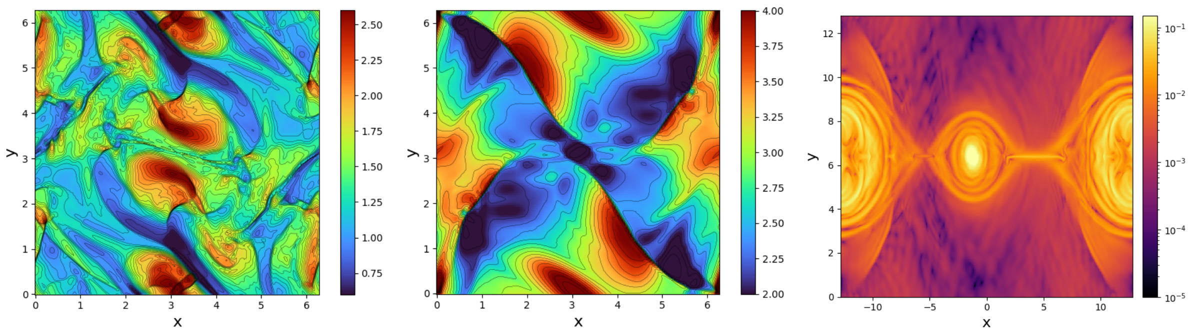

Figure 1: *Validation test cases for both small and large length and time scales. From left to right - ideal MHD Orszag-Tang vortex, two-fluid Orszag-Tang vortex, GEM magnetic reconnection challenge.*