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This project funding supported approximately 74 percent of a Ph.D. graduate student, not including costs of travel and supplies. We had a highly successful research project including the development of a second-order implicit electromagnetic kinetic ion hybrid model [Cheng 2013, Sturdevant 2016], direct comparisons with the extended MHD NIMROD code and kinetic simulation [Schnack 2013], modeling of slab tearing modes using the fully kinetic ion hybrid model and finally, modeling global tearing modes in cylindrical geometry using gyrokinetic simulation [Chen 2015, Chen 2016].

We developed an electromagnetic second-order implicit kinetic ion fluid electron hybrid model [Cheng 2013]. As a first step, we assumed isothermal electrons, but have included drift-kinetic electrons in similar models [Chen 2011]. We used this simulation to study the nonlinear evolution of the tearing mode in slab geometry, including nonlinear evolution and saturation [Cheng 2013]. Later, we compared this model directly to extended MHD calculations using the NIMROD code [Schnack 2013]. In this study, we investigated the ion-temperature-gradient instability with an extended MHD code for the first time and got reasonable agreement with the kinetic calculation in terms of linear frequency, growth rate and mode structure. We then extended this model to include orbit averaging and sub-cycling of the ions and compared directly to gyrokinetic theory [Sturdevant 2016]. This work was highlighted in an Invited Talk at the International Conference on the Numerical Simulation of Plasmas in 2015. The orbit averaging sub-cycling multi-scale algorithm is amenable to hybrid architectures with GPUS or math co-processors.

Additionally, our participation in the Center for Extend Magnetohydrodynamics motivated our research on developing the capability for gyrokinetic simulation to model a global tearing mode. We did this in cylindrical geometry where the results could be benchmarked with existing eigenmode calculations. First, we developed a gyrokinetic code capable of simulating long wavelengths using a fluid electron model [Chen 2015]. We benchmarked this code with an eigenmode calculation. Besides having to rewrite the field solver due to the breakdown in the gyrokinetic ordering for long wavelengths, very high radial resolution was required. We developed a technique where we used the solution from the eigenmode solver to specify radial boundary conditions allowing for a very high radial resolution of the inner solution. Using this technique enabled us to use our direct algorithm with gyrokinetic ions and drift kinetic electrons [Chen 2016]. This work was highlighted in an Invited Talk at the American Physical Society - Division of Plasma Physics in 2015.

References

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