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Multiscale Full Kinetics as an Alternative to Gyrokinetics[1]

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Gyrokinetics has been extremely successful for modeling low frequency well-magnetized plasmas. However, for many plasmas, the expansion parameters in gyrokinetic theory are not so small. Until now, gyrokinetics was the only useful kinetic simulation model available for low frequency and weakly unstable plasmas even when its validity was questionable. Here, we report a new simulation model with full kinetic ions (Lorentz force dynamics) using implicit multi-scale techniques. This is the first six-dimensional model to accurately capture low-frequency physics, including finite Larmor radius (FLR) effects and weak gradient drive drift wave-type instabilities, operating comfortably within domain of gyrokinetics. Such a model allows for verification of gyrokinetics and can help identify the relative importance of higher order terms in gyrokinetic theory. Here we present full kinetic simulations of the toroidal ion-temperature-gradient (ITG) instability in tokamak plasma geometry. We will discuss the orbit averaging and sub-cycling techniques as well as the implicit variational integrator for the particle trajectories necessary to preserve adiabatic invariants. Results comparing the full kinetic model with gyrokinetics are reported. In slab geometry, excellent agreement is obtained linearly and nonlinearly including full FLR effects. High-frequency Ion Bernstein waves, which are present in the full kinetic model can easily be suppressed with the implicit time advance while maintaining FLR effects. The fully kinetic toroidal model uses field-line-following coordinates for the field quantities providing well-resolved field-aligned mode structure. Benchmarks with gyrokinetics within the domain of validity of gyrokinetics show excellent agreement. Nonlinear ITG simulations in slab geometry with both gyrokinetics and full kinetics will be compared in more marginal steep gradient regimes. Reference: "An Implicit Delta-f Particle-in-Cell Method with Sub-Cycling and Orbit Averaging for Lorentz Ions, B.J. Sturdevant, S.E. Parker, Y. Chen, and B. Hause, J. Comput. Phys., **316** 519 (2016).

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