Differences between PIC, real, and Vlasov-Maxwell plasmas

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The widespread use of particle-in-cell (PIC) codes for studying plasmas out of equilibrium calls for a deep understanding of the PIC model, and of its relations with a real plasma and with the Vlasov-Maxwell description.
The PIC model lies on two building blocks. The first stems from the capability of computers to handle only up to ~ 10^{10} particles, while real plasmas contain from 10^4 to 10^{20} particles per Debye sphere: a coarse-graining step must be used, whereby of the order of p ~ 10^{10} real particles are represented by a single computer “superparticle”. The second is field storage on a grid with its subsequent finite superparticle size.
We introduce the notion of coarse-graining dependent quantities, i.e. physical quantities depending on p. They all derive from the plasma parameter Λ, that we show to behave as $\Lambda \propto 1/p$. Important applications include the PIC collision- and fluctuation-induced thermalization times, that scale with the number of superparticles per grid cell and are a factor p ~ 10^{10} smaller than in real plasmas, and the level of electric field fluctuations, that scales as $1/\Lambda \propto p$. We show how large superparticle sizes of the order of the Debye length modify these scalings.
We investigate the extent to which these unphysically large parameters alter the PIC plasma physics with two main examples: the rapid thermalization of plasmas with two different temperatures, and the blurring of the linear spectrum of the filamentation instability. In the latter case, the fastest growing modes do not dominate the total energy because of a high level of fluctuations, and effective growth rates measured on the totalenergy can differ by more than 50% from the linear cold predictions.
We also stress that a PIC plasma bears differences with the Vlasov-Maxwell description, which models a phase-space fluid with $\Lambda = +\infty$ and no correlations.