Title: The effect of electrostatic fields on filament formation in counterstreaming plasma beams: Particle-In-Cell Simulations

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Abstract:

Context: Powerful magnetic fields inferred in multi-wavelength observations of gamma ray bursts and supernova remnants can be self-generated and amplified by kinetic effects in a collisionless plasma. Since Coulomb collisions are negligible, the interaction of counterstreaming plasma beams is mediated by the electric and magnetic fields. The filamentation instability is a key mechanism for self-generation of magnetic field in a quasi-neutral plasma.

Aims: We assess the impact of the electrostatic fields on the shape and on the interplay of the current filaments during the nonlinear interaction of counterstreaming electron-only and electron-positron beams, since strong electrostatic fields are observed only for electron-only beams but are suppressed in electron-positron beams

Method: We select beam speeds and densities for which the filamentation instability is by far the fastest growing one [1]. It will dominate the plasma evolution and, because of our initial conditions, its wave vectors are strictly orthogonal to the beam velocity vector. This maximizes the physical realism of our 2D particle-in-cell (PIC) simulation. We consider here symmetric counter-streaming beams of charged particles and an initially field-free charge- and current neutral plasma. The numerical simulations were carried out using the well-tested PSC code [2] on 4096 processors of an IBM BlueGene/P which permitted an unprecedented resolution. The simulations averaged approximately 36 hours of walltime or $\sim$144,000 hours of CPU time.

Results: We confirm that the exponential growth rate of the magnetic field is close to the analytical value of $\beta\sqrt{2/\Gamma_b}$. The growth rate and saturation amplitude of the non-linearly driven electrostatic field differ strongly between positron and fixed ion simulations. The absence of mobile positrons allows the growth of the electrostatic fields. The net current in the filaments at the end of the simulation is reduced compared to its peak value by 1-2 orders of magnitude thanks to the dissipation of the beam energy by the filament mergers and the action of in-plane currents driven by the magnetic pressure gradient force.

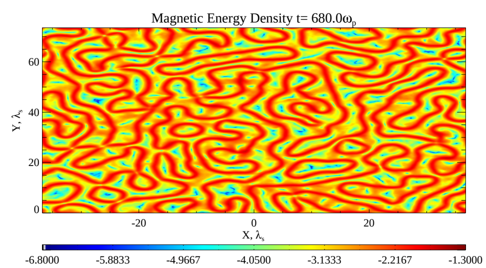

FIGURE 1. Magnetic energy density for EP beam

Conclusions: We find that the growth and saturation of magnetic field is negligibly affected by the presence/absence of electrostatic fields. Magnetic trapping, which neglects electrostatic fields, is thus a good approximation for the saturation amplitude of the magnetic field. However, we find that the electrostatic fields strongly affect the size, shape and statistical distribution of the current filaments. The decrease in electric current thanks to dissipation of filaments is also accelerated by the presence of electrostatic fields.

References

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