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Interplay between protons and electrons in a firehose-unstable plasma: Particle-in-cell simulations

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Kinetic plasma instabilities originating from unstable, non-Maxwellian shapes of the velocity distribution functions serve as internal degrees of freedom in plasma dynamics, and play an important role near solar current sheets and in solar wind plasmas. In the presence of strong temperature anisotropy (different thermal spreads in the velocity space with respect to the mean magnetic field), plasmas are unstable either to the firehose mode or to the mirror mode in the case of predominant parallel and perpendicular temperatures, respectively. The growth rates of these instabilities and their thresholds depend on plasma properties, such as the temperature anisotropy and the plasma beta. The physics of the temperature anisotropy-driven instabilities becomes even more diverse for various shapes of velocity distribution functions and the particle species of interest. Recent studies based on a linear instability analysis show an interplay in the firehose instability between protons and electrons when the both types of particle species are prone to unstable velocity distribution functions and their instability thresholds. In this work we perform for the first time 3D nonlinear PIC (particle-in-cell) numerical simulations to test for the linear-theory prediction of the simultaneous proton-electron firehose instability. The simulation setup allows us not only to evaluate the growth rate of each firehose instability, but also to track its nonlinear evolution and the related wave-particle interactions such as the pitch-angle scattering or saturation effects. The specialty of our simulation is that the magnetic and electric fields have a low numerical noise level by setting a sufficiently large number of super-particles into the simulation box and enhancing the statistical significance of the velocity distribution functions. We use the iPIC3D code with fully periodic boundaries under various conditions of the electron-to-proton mass ratio, which gives insight into the instability interplay at the intermediate electron-proton and on the scaling of our results towards more realistic particle settings.