Generalized entropy production and nonthermal particle acceleration in collisionless plasmas

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Collisionless plasmas develop nonthermal particle distributions after being energized, and thus enter a state of non-maximal Boltzmann-Gibbs entropy. While the Vlasov equation predicts that Boltzmann-Gibbs entropy is formally conserved (along with an infinite set of other Casimir invariants), coarse-grained entropy production is enabled by phase mixing and nonlinear entropy cascades. Characterizing the nature and extent of entropy production for various irreversible processes is a key problem in plasma physics. I will describe a theoretical framework for representing entropy production via an infinite set of dimensional quantities, the "Casimir momenta", which generalize the Boltzmann-Gibbs entropy. Evolution of the Casimir momenta indicates violation of the Vlasov equation (and therefore irreversibility) at the corresponding energy scales. I will describe how Casimir momenta can be used as a diagnostic to demonstrate efficient entropy production (skewed toward high energies) in particle-in-cell simulations of relativistic turbulence. I will also describe the application of Casimir momenta to modeling nonthermal particle acceleration in turbulence and magnetic reconnection, where kappa distributions are obtained by maximizing the Casimir momenta subject to the energy constraint. This framework may be applied to model astrophysical and space systems, such as the solar wind and Earth's magnetosphere.