Nonlinear wave-particle interaction and electron kappa distribution

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In this presentation, I will discuss the physics of nonlinear wave-particle interactions that lead to the electron kappa velocity distribution function as a stationary asymptotic state. The theoretical framework is based upon the plasma weak turbulence theory, which does not invoke non-extensive thermodynamics, but the final time-asymptotic solution shows that the kappa distribution is the only allowable state in weakly turbulent plasma, the other exact solution being the Maxwell-Boltzmann distribution for quiescent plasma. I will also discuss the transition from initial Vlasov equilibrium, which can be viewed as a system far from equilibrium, followed by the collective relaxation via beam-plasma instability excitation. The beam-plasma instability is a well-known and textbook problem that involves the emission of Langmuir waves by a streaming electron beam in the background of stationary plasma. The linear instability theory predicts exponential wave growth, but quasilinear relaxation saturates the linear instability. However, the quasilinear saturation is not a true time-asymptotic steady state since nonlinear mode coupling stage follows the quasilinear saturation. The nonlinear mode coupling processes(s) eventually bring(s) the system to the so-called turbulent quasi equilibrium state [Treumann, 1999], which is characterized by the kappa distribution. The final turbulent quasi-equilibrium state can be rigorously studied by employing the steady-state assumption of kinetic weak plasma turbulence theory. Analytical solution shows that one possible steady-state solution is the thermodynamic equilibrium solution (Maxwell-Boltzmann state). On the other hand, if the steady state includes a finite level of turbulent fluctuations, then the only allowable solution is the kappa solution (the non-extensive state) with a specific value of kappa index [Yoon, 2012, 2014]. Thus, this seems to show that nature allows either a thermodynamic equilibrium state or kappa equilibrium state. This finding implicates a profound inter-relationship between the turbulent equilibrium state in plasmas and the non-extensive thermodynamic description.

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