AURORAL ELECTRON ENERGIZATION DUE TO KINETIC ALFVÉN WAVE TURBULENCE

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1. Introduction

One of the most ubiquitous aspects of particle properties in the auroral magnetosphere and cusp/cleft regions is the observation of a nearly mono-energetic peak in the electron energy spectra parallel to the ambient magnetic field [1]. This structures are commonly interpreted as a consequence of a field-aligned potential drop, produced when magnetic field lines are being reconnected [2] but may result also from an acceleration mechanism by wave-particle interaction due to the presence of auroral kinetic Alfvén wave turbulence [3, 4, 5]. Basic properties of charged particle dragging by an unidirectional kinetic Alfvén wave through momentum transfer from waves to particles where analyzed by Tsui and de Assis [6] and de Assis and Tavares [7] and discussed in a restrictive way by Dendy et al. [8] and de Assis et. al. [9]. We formulate the problem in view of auroral electron acceleration processes by kinetic Alfvén waves, where the unperturbed particle distribution already exhibits observed, superthermal tails and model the time evolution of the distribution function due to wave-particle interaction within the Fokker-Planck diffusive formalism.

2. Theory

The advantage to model energetic particles of space plasmas by a power law at high energies was already pointed out by Vasyliunas [10] and applied by Leubner [11]. With respect to the observed superthermal tails of magnetospheric electron distributions we consider a uniformly magnetized electron-ion plasma where the electron species is modeled in parallel direction by a one dimensional κ-distribution of the form

$$F(v_{\parallel}) = \frac{N}{\Theta_{\parallel}\sqrt{\pi}} \frac{\Gamma(\kappa+1)}{\kappa^{3/2}\Gamma(\kappa-1/2)} \left(1+\frac{v_{\parallel}^2}{\kappa\Theta_{\parallel}^2}\right)^{-(\kappa+1)} \tag{1}$$

see Figure 1. The parameter κ shapes predominantly the superthermal tails of the distribution,

Γ denotes the standard Gamma function and N the particle density.

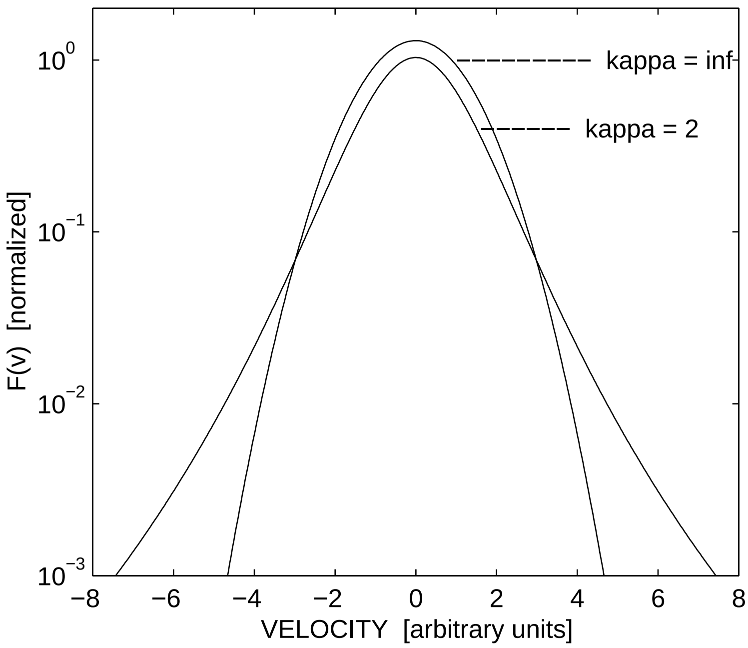

Figure 1. Schematic plot of a $\kappa-$ distribution and a Maxwellian

Defining the temperature as moment over the entire distribution function yields the effective parallel thermal velocity $\Theta_{\|} = \sqrt{2k_B T_{\|}(\kappa - 3/2)/m\kappa}$. As $\kappa \to \infty$, $F(v_{\|})$ approaches a Maxwellian distribution. The problem can be reduced to one dimensions assuming axial symmetry, low collisionality such that changes in the pitch angle are negligible and noting that the main dynamics of wave-particle energy exchange due to Cherenkov interactions is regulated in parallel velocity space. Hence, modeling the wave-particle interaction by a diffusive process, we consider the time evolution of the electron distribution function $F(v_{\|}, t)$ being regulated by the Fokker-Planck equation as

$$\frac{\partial F}{\partial t} = \frac{\partial}{\partial v_{\|}} \nu_c(v_{\|}) \left[v_{\|} F + v_{th}^2 \frac{\partial F}{\partial v_{\|}} \right] + \frac{\partial}{\partial v_{\|}} D(v_{\|}) \frac{\partial F}{\partial v_{\|}} \tag{2}$$

Here $\nu(v_{\|})$ and $D(v_{\|})$ denote the collision and diffusion operators, respectively, v_{th} is the electron thermal speed and the initial condition $F(v_{\|}, t = 0)$ is specified by equation (1). Combining all constants into a normalizing diffusion constant D_0 and introducing a width shaping parameter s, we approximate the diffusion operator by a Gaussian spectrum [8, 12] shifted by the Alfvén velocity v_A as

$$D(v_{\|}) = D_0 \exp \left[-\frac{(v_{\|} - v_A)^2}{(s v_{th})^2} \right] \tag{3}$$

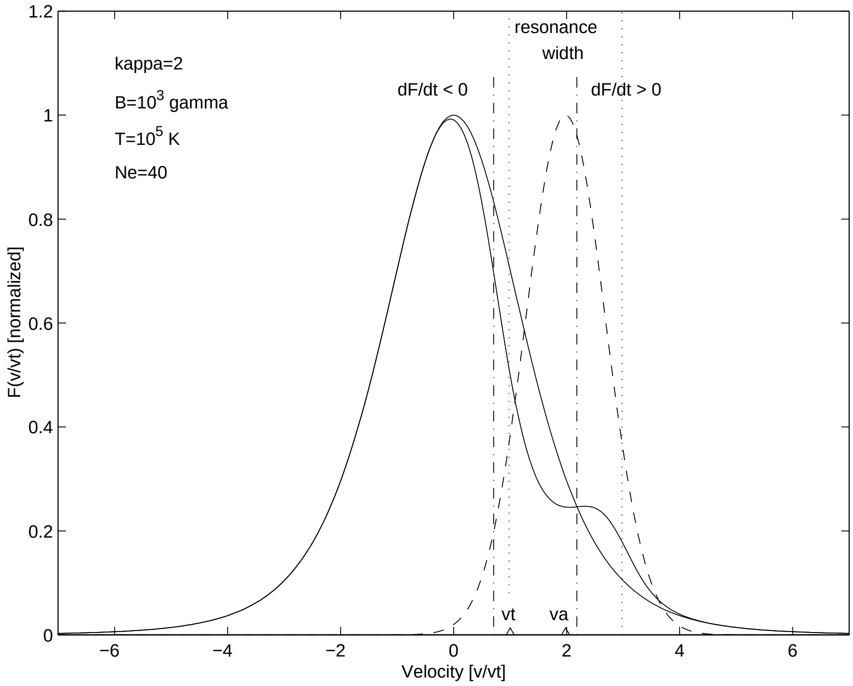

Figure 2. Wave-particle interaction regions

3. Results and conclusions

From the numerical simulation of the time evolution of the electron distribution some basic characteristics of a diffusive energy transfer from a Gaussian wave spectrum, indicated by the dashed lines and centered at v_A are illustrated in Figure 2.

The solid lines represent the time evolution of a κ distribution and the resonance width sv_{th} is indicated by dotted lines. With respect to the sign of $\partial F(v_\parallel, t)/\partial t$ as depending on the position $v_\parallel$, the velocity space can be separated into three distinct regions. For $v_\parallel \ \& \ v_A$ energy transfer to particles from the time-constant Gaussian wave power spectrum is a persistent feature, shaping consistent with Kletzing [4] a bump in the tail of the particle distribution as time proceeds.

The peaks of typical auroral electron energy spectra are commonly observed in the range of hundred eV's to 1keV. With respect to energy dependence, figure 3 shows a time sequence of an initially unperturbed $\kappa-$ distribution reflecting accurately the properties of inverted 'V' events and electron structure shapes as measured by DE 1 and DE 2 experiments [1, 13]. In addition, turning on a constant collision frequency ν_c yields a thermalization of the distribution around E_{res}, the maximum of the wave spectrum, where particle conservation is maintained throughout the simulations.

From a detailed parameter study it is concluded that for wave driven acceleration processes the superthermal tails of the unperturbed auroral electron distributions predominantly regulate the final observed structure shapes. The power spectrum width optimizes the parallel energization rate with $s = 1$ just at the thermal velocity.

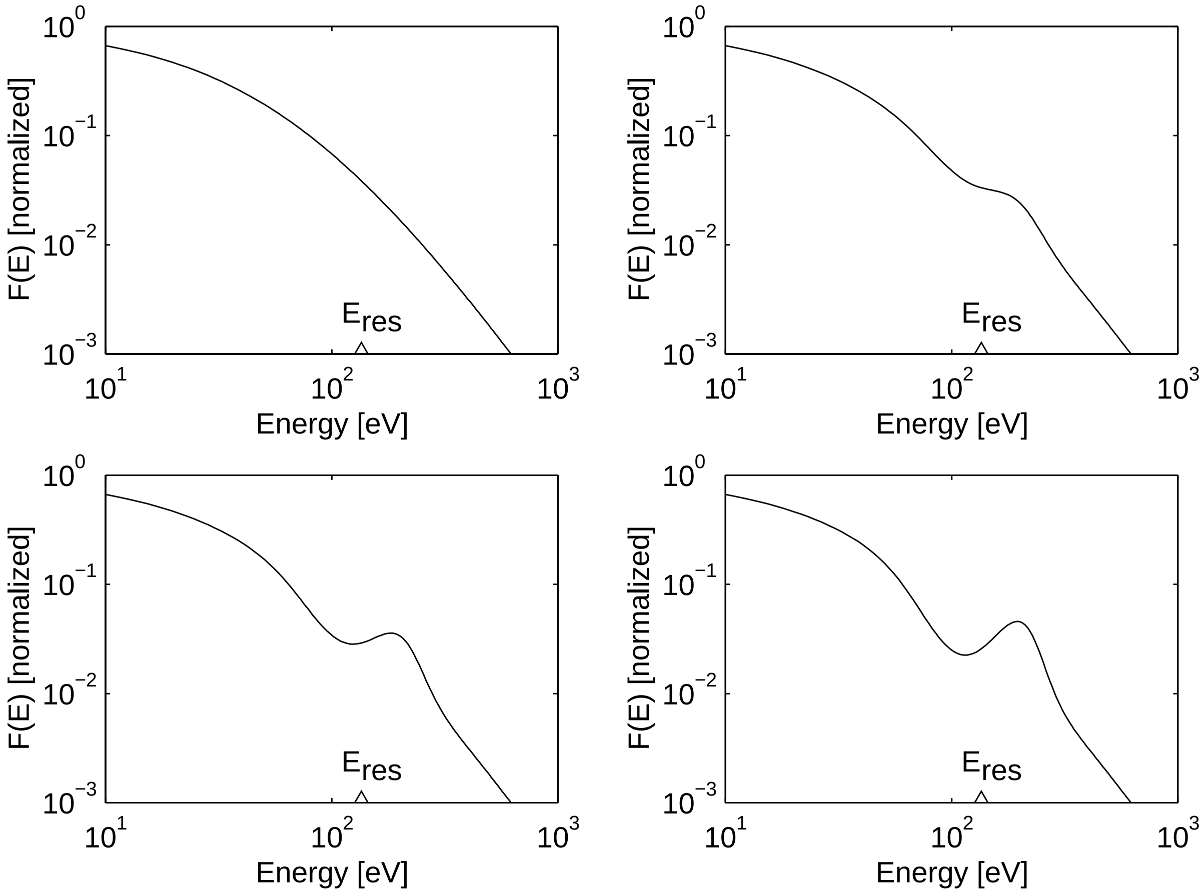

Figure 3. Time evolution of a $\kappa = 2$ distribution: $B = 0.02G,\ T = 10^5K,\ N = 40cm^{-3}$

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