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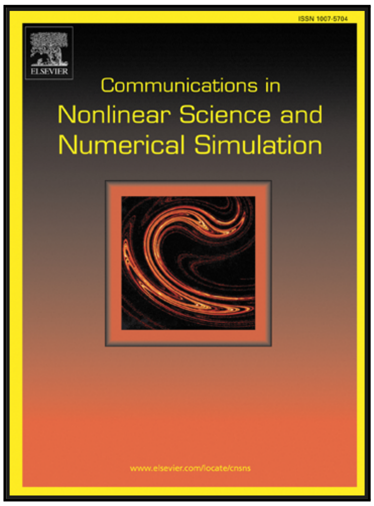

Generation of discrete structures in phase-space via charged particle trapping by an electrostatic wave

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Highlights

- We investigated the fine structure of motion of particles trapped (captured) into resonance with electrostatic wave
- We showed that the energy distribution of trapped particle ensemble has several maxima
- We computed the profile of each maxima

Generation of discrete structures in phase-space via charged particle trapping by an electrostatic wave

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Abstract

The wave-particle resonant interaction plays an important role in the charged particle energization by trapping (capture) into resonance. For the systems with waves propagating through inhomogeneous plasma, the key small parameter is the ratio of the wave wavelength to a characteristic spatial scale of inhomogeneity. When that parameter is very small, the asymptotic methods are applicable for the system description, and the resultant energy distribution of trapped particle ensemble has a typical Gaussian profile around some mean value. However, for moderate values of that parameter, the energy distribution has a fine structure including several maxima, each corresponding to the discrete number of oscillations a particle makes in the trapped state. We explain this novel effect which can play important role for generation of unstable distributions of accelerated particles in many space plasma systems.

Keywords: wave-particle interaction; resonance; adiabatic invariant

1. Introduction

Wave-particle resonant interaction in strong magnetic fields explains many observable effects in space plasma systems [1, 2]. For sufficiently intense waves, this interaction is nonlinear, [3, 4] and includes such effects as phase trapping (capture) and phase bunching. Natural inhomogeneity of plasma and magnetic fields in the near-Earth space (radiation belts, the outer magnetosphere, solar wind) results in significant modification of resonant particle interaction [5, 6, 7]. Particle trapping in inhomogeneous plasma can lead to formation of unstable plasma distributions and emission of secondary waves [8, 9, 10]. This theory is widely used for description of wave generation in the Earth's radiation belts [11, 12, 13, 14, 15].

Dynamics of trapped particles is defined by a (small) parameter of the plasma system with a wave: the ratio of wavelength $\sim 1/k$ and background plasma inhomogeneity scale L: $\kappa = 1/kL$. For the nonlinear wave-particle interaction to be important, the wave amplitude Φ_0 should be of order of κ (or larger), otherwise wave electromagnetic fields are too weak to significantly affect charged particle motion [3, 4, 16]. Intense waves generate effective potential wells where particles can be trapped. Trapped particles oscillate in the effective potential with a frequency $\Omega_{trap} \sim \sqrt{1/\kappa}$ (see, e.g., [17, 18, 19]), whereas the duration of the trapped motion is of order of $O(1)$, i.e., it does not depend on κ. Thus, trapped particles make $N \sim \sqrt{1/\kappa}$ oscillations between the instance of trapping (capture) into resonance and escape from resonance. For $N \gg 1$ asymptotic theory adequately predicts change of particle energy between trapping and escape [20, 21, 22, 23, 24]. In this case, the final particle spectrum does not depend on N (i.e., on κ).