# Nonlinear wave-particle and wave-wave interactions in the outer radiation belt: physical mechanisms and observational effects

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Observations by the Van Allen Probes provide high-quality ELF/VLF measurements of wave electric field component parallel to the ambient magnetic field that revealed new nonlinear electron scales features in the outer radiation belt, important for particle acceleration and scattering and showing the influence of nonlinear wave-particle interactions on the energetic electron distribution over macroscopic spatial scales.

The parallel electric field component of whistler-mode waves provides trapping of hot electrons into the effective potential and in inhomogeneous systems such as the dipole-like geomagnetic field allow an efficient parallel acceleration up to ~20-200 keV eventually leading to bursty precipitation (observed as microbursts at ionospheric altitudes). The mechanisms that produce nonlinear electric field structures, including the nonlinear evolution of oblique whistler-mode waves due to electron trapping and the parametric interaction of whistler waves have been determined. Important nonlinear processes responsible for rapid particle acceleration or scattering, with a significant effect on the global dynamics of the outer radiation belt, are listed below:

- the distribution of high amplitude whistler-mode waves (oblique and parallel) and resonant electron distribution function features in the outer radiation belt are connected self-consistently;

- whistler-mode waves with a large parallel electrostatic component (up to 100 mV/m) may allow Landau trapping of hot electrons into the wave effective potential with rapid parallel acceleration and possible bursty precipitation;

- specific plasma conditions: a prevalence of the hot electron population provides the possibility of generating an electron acoustic mode, and corresponding mechanisms of nonlinear wave-wave coupling lead to the formation of nonlinear parallel electric field bursts from oblique whistlers

- nonlinear wave-particle interactions with oblique whistlers influence the global dynamics of the electron distribution in the outer radiation belt; parallel acceleration of low-energy electrons trapped by very oblique waves up to the energy range of cyclotron resonance with parallel waves is very efficient and can result in a quick suppression of the temperature anisotropy necessary for parallel wave growth, leading to separate observations of intense very oblique and parallel chorus in the outer radiation belt.