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Nonlinear Drift Bounce Resonance Between Charged Particles and Ultralow Frequency Waves

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In Earth's magnetosphere, ultra-low frequency (ULF) electromagnetic waves in the mHz frequency range are ubiquitously identified in space and ground-based observations, which have been found to play a key role in accelerating and transporting charged particles in the Van Allen radiation belts, and thereby regulate the energy flow of the Sun-Earth system (e.g., Zong et al., 2007; Claudepierre et al., 2013; Li et al., 2022). The elemental process in the ULF wave-particle interaction is called "drift-bounce resonance", which occurs when charged particles experience the same polarity of wave field along the drift and bounce trajectory. Drift-bounce resonance is also a typical mechanism for exciting ULF waves. Studying the nonlinear drift-bounce resonance is helpful to understand the ULF wave characteristics in the excitation process.

In this work, we extend the drift-bounce resonance theory into a nonlinear regime, to formulate nonlinear trapping of particles in the ULF wave-carried potential well. We find that the nonlinear particle behavior can be described by a pendulum equation (given by equation 1). We also predict the corresponding observable signatures such as rolled-up structures in particle pitch angle spectrum (see Figure 1), which can be compared with observational data to extract information on ULF waves in the inner magnetosphere. More interestingly, we discuss the potential drivers of the pendulum (Li), including the convection electric field and dayside magnetospheric compression. The predicted preferred regions for nonlinear wave growth are consistent with the previous statistical studies.

$$\frac{d^2\zeta}{d\,t^2} = -A_1 \sin\zeta \qquad (1)$$

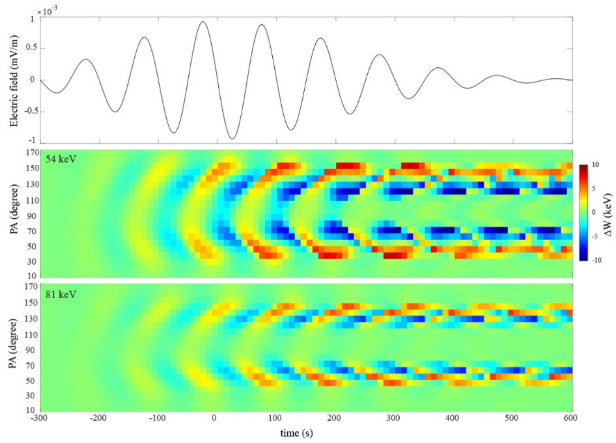

Figure 1. Predicted ion signatures at a fixed, virtual spacecraft location. The top panel corresponds to ULF wave electric field with a finite lifespan. The last two panels correspond to energy spectrum of the ion energy gain/loss from ULF waves.

References

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