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Charged particle behavior in the growth and damping stages of ultralow frequency waves: theory and Van Allen Probes observations

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Ultralow frequency (ULF) electromagnetic waves in Earth's magnetosphere can accelerate charged particles via a process called drift resonance. In the conventional drift-resonance theory, a default assumption is that the wave growth rate is time-independent, positive, and extremely small. However, this may not always be the case in the magnetosphere. The ULF waves must have experienced a earlier growth stage when their energy was taken from external and/or internal sources, and as time proceeds the waves have to be damped with a negative growth rate. Therefore, a more generalized theory on particle behavior during different stages of ULF waves is required. In this paper, we introduce a time-dependent imaginary wave frequency to accommodate the growth and damping of the waves in the drift-resonance theory, so that the wave-particle interactions during the entire wave lifespan can be studied. We then predict from the generalized theory particle signatures during different stages of the waves, which are consistent with observations from Van Allen Probes. The more generalized theory, therefore, provides new insights into ULF wave evolution and wave-particle interactions in the magnetosphere.