

Exploring Modulated Electron Beam Physics for Controlled Plasma Wave Generation in Space

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The Beam Plasma Interactions Experiment (Beam-PIE), a NASA sounding rocket mission conducted in collaboration with Los Alamos National Laboratory (LANL) and NASA Goddard Space Flight Center, was launched from Alaska, in November 2023. This experiment aimed to investigate the generation of plasma waves by modulated electron beams and their role in pitch-angle scattering of electrons into the atmosphere. While Beam-PIE successfully detected electromagnetic whistler-mode waves, they did not exhibit the anticipated characteristics of beam-generated waves, potentially due to anomalies in the accelerator payload. Despite these challenges, the mission provided valuable insights into beam-plasma interactions and the technological requirements for controlled wave excitation in space.

Building on these findings, LANL is developing Beam2PIE, an advanced accelerator designed to enhance capabilities for studying beam-generated waves, particularly for applications in Radiation Belt Remediation (RBR). Whistler-mode waves, the primary focus of Beam2PIE, play a crucial role in the dynamics of Earth's magnetosphere by scattering relativistic electrons into the loss cone, thereby contributing to the regulation of the Earth's radiation belts. Understanding these wave-particle interactions is essential for developing effective strategies for radiation belt mitigation. To further develop the accelerator design, a comprehensive investigation of beam-plasma interaction theory is conducted to further extend knowledge in wave-particle dynamics and non-linear wave growth mechanisms within space plasma using a modulated electron beam. Recent studies have shown that high-amplitude whistler waves can excite drift instabilities that dissipate wave energy by heating ambient cold magnetospheric electrons, thus affecting wave amplitudes. Investigating methods to enhance whistler wave amplitudes is critical for optimizing their effectiveness in radiation belt remediation and other space applications. By exploring controlled wave excitation mechanisms, Beam2PIE aims to identify conditions that maximize wave amplitude while mitigating unintended energy dissipation effects, which will support future space particle accelerator designs.

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