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Kinetic simulations of electron-positron streaming instability in the context of gamma-ray halos and X-ray filaments around pulsars

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The presence of slow diffusion regions as a possible explanation for extended TeV emission around pulsars such as Geminga, Monogem, and PSR J0622+3749, as well as for the X-ray filaments surrounding bow shock pulsar wind nebulae like the Guitar Nebula, PSR J2030+4415, and the Lighthouse Nebula, challenges the conventional understanding of the cosmic ray diffusion coefficient in the interstellar medium.
One proposed mechanism for the suppression of the diffusion process, which is essential for shaping these halos, is the self-generated turbulence driven by streaming electron-positron pairs escaping the pulsar wind nebula. In this work, we study the magnetic field amplification driven by plasma instabilities induced by pair beams using fully kinetic 2D particle-in-cell simulations, focusing on a scenario where electrons and positrons stream with equal densities in an electron-proton background plasma, resulting in no net beam current. Our results show that the amplification of the background magnetic field strongly depends on the ratio between the beam's energy density and the total energy density of the background plasma, including both magnetic and thermal components.
A key finding is that when the magnetic field is amplified, local charge separation naturally emerges, leading to localized overdensities of electrons relative to positrons or vice versa. These results suggest that this asymmetry could eventually give rise to a non-resonant streaming instability, significantly influencing the magnetic field structure. The identified mechanism provides a natural way to induce local asymmetry in the initial beam, leading to distinct electron and positron dynamics. These effects could have important implications for turbulence generation near pulsar wind nebulae, as well as for the formation of TeV halos and X-ray filaments around bow shock pulsar wind nebulae.

Collaboration(s)

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