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The electron foreshock at oblique SNR shocks

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The interaction of a supersonic plasma flow with an obstacle results in collisionless shocks that are often associated with intense nonthermal radiation and the production of cosmic ray particles. Motivated by simulations of non-relativistic high-Mach-number shocks in supernova remnants, we investigate the instabilities excited by relativistic electron beams in the extended foreshock of oblique shocks. The phase-space distributions in the inner and outer foreshock regions are derived with a Particle-in-Cell simulation of the shock and used as initial conditions for simulations with periodic boundary conditions to study their relaxation towards equilibrium. We find that the observed electron-beam instabilities agree very well with the predictions of a linear dispersion analysis: the electrostatic electron-acoustic instability dominates in the outer region of the foreshock, while the denser electron beams in the inner foreshock drive the gyroresonant oblique-whistler instability.