Cosmic-ray current driven turbulence in shocks with efficient particle acceleration: the oblique, long-wavelength mode instability

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In order for diffusive shock acceleration (DSA) to accelerate particles to high energies, the energetic particles must be able to interact with magnetic turbulence over a broad wavelength range. The weakly anisotropic distribution of accelerated particles, i.e., cosmic rays (CRs), is believed capable of producing this turbulence in a symbiotic relationship where the magnetic turbulence required to accelerate the CRs is created by the accelerated CRs themselves. In efficient DSA, this wave-particle interaction can be strongly nonlinear where CRs modify the plasma flow and the specific mechanisms of magnetic field amplification. Resonant interactions have long been known to amplify magnetic fluctuations on the scale of the CR gyroradius, and Bell (2004) showed that the CR current can efficiently amplify magnetic fluctuations with scales smaller than the CR gyroradius. Here, we show with a multi-scale, quasi-linear analysis that the presence of turbulence with scales shorter than the CR gyroradius enhances the growth of modes with scales longer than the gyroradius, at least for particular polarizations. We use a mean-field approach to average the equation of motion and the induction equation over the ensemble of magnetic field oscillations accounting for the anisotropy of relativistic particles on the background plasma. We derive the response of the magnetized CR current on magnetic field fluctuations and show that, in the presence of short-scale, Bell-type turbulence, long wavelength modes are amplified. The polarization, helicity, and angular dependence of the growth rates are calculated for obliquely propagating modes for wavelengths both below and above the CR mean free path. The long wavelength growth rates we estimate for typical supernova remnant parameters are sufficiently fast to suggest a fundamental increase in the maximum CR energy a given shock can produce.

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