

# Time-dependent treatment of cosmic-ray spectral steepening due to turbulence driving

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Cosmic-ray acceleration at non-relativistic shocks relies on scattering by turbulence that the cosmic rays drive upstream of the shock. We explore the rate of energy transfer from cosmic rays to non-resonant Bell modes and the spectral softening it implies. Accounting for the finite time available for turbulence driving at supernova-remnant shocks yields a smaller spectral impact than found earlier with steady-state considerations. Generally, for diffusion scaling with the Bohm rate by a factor  $\eta$ , the change in spectral index is at most  $\eta$  divided by the Alfvénic Mach number of the thermal sub-shock. For  $M_A$  less than 50 it is well below this limit. Only for very fast shocks and very efficient cosmic-ray acceleration the change in spectral index may reach 0.1. For standard SNR parameters it is negligible. Independent confirmation is derived by considering the synchrotron energy losses of electrons: if intense nonthermal multi-keV emission is produced, the energy loss, and hence the spectral steepening, is very small for hadronic cosmic rays that produce TeV-band gamma-ray emission.

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