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The spectrum of Cosmic Rays escaping from relativistic shocks

Boaz Katz, Peter Meszaros, Eli Waxman

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We derive expressions for the time integrated spectrum of Cosmic Rays (CRs) that are accelerated in a decelerating relativistic shock wave and escape ahead of the shock. It is assumed that at any given time the CRs have a power law form, carry a constant fraction of the energy E_tot of the shocked plasma, and escape continuously at the maximal energy attainable. The spectrum of escaping particles is highly sensitive to the instantaneous spectral index due to the fact that the minimal energy, E_min ~ \Gamma^2 m_pc^2 where \Gamma is the shock Lorentz factor, changes with time. In particular, the escaping spectrum may be considerably harder than the canonical N(E)\propto E^-2 spectrum. For a shock expanding into a plasma of density n, a spectral break is expected at the maximal energy attainable at the transition to non relativistic velocities, E ~ 10^19 (\epsilon_B/0.1)(n/1 cm^-3)^(1/6) (E_tot/10^51 erg)^(1/3) eV where \epsilon_B is the fraction of the energy flux carried by the magnetic field. If ultra-high energy CRs are generated in decelerating relativistic blast waves arising from the explosion of stellar mass objects, their generation spectrum may therefore be different than the canonical N(E)\propto E^-2.

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