MAXIMUM PARTICLE ENERGIES BY FERMI ACCELERATION IN NONRELATIVISTIC AND RELATIVISTIC FLOWS

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We derive the maximum accelerated particle energy $\mathcal{E}_{max}$ from first-order and second-order Fermi acceleration in nonrelativistic and relativistic flows. The maximum values of $\mathcal{E}_{max}$ for acceleration by quasi-parallel and quasi-perpendicular shocks in nonrelativistic Sedov flows are obtained. Following Gallant and Achterberg, we derive $\mathcal{E}_{max}$ for relativistic shock acceleration in adiabatic blast waves that evolve by interacting with a uniform external medium. Second-order stochastic processes in relativistic flows is shown to accelerate cosmic rays to ultra-high energies. Stochastic particle acceleration in relativistic flows, such as those occuring in gamma-ray bursts and unusual supernovae such as SN 1998bw, can accelerate cosmic rays above the knee of the cosmic ray spectrum, including the metagalactic ultra-high energy cosmic rays.