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Reinterpretation of the Fermi acceleration of cosmic rays in terms of the ballistic surfing acceleration in supernova shocks

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The applicability of first-order Fermi acceleration in explaining the cosmic ray spectrum has been reexamined using recent results on shock acceleration mechanisms from the Multiscale Magnetospheric mission in Earth's bow shock. It is demonstrated that the Fermi mechanism is a crude approximation of the ballistic surfing acceleration (BSA) mechanism. While both mechanisms yield similar expressions for the energy gain of a particle after encountering a shock once, leading to similar power-law distributions of the cosmic ray energy spectrum, the Fermi mechanism is found to be inconsistent with fundamental equations of electrodynamics. It is shown that the spectral index of cosmic rays is determined by the average magnetic field compression rather than the density compression, as in the Fermi model. It is shown that the knee observed in the spectrum at an energy of 5×10^{15} eV could correspond to ions with a gyroradius comparable to the size of shocks in supernova remnants. The BSA mechanism can accurately reproduce the observed spectral index $s = -2.5$ below the knee energy, as well as a steeper spectrum, $s = -3$, above the knee. The acceleration time up to the knee, as implied by BSA, is on the order of 300 years.
First-order Fermi acceleration does not represent a physically valid mechanism and should be replaced by ballistic surfing acceleration in applications or models related to quasi-perpendicular shocks in space. It is noted that BSA, which operates outside of shocks, was previously misattributed to shock drift acceleration (SDA), which operates within shocks.
K. Stasiewicz, https://dx.doi.org/10.48550/arXiv.2407.15767

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