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Particle Acceleration in Relativistic Magnetized Astrophysical Shocks

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The termination shock of pulsar winds and internal shocks in gamma-ray bursts and AGN jets are likely to be seeded with a substantial magnetic field (ratio σ of magnetic to kinetic energy density > few percent), oriented mostly perpendicular to the shock normal. By means of two- and three-dimensional particle-in-cell simulations, we study how the efficiency of particle acceleration in relativistic shocks depends on the magnetization of the pre-shock flow and the geometry of the upstream field. We study both uniform and alternating pre-shock fields. For uniform fields, we find that if $\sigma > 0.001$ only nearly-parallel shocks lead to particle acceleration, via the first-order Fermi process. The downstream particle spectrum consists of a relativistic Maxwellian and a high-energy power-law tail with slope around -2.5, which typically contains $\sim 1\%$ of particles and $\sim 10\%$ of flow energy. The scattering is provided by magnetic turbulence generated self-consistently by the shock-accelerated particles that propagate ahead of the shock along the magnetic field lines. On the contrary, in quasi-perpendicular shocks, where relativistic particles cannot outrun the shock along the field, the self-generated turbulence is not strong enough to permit efficient Fermi acceleration, and the downstream particle spectrum is consistent with a thermal distribution. Alternatively, if the pre-shock medium consists of magnetic stripes of alternating polarity and $\sigma \gg 1$, as expected in the relativistic wind of oblique pulsars, dissipation of the stripes when compressed at the shock front can transfer energy from the field to the particles, via driven magnetic reconnection. In the limit of long stripe wavelengths, the post-shock spectrum approaches a flat power-law tail with slope around -1.5, populated by particles accelerated by the reconnection electric field. Our findings place important constraints on the models of non-thermal radiation from Pulsar Wind Nebulae, gamma-ray bursts and AGN jets that invoke particle acceleration in relativistic magnetized shocks.