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Magnetic Reconnection in Relativistic and Semirelativistic Plasmas: Extreme Particle Acceleration and Radiation[1]

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Magnetic reconnection is a fundamental plasma process that rapidly converts magnetic energy to particle kinetic energy. It has been studied mostly in nonrelativistic electron-ion plasmas relevant to the solar corona, Earth's magnetosphere, and lab plasmas. However, reconnection in collisionless relativistic electron-ion and electron-positron (pair) plasmas may be important in astrophysical systems such as pulsar wind nebulae and black-hole jets, and is, moreover, more amenable to first-principles particle-in-cell (PIC) simulation. A striking consequence of relativistic reconnection is efficient nonthermal particle acceleration (NTPA). With power-law energy distributions extending to high energies, electrons (and positrons) should emit distinctive, observable synchrotron and/or inverse Compton radiation signatures. PIC simulations show that the NTPA power-law slope steepens with decreasing magnetization and guide magnetic field. NTPA also becomes less efficient in the semirelativistic regime where electrons are relativistic but ions are subrelativistic. Even in environments where accelerated particles promptly radiate away most energy gains, self-consistent radiative-PIC simulations show that reconnection still functions efficiently. In this strongly-radiative regime, the beaming of relativistic particles (hence radiation) is enhanced, potentially yielding shorter, brighter flares. While reconnection-driven NTPA has been studied in 2D simulations over a broad range of plasma conditions, a critical question is whether reconnection behaves similarly in 3D. Large 3D PIC simulations show that, in the magnetically-dominated ultrarelativistic pair regime, reconnection and NTPA are similar in 2D and 3D. However, when the magnetic energy is comparable to the plasma energy ($\beta \sim 1$), reconnection slows and is disrupted by 3D effects like the relativistic drift-kink instability; nonetheless, NTPA remains robust even as reconnection dynamics alter significantly.

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