Acceleration mechanisms in extreme photon-plasma interactions

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High-energy astrophysical phenomena, such as pulsars and GRBs, can emit extreme gamma-ray fluxes, with a peak of emission around the keV-MeV range [1]. Plasma electrons acted upon by such radiative fluxes can be accelerated to relativistic energies via Compton scattering. This scenario can also be envisioned, to some extent, in extreme-intensity laser-plasma interactions in future laboratory astrophysics experiments. Only recently has this problem been accessible to PIC simulations [2].

Using the CALDER PIC code enriched with a Monte Carlo module describing Compton scattering [3], we have simulated the interaction of an initially cold hydrogen plasma with an extreme gamma-ray flux, of relative density $n_\gamma/n_p \sim 5.10^7$ and photon energy $\varepsilon_\gamma = 4m_ec^2$.

Our simulations reveal that the plasma dynamics proceeds through several stages. First, the radiative flux accelerates an increasing number of plasma electrons via Compton scattering, thus forming a forward-moving fast electron beam which is neutralized by a denser current of counterstreaming electrons. Then, as more electrons get scattered, we observe a phase-mixing between the cold return current and the electron beam into a relativistically hot, forward-drifting electron bulk.

The slower dynamics of the ions gives rise to a coherent charge-separation field that acts against the electron acceleration [4]. Ions themselves are accelerated by this field to near-relativistic speeds, moving the bulk of the plasma forward and dictating the average electron drifting speed [5]. Simultaneously, the electrons that have not yet Compton-scattered are accelerated backwards by the charge-separation field to energies way beyond that of the driving photons.

The anisotropic acceleration processes at work give rise to the so-called Weibel instability [6]. The Weibel-induced magnetic structures approximately move at the ions' drifting speed and act as scattering centers on the counterstreaming high-energy electrons, leading to a population of very energetic, forward-propagating electrons. These electrons are susceptible to both the charge separation field and Compton scattering, which tend to bring their momentum back to the hot plasma bulk.

After elaborating on these various stages, we will illustrate their sensitivity to variations in some of the system's parameters.

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