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Direct Electron Acceleration and Radiation Generation in Space–Time Structured Laser Pulses

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By manipulating the space–time focusing of a laser field, recent experiments have created novel laser pulses with properties that promise to revolutionize a wide range of laser–plasma applications. These "flying focus" pulses feature an intensity peak that travels with a near-constant profile at an arbitrary, tunable velocity over distances far greater than a Rayleigh range. The velocity control offered by flying-focus pulses enables unique configurations of light–matter interactions and introduces new pathways to optimization. In particular, a flying focus pulse can be structured so that its intensity peak travels in the opposite direction as its phase fronts—a configuration that is impossible with conventional laser fields. Using newly derived, exact solutions to Maxwell's equations for flying-focus fields, we demonstrate that a backward-travelling intensity peak can ponderomotively accelerate electrons to relativistic momenta in the backwards direction, providing unprecedented control over the electron trajectory in nonlinear Thomson scattering (NLTS). With sufficient amplitude, a backward-travelling, subluminal intensity peak can impart enough momentum to an electron that it outruns the intensity peak and gains net energy. A backward-travelling intensity peak with insufficient amplitude or superluminal velocity can accelerate electrons against the phase fronts for an extended distance. This acceleration compensates the ponderomotive deceleration that diminishes the scaling of the radiation properties of NLTS in traditional laser pulses. By appropriately setting the velocity of the intensity peak, a flying focus pulse can increase the power radiated by orders of magnitude and allow for operation at significantly lower electron energies or intensities.

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