Twisted particle beams from wakefields with orbital angular momentum

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The orbital angular momentum is an intrinsic degree of freedom of light that results in doughnut shaped laser intensity profiles with twisted wavefronts. The orbital angular momentum from the laser is not transferred to the plasma waves in the underdense plasma, below solid density [J. Vieira, J. T. Mendonça PRL 112 215001 (2014)]. This picture changes dramatically when the laser driver contains multiple OAM levels characterized by distinct frequencies. The beating between each mode results in a spiralling laser intensity profile, also known as a light spring [G. Pariente, F. Quéré Optics Lett. 40, 2037 (2015)].

We show that a light spring laser driver can efficiently transfer OAM to the plasma wave. Unlike a Gaussian laser pulse driver, where the wakefield amplitude decreases with the pulse duration (because the ponderomotive force becomes smaller), we show that the wakefields can be resonantly excited by the light spring driver. The wakefield amplitude can then grow secularly along a long light spring, paving the path to excite strongly nonlinear plasma waves using lasers with non-relativistic peak intensities. We also show that the twisted wakefield structure modifies particle trapping and acceleration. An additional trapping condition, related to the conservation of angular momentum, forces trapped particles to execute helical trajectories as they de-phase in the wakefields, leading to the generation of helical particle (electron and/or positron) bunches. Unlike in no-OAM plasma waves, particles can be trapped even if their longitudinal velocity is below the longitudinal wakefield phase velocity. Although the energy gain is generally smaller, trapped particles can rotate in the wakefields indefinitely, without ever entering into defocusing regions. In addition to radial variations of the laser spot-size, light springs can also rotate azimuthally when a plasma channel is present. This interesting feature can be used to reduce or increase the phase velocity of the plasma wave. Light springs can then be employed to drive superluminal phase velocity plasma waves, which can contribute to prolong the acceleration distance in a plasma accelerator. We support our theoretical findings with three-dimensional particle-in-cell (PIC) simulations using the PIC code Osiris [R.A. Fonseca et al, PPCF, 55 124011 (2013)].