Optical control of the topology of plasma accelerators

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Exploring advanced plasma based accelerators is important research issue, as they can lead to more compact particle accelerators and light source for scientific and societal applications. One of the most advanced schemes is the laser wakefield accelerator, which employs laser pulses to excite the plasma.

A twisted laser pulse driver with orbital angular momentum can change the spatial structure of the plasma wave dramatically, in comparison to Gaussian drivers. Plasma waves driven by intense twisted light acquire a doughnut shape, which are useful to accelerate ring shaped electron beams, which could be used as a lens, being also suited for high gradient positron acceleration, providing a solution to an ongoing outstanding challenge. These results point towards a remarkable property, specific of plasma accelerators, which is the topological flexibility of plasma wakefields, which may provide unprecedented control over the internal degrees of freedom of relativistic beams. We illustrate the concept with lasers characterized by helical intensity profiles, also known as light springs. This approach is motived by the recent advances on ultra-fast beam shaping, which provide new paths to produce ultra-intense lasers with unusual spatiotemporal properties. We show that light springs can drive relativistic twisted plasma wakefields, which carry orbital angular momentum themselves. In the nonlinear regime, these twisted wakes can generate and accelerate relativistic vortex electron beams, which have quantized orbital angular momentum levels, although they are of a purely classical origin. These beams are challenging to produce by other means, and could be already of interest to the communities exploiting particle beams to probe matter. We confirm our theoretical results with 3D particle-in-cell simulations in Osiris.

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