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Pulse Envelope Forces in Linear Media: From Confinement to Collision Dynamics

The interaction of ultrashort femtosecond laser pulses with dielectric media reveals a new mechanism for trapping particles into the pulse envelope through a longitudinal optical force [1]. The effect is due to the linear and nonlinear polarization of the media and works for pulses with intensities, significantly below from the well-studied multiphoton and tunnel ionization regimes. Unlike tunnel ionization, which depends on high field amplitudes and low frequency, or multiphoton processes driven by nonlinear intensity scaling, the proposed collision-driven ionization regime is a result of kinetic energy accumulation due to this confinement. When the trapped particles reach sufficient density, the kinetic energy of the collision with ambient molecules in air is of order of 12-24 GeV and lead to ionization of the media for intensity of the pulse below than typical ionization thresholds. This presents a qualitatively new ionization regime, offering potential applications in directed particle acceleration and plasma generation, bridging the gap between linear optics and high-energy density physics. [1, 2]
In this work, we explore more precisely as the longitudinal radiation forces arising from the time derivative of the Poynting vector, depends from diffraction and dispersion of the optical pulse by solving analytically the 3D+1 paraxial equation in linear regime [3].

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