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Relativistic dynamical bi-stability and adiabatic excitation of strong plasma waves[1]

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Resonant excitation of nonlinear dynamical systems is one of the most common uniting threads throughout plasma science. Best known examples are ECR rf heating of plasma and beat-wave excitation of electron plasma waves in a plasma beat-wave accelerator (PBWA). Beat-wave excitation mechanism is realized when the laser intensity is modulated with the temporal periodicity of the plasma wave. Despite being the oldest of the plasma-based theoretical and experimentally realized acceleration concepts, it continues attracting significant experimental and theoretical attention. It was recently realized that one can improve a PBWA by using a pair of long laser pulses with beat-wave amplitude exceeding a certain threshold and detuned from each other by a frequency less than the plasma frequency. The resulting plasma wake is essentially bi-stable as it can be either with certain large amplitude or near-zero. Its amplitude only weakly depends on the beat-wave amplitude and, because there are only two outcomes, can be reliably controlled by the beat-wave pulse duration. This phenomenon, referred to as Dynamical Bi-Stability (DBS), is caused by the relativistic nonlinearity of a high-amplitude plasma wave. We developed the description of strongly driven plasma wave whose phase and amplitude are described as a representative particle [1] moving according to a nonlinear Hamiltonian. The Hamiltonian, depending on the driver parameters, has a variable number of fixed points and always follows the same trajectory for a slow varying driver, regardless of whether the plasma is excited or left quiescent. Using the standard nonlinear dynamics concepts such as separatrix crossing, we analyze the evolution of the plasma wave and explain how a long adiabatic laser beat-wave pulse can leave behind a large wake. Also it is shown that the "auto-resonant" excitation by slowly varying ("chirping") the driver frequency is described by the same Hamiltonian as DBS and, consequently, can be understood from the same standpoints as the latter. Further, it is demonstrated that the auto-resonance and dynamical bi-stability can be combined in one mixed DBS-auto resonant scheme [2] which relaxes the beat-wave conditions needed to produce a large plasma wake.

[1] S. Kalmykov, O. Polomarov et. al,, Phil. Trans. Royal. Soc. 364 (1840), 725 (2006)
[2] O. Polomarov and G. Shvets, Phys. Plasmas 13, 054502 (2006)

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