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Intense Beam Channeling in Underdense Plasmas

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Realization of the "fast ignitor" fusion scheme requires the channeling of an intense laser beam through a long underdense plasma. Not yet well understood is possible beam degradation due to strong self-focusing. Both ponderomotive and relativistic self-focusing are important for the laser pulse parameters contemplated (intensities greater than 10^{17} W/cm^2 and pulselengths on the order of 100 ps). We report here numerical simulations that indicate that relativistic effects tend to suppress catastrophic self-focusing and stabilize the empty channel formed in the plasma.

We developed a model treating both ponderomotive and relativistic self focusing. The equations of the model were derived from a multiple scales expansion of the exact equations for underdense plasmas. There is no restriction to weakly relativistic intensities. These equations include a paraxial wave equation which contains the relativistic nonlinearities in refractive index due to the above effects. In addition, the plasma is treated as a fluid. Since ion motion is highly supersonic at these high intensities, thermal pressure is neglected. Our approach differs from traditional treatments in that ion motion must be taken into account for such long pulses. The simplicity of the model allows implementation of a three dimensional simulation (assuming cylindrical symmetry) on a workstation. Three dimensional modeling is necessary since beam behavior near a strong self-focus differs in one and two transverse dimensions.

Our results demonstrate the onset of catastrophic self-focusing for weakly relativistic fields (intensities on the order of 10^{17} W/cm^2). Relativistic effects become important at intensities an order of magnitude higher than this. For still higher intensities (10^{19} W/cm^2), the relativistic increase in the critical density saturates the self-focusing nonlinearity and arrests the beam contraction. This leads to a wider empty channel through which the laser radiation can be transported.

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