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Nonlinear plasma kinetic theory and applications to plasma instabilities

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In this talk, we show how to solve analytically the nonlinear Vlasov equation in a situation corresponding to plasma instabilities. Our theory holds whatever the growth rate of the instability, so that our results go beyond the usual paradigm of envelope equations. As an application of our theory, we provide the first analytical description of the nonlinear growth and saturation of the beam-plasma instability, by deriving an explicit equation for the nonlinear growth rate [1].

When specializing to envelope equations, we show how to derive such equations at any order in the space and time derivatives of the field amplitude. In particular, the nonlinear decrease of the zeroth order term, which may be viewed as an equivalent of the Landau damping rate, is described very accurately for an externally driven instability, such as stimulated Raman scattering. Moreover, our envelope equations account for plasma inhomogeneity and non-stationarity [2]. The numerical resolution of such equations is a difficult issue, which we address by introducing a novel method based on Particle in Cell codes [3].

In addition to the envelope equation for the amplitude of the unstable wave, we provide a very accurate description of its nonlinear dispersion relation, from which we derive several important results. In particular, we provide an upper limit for the wavebreaking amplitude. Moreover, for a laser-driven wave, we describe the nonlinear growth of transverse modes resulting from the wavefront bowing. Furthermore, in the adiabatic regime, we provide explicit analytical expressions for the nonlinear wave electric field, depending on $k\lambda_D$, k being the wavenumber and λ_D the Debye length. In particular, we show that, when $k\lambda_D<0.1$, the well-known expression for the field derived by Dawson in [4] is quite accurate while, when $k\lambda_D>0.3$, the wave is nearly sinusoidal. When $0.1 < k\lambda_D < 0.3$, the electric field is essentially the sum of the zeroth and first harmonics, a situation actually very similar to that corresponding to a sinusoidal wave.

Finally, from our accurate theory, we extract a simplified model that was implemented in the hydrodynamical code, TROLL, used at CEA to design fusion experiments at the Laser MégaJoule Facility. First results of this model will be given.

References

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