Spatiotemporal evolution of large amplitude plasma waves in warm plasmas

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Spatiotemporal evolution of nonlinear plasma waves and their breaking is a subject of interest to both laboratory as well as astrophysical plasmas. The estimation of maximum sustainable amplitude, so called wave-breaking amplitude, of nonlinear electron plasma oscillations/waves is a well-studied problem in both cold[1] and warm[2] plasmas for immobile ions with homogeneous density profile. Again in the cold plasma case, it is well known that, inclusion of inhomogeneity in ion density profile leads to breaking of the wave, even below the wave-breaking amplitude, via phase-mixing.[1, 3, 4] This happens because the background inhomogeneity makes the oscillation frequency space dependent, which results in generation of higher harmonics *i.e.* the wave number (k) increases and the wave breaking limit $k_{wb}A = 1$[1] is reached. Another important problem is the influence of ion motion on the wave breaking amplitude. For a cold homogeneous plasma, the wave breaking amplitude weakly depends on electron to ion mass ratio$(\mu)$and mildly increases with increase in μ.[5]

In the present work, the the effect of finite electron temperature on the space-time evolution of nonlinear plasma oscillations against a static inhomogeneous ion density profile is discussed. The study is further extended to estimate the effect of both warm electrons and warm ions on the wave breaking amplitude in homogeneous plasmas.

Firstly, in the limit of immobile ions with a static inhomogeneous ion density profile, the effect of finite electron temperature on the space-time evolution of nonlinear plasma oscillations is studied using an in-house developed one-dimensional particle-in-cell (PIC) code[6]. In contrast to the conventional wisdom, it is found that for inhomogeneous plasmas, there exists a critical value of electron temperature beyond which wave breaking does not occur. This novel result, which is of relevance to laboratory experiments, has been explained on the basis of interplay between electron thermal pressure and background inhomogeneity. Physically, it happens as follows: density inhomogeneity on its own causes growth and "accumulation" of $k's$ at a given spatial location, resulting in peaking of density profile, while thermal effects cause advection of $k's$ resulting in smoothening of density profile. If the rate at which $k's$ advect is greater than the rate at which $k's$ grow and "accumulate", wave breaking will not occur and k gets limited to a maximum value k_{max}, which is determined by electron temperature and inhomogeneity amplitude.

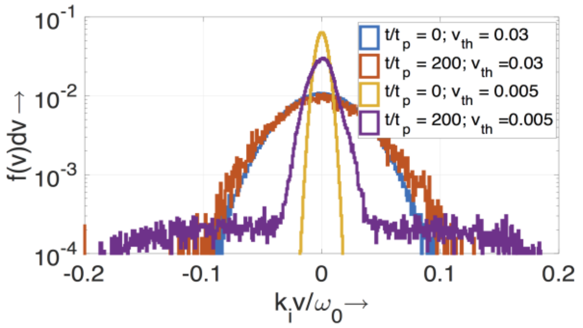

Figure 1. Velocity distribution function for $\delta n_i/n_0 = 0.05$, for both walk-off $(v_{th} = 0.03)$and wave-breaking $(v_{th} = 0.003)$ cases. The blue curve shows the initial distribution function and the orange curve represents distribution function at $t/t_p = 200$, for the walk-off case. It is clear that the distribution function does not change much in this case. Whereas for the breaking case the distribution function at $t/t_p = 200$ (purple curve) substantially broadens in comparison to the initial distribution function (yellow curve). [6]

Further studies with finite electron to ion mass ratio, in homogeneous plasma, is carried out analytically using pseudo-potential[5] method where finite temperature effects for both the species are investigated within the framework of water bag model. This study is built on the seminal work by Coffey [2]. In this case it is found that maximum sustainable amplitude for a plasma wave decreases monotonically with the increase in temperature and mildly increases with increase in mass ratio. This latter result, when applied to pair ion plasmas, is of relevance to astrophysical scenarios. [7]

References

[1] J. M. Dawson, Phys. Rev. **113**, 383 (1959)
[2] T. P. Coffey, Phys. Fluids **14**, 1402 (1971)
[3] P. K. Kaw, A.T. Lin and J. M. Dawson, Phys. Fluids **16**, 1967 (1973)
[4] E. Infeld and G. Rowlands, Phys. Rev. Lett. **62**, 2269 (1989)
[5] A. G. Khachatryan, Phys. Rev. E **58**, 7799 (1998)
[6] N. Rathee, A. Mukherjee, R.M.G.M. Trines and S. Sengupta, Phys. Plasmas **28**, 012105 (2021)
[7] A. Adak, N. Rathee and S. Sengupta, Wave Breaking limit in arbitrary Mass Ratio Warm Plasma. https://arxiv.org/abs/2008.07762v2