Kinetic trapped particle instability in homogeneous and inhomogeneous 1D Vlasov plasmas

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In 1957, using the Vlasov-Poisson model, Bernstein, Greene and Kruskal published a seminal paper which showed the existence of an infinite family of exact stationary solutions for electrostatic, collisionless plasmas. Such solutions are now called Bernstein-Greene-Kruskal (BGK) modes [1]. O'Neil theoretically demonstrated that in a uniform or homogeneous plasma, after some initial Landau damping a large amplitude electrostatic wave oscillates in amplitude [2], and finally settles down to a BGK mode. Manfredi demonstrated that a BGK mode with largest possible wavelength is stable [3]. Kruer, Dawson and Sudan proposed a model for kinetic instability for BGK modes with wavelength smaller than the system size, which results from trapped particles in these large amplitude electrostatic waves (BGK modes) [4]. This model proposes that due to the large amplitude of the wave, significant number of particles are trapped in the trough of the wave, which then move with the wave with mean velocity equal to phase velocity of the wave and act coherently (like a beam) leading to a phenomenon similar to two-stream instability. Since then numerous studies were performed to emphasize the two different physical mechanisms, namely, wave particle interaction and mode coupling interaction phenomena which are responsible for growth in the upper and lower side band modes leading to trapped particle instability. However, effect of the above said phenomena were not addressed together using high quality simulations, as function of amplitude of the BGK mode, to understand the complete picture.

In the present work, using high resolution in space and velocity domains ($[N_x x N_v]$=2048x10000) OpenMP based Vlasov-Poisson solver VPPM-OMP 1.0, we present an extensive study demonstrating trapped particle instability phenomenon in 1D, collisionless, periodic, homogeneous plasmas as shown in Figure 1 for perturbation amplitude α=0.075 [5,6]. For the first time, kinetic trapped particle instability is addressed for an inhomogeneous plasma, with fixed nonuniform background of immobile ions and we have demonstrated that the wave particle interaction and the mode coupling interactions are equally responsible for the occurrence of trapped particle instability, especially in the cases of inhomogeneous plasmas [7]. In addition, results on the effect of perturbation as well as the equilibrium inhomogeneity amplitudes on trapped particle instability along with their new scaling laws are reported [6,7].

References

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Figure 1:

Phase space portrait of electron distribution function f(x,v) for α=0.075 case with primary perturbation mode k/k_{min}=4, k_{min}=0.1 at different times i.e t= 2000, 3000, 3500, 4000, 4500, 10000 ω_{pe}^{-1} is shown in (a), (b), (c), (d), (e) and (f) respectively. Beginning of destabilization effect due to trapped particle instability starts to occur at $t=T_D^{\alpha=0.075}$= 3000 ω_{pe}^{-1} as illustrated in (b).