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A New Plasma Physics Periodic Kinetic Electrostatic Electron Nonlinear (KEEN) Excitation and its Relation to SEAS (Stimulated Elecron Acoustic Scattering)

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ABSTRACT: This topic, new to basic nonlinear plasma physics, is related to and inspired by an important recent result in laser-plasma interaction [1]. This result has been related to the so-called SEAS process [2](Stimulated Electron Acoustic Scattering). Vlasov code simulation studies on our efforts to drive up such waves with an imposed (ponderomotive) driver of limited duration show that long-lived travelling wave excitations (well below the electron plasma frequency and with phase velocities comparable to the electron thermal velocity) only survive only if they are nonlinear and not too weak, with considerable harmonic phase-locked content. We have named these Kinetic Electrostatic Electron Nonlinear waves and find that that (in contrast to previous assumptions) the production of KEEN excitations is not particularly resonant. They thus do not deserve the adjective "acoustic", since they can be driven over a considerable range of velocities.

PAPER: In order to understand how waves could be made to exist in the spectral gap between the electron and (combined) ion plasma frequencies, as observed in experiment [1,2], Vlasov-Poisson simulations employing a prescribed ponderomotive driver were undertaken using (because of its lack of noise) an electron Eulerian phase-space-fluid Vlasov code[3] with cubic spline interpolation. Much more on our work is to be found in a Conference Proceedings which is soon to be published [4]. Under the assumption that such solutions ought to behave in the BGK [5] manner (i.e., unchanging in an appropriately moving frame) and resemble a soliton train, many [6-9] who have attempted to prescribe such solutions assumed that they could be made indefinitely weak, and would then obey an EAW dispersion relation, where EAW stands for Electron Acoustic Wave. Such a dispersion relation could be obtained by simply setting the damping component of the Vlasov electron susceptibility to zero. Our simulation protocol was to apply a ponderomotive drive for a specified frequency and wavenumber for a few plasma periods (more than ten), the behavior of the wave train being evaluated after several hundred plasma periods. Somewhat surprisingly, it was impossible to generate long-lasting waves weak enough for the EAW assumption to be valid. Weak KEEN-like (KEEN = Kinetic Electrostatic Electron Nonlinear) structures thus produced proved to have too little self-generated electric field to survive on their own. The modest-strength KEEN structures we did generate and study had a very nonsinusoidal (but stable) wave shape and clearly involved a significant number of harmonics [4]. (These were naturally locked in phase, thus providing the stable wave shape.) With a drive significantly over the minimum required for survival, and a prescribed wavenumber, the range of acceptable frequencies (which did include the EAW value) was remarkably large [4], something like 3:1. Being long-lived over a remarkable range of excitation frequencies for a given wavenumber, the KEEN wave must thus be considered as basically non-resonant. In Fig. 1 we show a typical $f(x,v)$ snapshot in x,v phase space of a nicely-established KEEN wave.

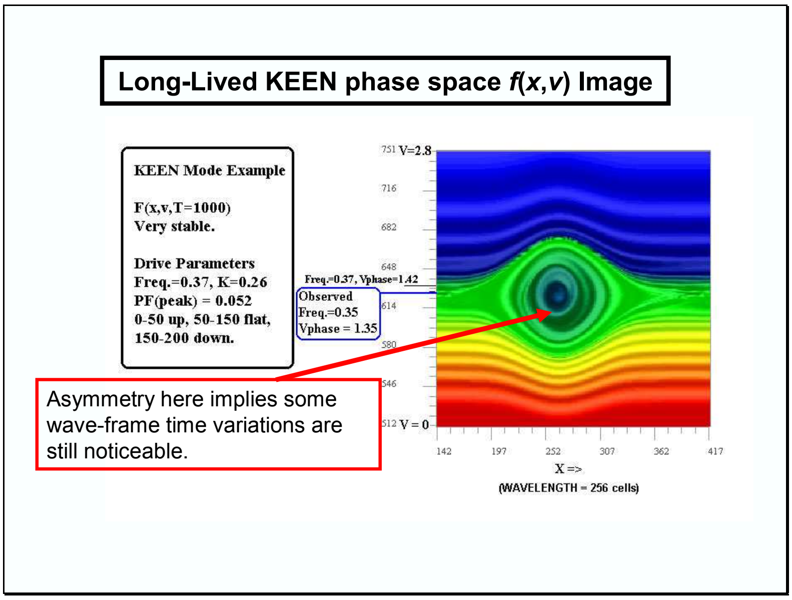

Fig. 1 Presented here is a typical well-developed KEEN phase space structure, from a peak ponderomotive force $F_P/v_t\omega_p$ of 0.052, at kl_D = 0.26, and ω/ω_p = 0.37. After the drive is turned off the (normalized) frequency drops slightly (standard behaviour) to 0.35. (There is still a slight irregular wobble from cycle to cycle.)

Since the behaviour of the plasma when the KEEN wave does not survive is a complicated disintegration, requiring many frames, we show here in Fig. 2 only the time behaviour (from a point probe) of the associated electric field (EF) and ponderomotive force drive (PF) and their sum (EF+PF) for two cases: a sub-threshold result (on the left) and a solid KEEN wave (on the right), in fact it is the case of Fig. 1.

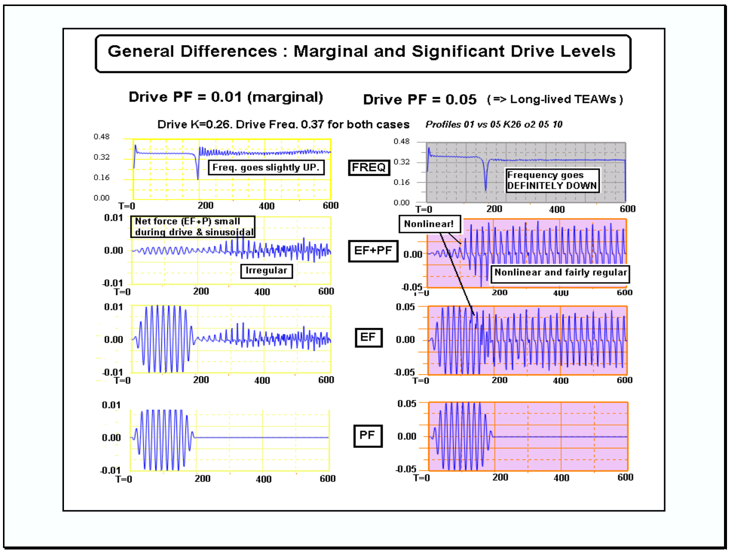

Fig. 2 The PF drive is shown at the bottom of each column, the EF is above it, and, above that, the sum of the two (EF + PF). In a successful KEEN wave case (on the right) the EF after the drive is quite comparable to the drive, otherwise (on the left) EF is much smaller and decays in an irregular manner. The KEEN electric field is very non-sinusoidal (resembling a negative tangent function), with many locked harmonics. At the very top of Fig. 2 is shown the frequency behaviour of the fundamental, which is discussed for Fig. 3.

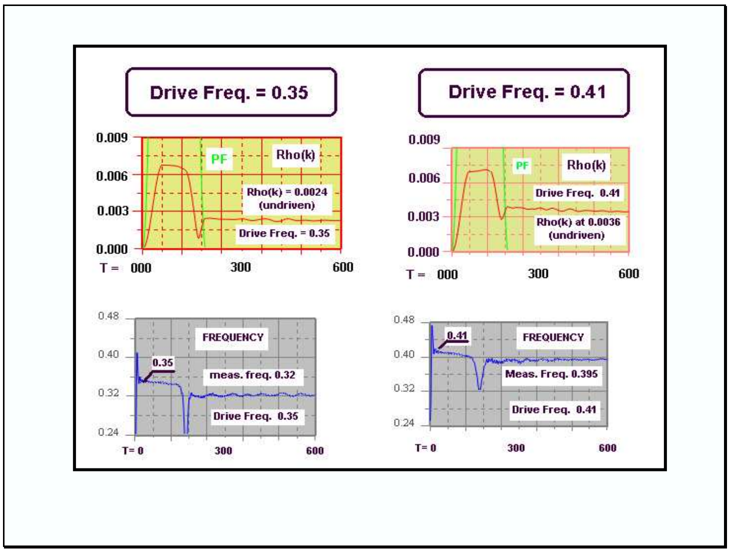

Fig. 3 Here we have the amplitude of the fundamental spatial Fourier component of the charge density rather than the complete time behaviour as in Fig. 2 for the electric field. There are noticeable but modest differences in the levels for the two drive frequencies after the drive ends, an amplitude of 0.0024 when $\omega/\omega_p = 0.35$, compared with 0.0036 when $\omega/\omega_p = 0.41$ (some 17% higher), and rather different frequency drops (0.03 and 0.015 respectively). These modest differences, so unlike those for a resonant system, are strong evidence that the KEEN system is not at all resonant in any usual sense. Also, the decrease in frequency when the drive is terminated is generic feature, but it is always a *decrease*, no matter what drive frequency is used. This is another indication that this is not a shift to a natural frequency (below which one might sometimes find oneself), but rather a renormalization of the way in which the system continues after the drive is stopped. (A nonlinear frequency shift estimate has yet to be made.)

To learn more than space permits here, the reader is referred elsewhere [4]. Work in many aspects of this behaviour is continuing, and several publications are in hand.

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And many more …