On the Effect of Electron Distribution on Double Layer Formation in Beam-Driven Plasmas

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1. INTRODUCTION

Energetic electron populations are frequently observed in laboratory, space, and astrophysical plasma environments, including the ionosphere, auroral regions, mesosphere, and lower thermosphere[1-3]. In many such systems, the electron velocity distribution departs markedly from the classical Maxwellian form and instead exhibits a pronounced high-energy tail, signifying the presence of superthermal, non-Maxwellian electrons. This deviation is commonly represented by the kappa distribution function, which has been shown to more accurately describe the energetic particle populations in a broad range of plasma conditions compared to a standard thermal Maxwellian distribution[4].

2. Basic Equations.

We consider collisionless plasma, composed of positve ions(i), kappa distributed electrons(e) and an electron beam(b). Using fluid model, the normalized basic equations are:

$$\frac{\partial N_{i,b}}{\partial \tau}+\frac{\partial}{\partial X}(N_{i,b}u_{i,b})=0,$$

$$\frac{\partial u_{i,b}}{\partial \tau}+u_{i,b}\frac{\partial u_s}{\partial X}+\mu_{i,b}f_{i,b}\frac{\sigma_{i,b}}{N_{i,b}}\frac{\partial P_{i,b}}{\partial X}=\mu_{i,b}j_{i,b}\frac{\partial \phi}{\partial X},$$

$$\frac{\partial^2\phi}{\partial X^2}=N_e-N_i-N_b,\qquad N_e=f_e\left[1+\frac{\phi}{(\kappa-3/2)}\right]^{-\kappa+1/2}.$$

For studying the arbitrary amplitude ion-acoustic double layers (IADLs), we use the Sagdeev pseudopotential approach, and so each dependent variable in above equations is transformed into a single independent variable in a moving frame of reference, denoted by ξ, where ξ = X −Mτ (where M is the normalized pulse propagation velocity). Using this transformation in basic equations the Sagdeev equation is given as follows:

$$\frac{1}{2}\left(\frac{d\phi}{d\xi}\right)^2+S(\phi)=0.$$

where S is the Sagdeev potential.

A negative second derivative of the Sagdeev potential at ϕ=0 is a fundamental criterion for the emergence of a double layer in plasma. This condition implies that double layers can only develop when the normalized phase speed of the localized wave—i.e., the Mach number—exceeds a certain critical threshold. The critical Mach value is obtained by numerically solving the governing equation below:

$$\mu_i f_b(M_{\min}{}^2-3\mu_i)+(M_{\min}-u_{0b})^2-3\mu_i\sigma_b$$
$$-f_eH_e(M_{\min}{}^2-3\mu_i)((M_{\min}-u_{0b})^2-3\mu_i\sigma_b)=0,$$

where

$$H_e=\frac{\kappa-3/2}{\kappa-1/2},\qquad f_{e,b}=n_{0e,b}/n_{0i},\quad \mu_{i,b}=m_{i,b}/m_e.$$

3. RESULTS AND DISCUSSIONS

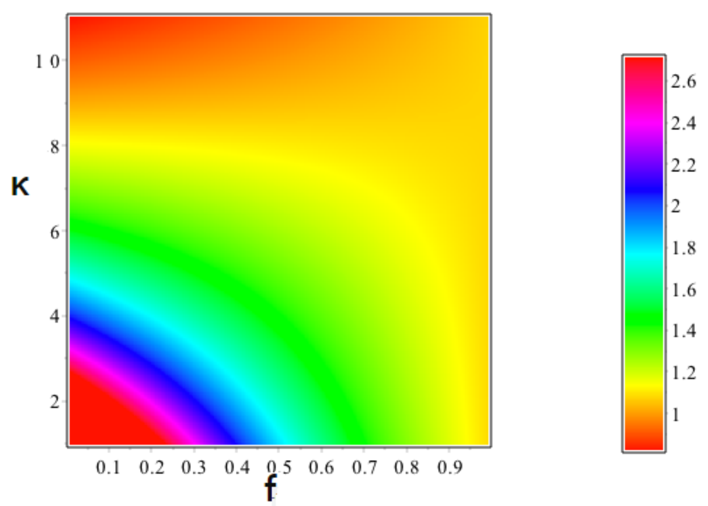

Fig. 1. variation of pulse propagation velocity versus kappa and fe.

From Fig. 1, it is found that the formation condition of IADLs is sensitively dependent on the superthermality index of electrons and their initial density in the considered plasma.

4. CONCLUSION

This work has examined the formation of ion-acoustic double layers (IADLs) in a plasma consisting of ions and κ-distributed electrons through the Sagdeev pseudopotential framework. By analyzing the role of essential plasma parameters, we identified the specific conditions that enable the emergence and stability of IADLs. Our results show that the allowable range of Mach numbers for double-layer formation is strongly restricted and highly sensitive to both the electron superthermality index (κ) and the fractional concentration of superthermal electrons (f).

5. REFERENCES

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