EXISTENCE AND FORMATION OF SMALL AMPLITUDE ELECTROSTATIC DOUBLE-LAYER STRUCTURE IN SUPERTHERMAL PLASMA

Dr Muhammad Adnan

Department of Physics, Kohat University of Science and Technology, KUST, 26000, Kohat, Pakistan

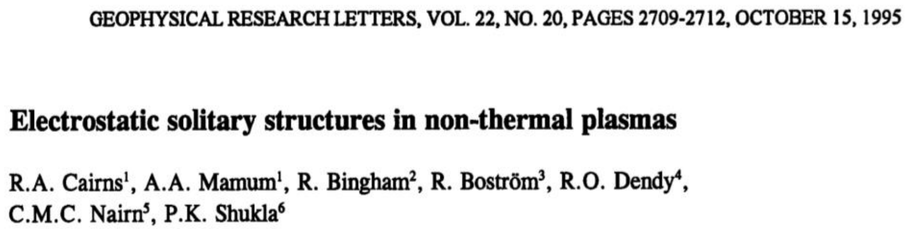
Email: adnan_physiks@yahoo.com

Contents

- Introduction and Motivation
- Methodology/Model Equations
- Dispersion Relation Dust-ion acoustic waves
- Nonlinear Shock waves/Double layers
- Conclusions
- References

Introduction and Motivation

- *Ion acoustic solitary structures observed by the FREJA satellite. FREJA* and *VIKING* satellite both observe the electric field in space plasma which suggest that they are mostly likely electrostatic in nature [Dovner et al., 1994].

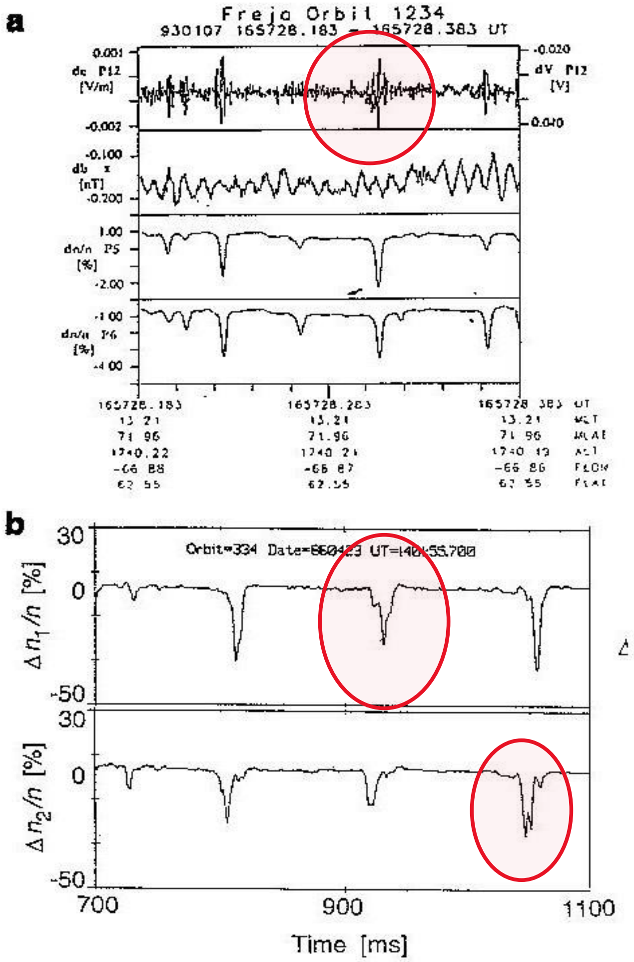


GEOPHYSICAL RESEARCH LETTERS, VOL. 22, NO. 20, PAGES 2709-2712, OCTOBER 15, 1995

Electrostatic solitary structures in non-thermal plasmas

R.A. Cairns[1], A.A. Mamum[1], R. Bingham[2], R. Boström[3], R.O. Dendy[4],
C.M.C. Nairn[5], P.K. Shukla[6]

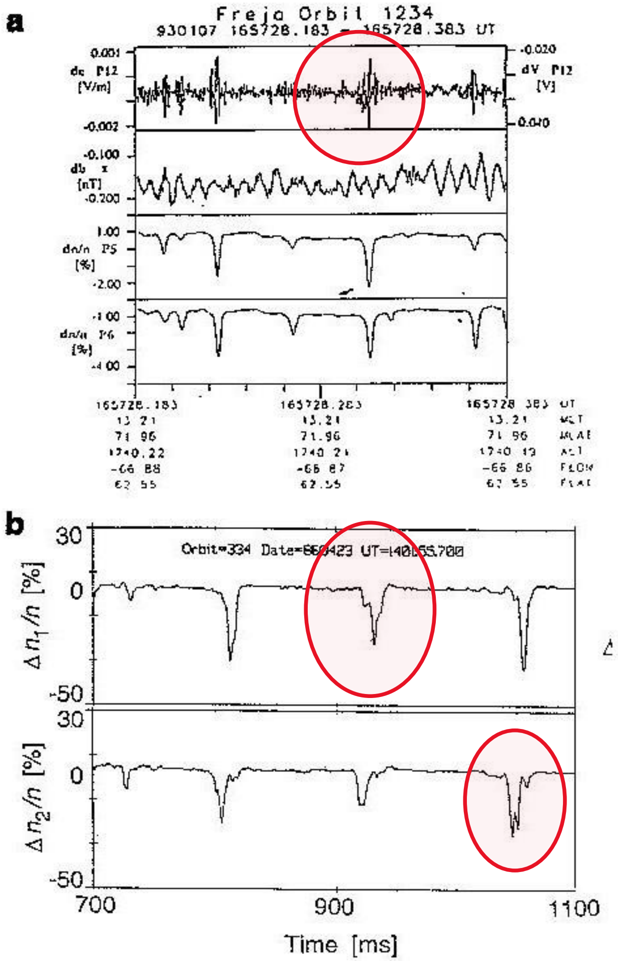
- He show that in the presence of a distribution of electron which is non-thermal, with an excess of energetic particles the nature of ion sound solitary structures changes and *that is possible to obtain the solution with density depletions and dimensions roughly agreement with those observed Freja and Viking satellite.*



freja observations of nonlinear structures - Google Search

Introduction and Motivation

- Cairns et al. (1995) describe the distribution for non-thermal electrons
- FREJA and VIKING satellite both observe the electric field in space plasma which suggest that they are mostly likely electrostatic in nature
- FREJA satellite observe density known as lower-hybrid cavitons
- VIKING satellite also observed similar structure without associated lower hybrid waves.
- Maxwell distribution cannot give the solution to the upper and lower cavities occur in the electrostatic waves



freja observations of nonlinear structures - Google Search

Model Equations

$$f(v) = \frac{n_{e0}}{(1+3\alpha)(\pi v_e^2)}\left(1+\alpha\frac{v^4}{v_e^4}\right)\exp\left(-\frac{v^2}{v_e^2}\right)$$

$$\Big\downarrow$$

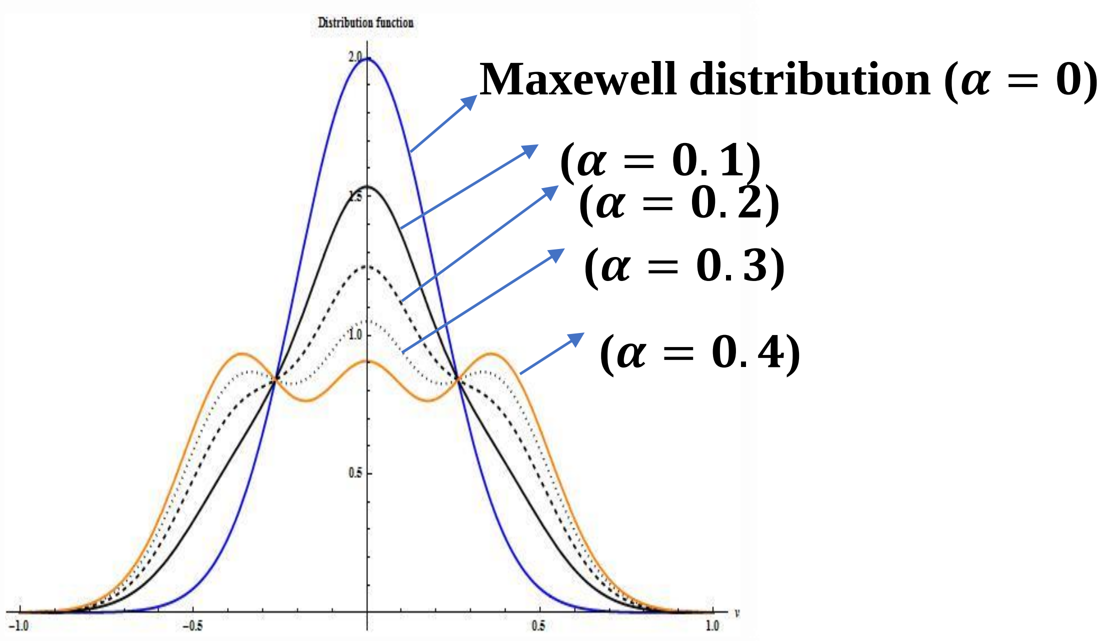
$$n_e = n_{e0}\left\{1-\frac{4\alpha}{1+3\alpha}\left(\frac{e\phi}{T_e}\right)+\frac{4\alpha}{1+3\alpha}\left(\frac{e\phi}{T_e}\right)^2\right\}\exp\left(\frac{e\phi}{T_e}\right)$$

$$\frac{\partial n_i}{\partial t}+\frac{\partial\left(n_i v_i\right)}{\partial x}=0,$$

$$\frac{\partial v_i}{\partial t}+v_i\frac{\partial v_i}{\partial x}=-\frac{\partial \phi}{\partial x}-\frac{1}{m_i n_i}\frac{\partial p_i}{\partial x}$$

$$\frac{\partial^2 \phi}{\partial x^2}=4\pi e\left(n_e-n_i+Z_d n_{d\_0}-Z_d n_{d_+0}\right)$$

$$\frac{n_{e0}}{n_{i0}}=1-\delta z, \Longrightarrow \delta = n_{d\_0}/n_{i0}+n_{d_+0}/n_{i0}$$



Maxewell distribution ($\alpha = 0$)

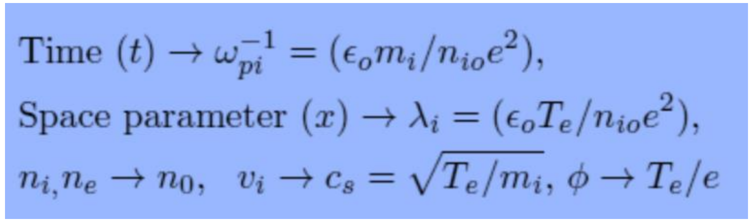
($\alpha = 0.1$)

($\alpha = 0.2$)

($\alpha = 0.3$)

($\alpha = 0.4$)

Normalization Scheme



Time $(t) \rightarrow \omega_{pi}^{-1} = (\epsilon_o m_i / n_{io} e^2)$,

Space parameter $(x) \rightarrow \lambda_i = (\epsilon_o T_e / n_{io} e^2)$,

$n_i, n_e \rightarrow n_0$, $\quad v_i \rightarrow c_s = \sqrt{T_e/m_i}$, $\phi \rightarrow T_e/e$

Introduction and Motivation

$$\Omega^2 = \left(\frac{1}{k^2 + (1-\delta z)\left(1 - \frac{4\alpha}{1+3\alpha}\right)} + \sigma \right) k^2$$

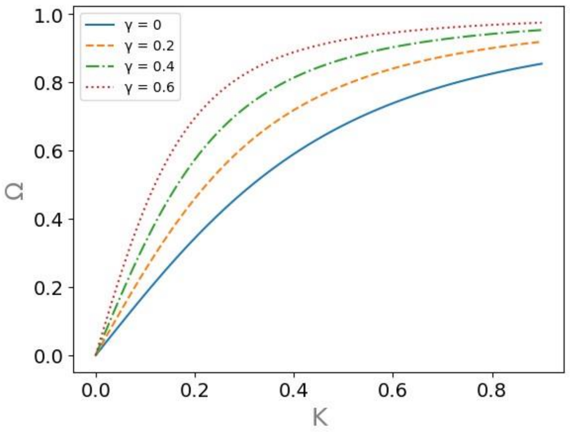


FIG. 1: The effect of nonthermal electrons on the dispersion relation configured at $\delta z = 0.59$ and $\sigma = 0.01$.

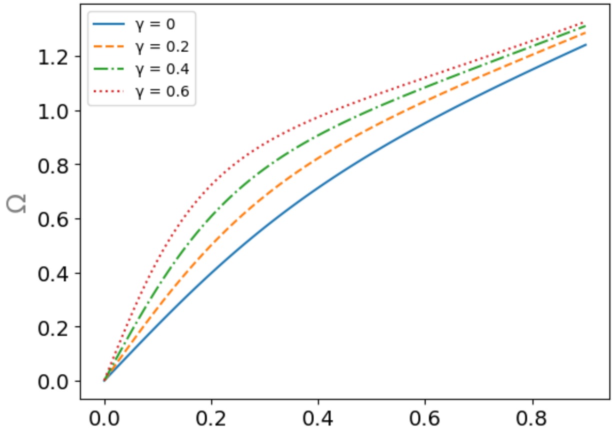


FIG. 1: The effect of nonthermal electrons on the dispersion relation configured at $\delta z = 0.59$ and $\sigma = 1$.

Small Amplitude Nonlinear Double Structures

$$X = \epsilon(x - \lambda t), \quad \tau = \epsilon^3 t,$$

$$n_i = 1 + \epsilon n_i^{(1)} + \epsilon^2 n_i^{(2)} + \ldots\ldots,$$

$$v_i = \epsilon v_i^{(1)} + \epsilon^2 v_i^{(2)} + \ldots\ldots,$$

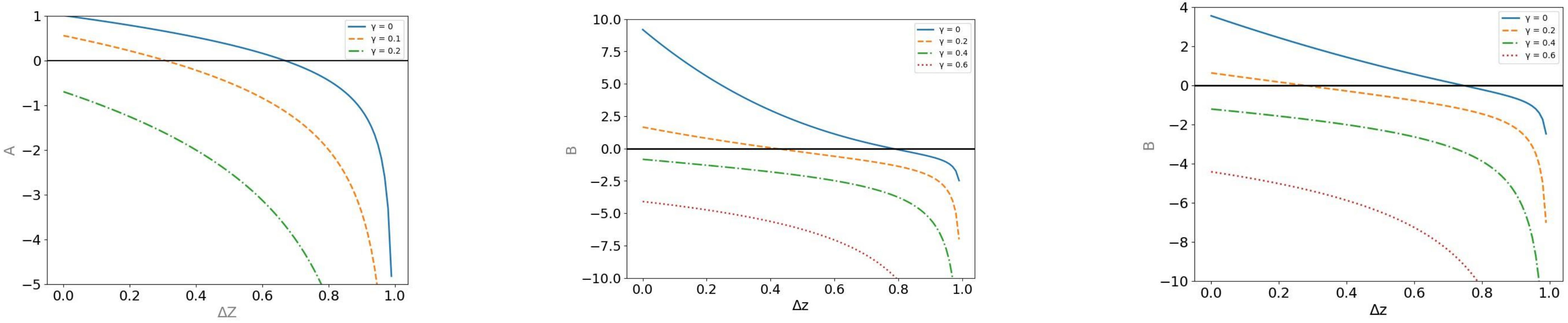
$$\Phi = \epsilon \Phi^{(1)} + \epsilon^2 \Phi^{(2)} + \ldots\ldots$$

$$\lambda = \sqrt{\frac{1}{(1-\delta z)\left(1 - \frac{4\alpha}{1+3\alpha}\right)} + \sigma.}$$

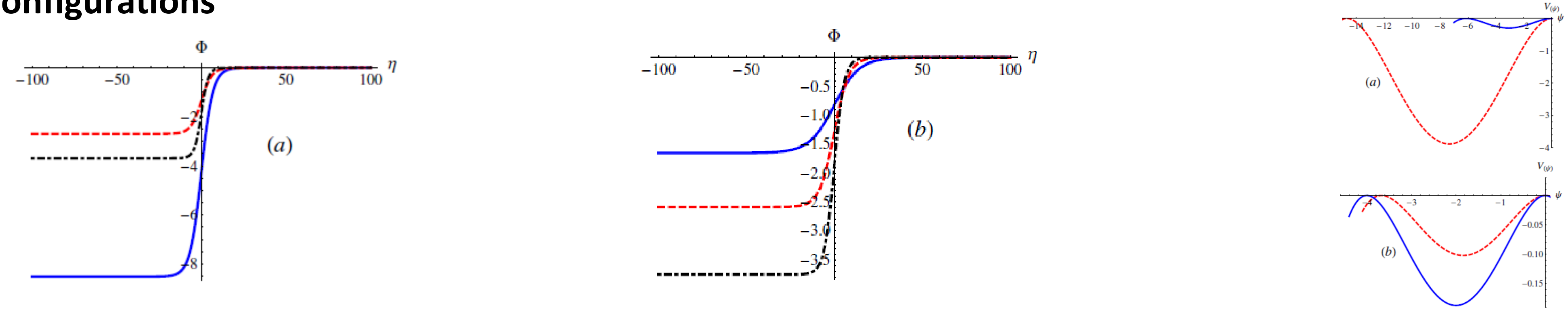
$$\frac{\partial}{\partial \tau}\Phi^{(1)} + A\Phi^{(1)}\frac{\partial}{\partial X}\Phi^{(1)} + B{\Phi^{(1)}}^2\frac{\partial}{\partial X}\Phi^{(1)} + C\frac{\partial^3}{\partial X^3}\Phi^{(1)} = 0.$$

$$\psi = \Phi^{(1)} = \left(\frac{\psi}{2}\right)\left[1 - \tanh\left(\frac{2\eta}{W}\right)\right]$$

Nonlinear Shock waves/Double layers



Nonlinear Coefficients “A” and “B” against Dust charge concentration with various non-thermality and ionic temperature configurations



Shock wave/double layer profiles for various Dust charge concentration, non-thermality and the corresponding Sagdeev Potential for the formation regime.

Conclusions

- **The present model support both positive and negative polarity shock structures (double layer) and switches sign with changing the dust charge concentration.**

- **Strong non-thermality favors only rarefactive structures irrespective of the ion temperature compared to the electron temperature.**

- **The existence regimes for the formation of ion-acoustic double layer in a dusty plasma is traced out**

- **It is found that increasing the nonthermal electrons in the system, the width of the double layer increases, furthermore, the shock structure forms with small dust charge concentrations.**

- **Our present work may be useful for understanding the electrostatic feature of DIAWs in both experiments and cosmic dusty plasmas such as discussed Ref. [4]**

- **The double layers (Shock structures) are also observed in dusty plasma in Q-machine experiments for $\sigma = 1$ and dust charge concentrations $\delta z \geq 0.75$ as mentioned in Ref. [5]**

References

1. Dovner, P O., A I Eriksson, R Bostr6m and B Holback, Freja multiprobe observations of electrostatic solitary structures, Geophys. Res. Lett, 21, 1827-1830, (1994).

2. Cairns, R. A., et al. "Electrostatic solitary structures in non-thermal plasmas." *Geophysical Research Letters* 22.20 (1995): 2709-2712.

3. Khan, G, Kumail, Z, Khan, Y, Ullah, I, Adnan, M. On the existence and formation of small amplitude electrostatic double-layer structure in nonthermal dusty plasma. *Contributions to Plasma Physics*. 2020; 60:e201900177.

4. Q. Z. Luo, N. D'Angelo, R. L. Merlino, *Phys. Plasmas* 1999, *6*, 3345.

5. J. Bremer, P. Hoffmann, A. H. Manson, C. E. Meek, R. Ruster, W. Singer, *Ann. Geophys.* 1996, *14*, 1317.

Acknowledgements:

- Special thanks to @IUPAP: Working Group on Women in Physics, for offering the Accessibility Grant.

- To Prof Anisa Qamar and Pakistan Physical Society for my Nominations

- *To Local Organizing Committee for all the arrangements*

- To my students for all the motivations and useful inputs

Thank You All!!!