بسم الله الرحمن الرحيم

Fully nonlinear ion-acoustic solitary waves in plasma with positive-negative ions and nonthermal electrons

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Outline

- **Aim of the work**
- **Ion-acoustic waves (IAWs)**
- **Normalized basic equations**
- **Large amplitude IAWs**
- **summary**

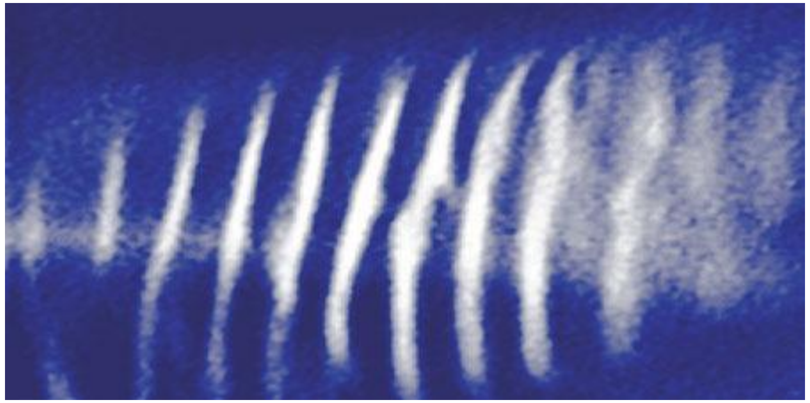
Aim of the work

- **Investigation of the Properties of fully nonlinear ion-acoustic solitary waves in a plasma with positive-negative ions and nonthermal electrons.**

- **For this purpose, the hydrodynamic equations for the positive-negative ions, nonthermal electron density distribution, and the Poisson equation are used to derive the energy integral equation with a new Sagdeev potential.**

Ion-acoustic waves (IAWs)

- They are a type of longitudinal oscillations of the ions and electrons in a plasma much like acoustic (sound) waves travelling in a neutral gas.



- The ion acoustic waves were predicted first by Tonks and Langumir based on the fluid dynamics in 1929.
- The first experimental observation for the waves was reported in 1933.

Normalized basic equations

Basic equations based on Fluid model are:

Continuity equation

(For positive and negative ions)

$$\frac{\partial n_{\pm}}{\partial t} + \frac{\partial}{\partial x}(n_{\pm} u_{\pm}) = 0$$

Momentum equations

1-For positive ions:

$$\left(\frac{\partial u_{+}}{\partial t} + u_{+} \frac{\partial u_{+}}{\partial x}\right) = - \frac{\partial \phi}{\partial x}$$

2-for negative ions:

$$\left(\frac{\partial u_{-}}{\partial t} + u_{-} \frac{\partial u_{-}}{\partial x}\right) = \frac{Z_{-}}{Z_{+}} Q \frac{\partial \phi}{\partial x}$$

[where Q $= m_{+}/m_{-}$ positive and negative ion masses ,Z$\pm$ ionic charge number]

For the nonthermal electrons we use carins distribution function :

$$f_0(v) = \frac{n_{e0}}{\sqrt{2\pi v_t^2}} \frac{\left(1 + \frac{\delta v^4}{v_t^4}\right)}{(1 + 3\delta)} \exp\left(-\frac{v^2}{2v_t^2}\right)$$

From this distribution after replacing $(\frac{v^2}{v_t^2})$ by $(\frac{v^2}{v_t^2}$ -2ϕ) and after integration we obtain the following expression for the density of nonthermal electrons

$$n_e = \mu\left[1 - \beta\frac{Z_-}{Z_+}\phi + \beta\left(\frac{Z_-}{Z_+}\right)^2\phi^2\right]\exp\left(\frac{Z_-}{Z_+}\phi\right)$$

where;

(vt)is the speed of hot electrons ,

($\beta = \frac{4\delta}{1+3\delta}$) is the nonthermality parameter,

($\mu = n_{eo}/n_{+o}$) ratio of the unperturbed electron to positive ion density.

Normalized Poisson Equatin

$$Z_+ \frac{\partial^2 \phi}{\partial x^2} = Z_- n_- + n_e - Z_+ n_+$$

$u_\pm$ is scaled by the ion sound speed $\boxed{C_s = (K_B T_e / m_+)^{1/2}}$, the potential $\boxed{\phi \text{ by } (K_B T_e / e Z_+)}$, the time by the ion plasma period $\boxed{\omega_{pi}^{-1} = (4\pi e^2 Z_+^2 n_{+0} / m_+)^{-1/2}}$, and the space is in units of the ion Debye radius $\boxed{\lambda_{Di} = (K_B T_e / 4\pi e^2 Z_+^2 n_{+0})^{1/2}}$.

To obtain localized solutions of the previous equations following the Sagdeev potential formalism, we consider a new moving frame of a single variable $\zeta = x - Mt$ which is the moving frame with velocity (Mach number) M.

Using this transformation and the equilibrium quasi-neutrality as well as the boundary conditions ;

$$\phi \to 0,\ n_+ \to 1,\ n_- \to \nu,\ u_+ \to 0, \text{ and } u_- \to 0 \text{ at } |\zeta| \to \infty,$$

- **For positive and negative ions we obtain the following expressions for the densities:**

$$n_+ = \frac{M}{\sqrt{M^2 - 2\,\Phi}} \qquad n_- = \frac{Mv}{\sqrt{M^2 + 2Q\,\Phi}}$$

Substitute the densities values of positive-negative ions in addition to that of nonthermal electrons,

$$n_e = \mu[1 - \beta\frac{z_-}{z_+}\Phi + \beta(\frac{z_-}{z_+})^2\Phi^2]\exp(\frac{z_-}{z_+}\Phi)$$

$$½\left(\frac{d\Phi}{d\zeta}\right)^2 = [\int_0^{\Phi}\frac{Mv}{\sqrt{M^2+2Q\,\Phi}} - \int_0^{\Phi}\frac{M}{\sqrt{M^2-2\,\Phi}} + \int_0^{\Phi}\mu[1-\beta\Phi+\beta\Phi^2]\exp(\Phi)]\mathbf{d}\,\Phi$$

Large Amplitude IAWs

- By integration we obtain the following equation:

$$\boxed{\frac{1}{2}\left(\frac{d\phi}{d\zeta}\right)^2 + V(\phi) = 0}$$

Where;

$$V(\phi) = \frac{Q(3\beta+1)\mu + M^2(Q+\nu)}{Q} - \frac{M\nu}{Q}\left(\sqrt{M^2+2Q\phi} + \frac{Q}{\nu}\sqrt{M^2-2\phi}\right) - \mu(1+3\beta-3\beta\phi+\beta\phi^2)\exp(\phi).$$

V(Φ) is the Sagdeev potential .for simplicity we assumed that Z+ =Z− =1

Large Amplitude IAWs

- Therefore, the existence of solitary wave solution of the large amplitude IAW is possible if the following conditions are satisfied:

(i) The potential (Φ) has the maximum value if $\frac{d^2 V(\Phi)}{d\zeta^2} < 0$ at Φ=0,this condition yields the inequality.

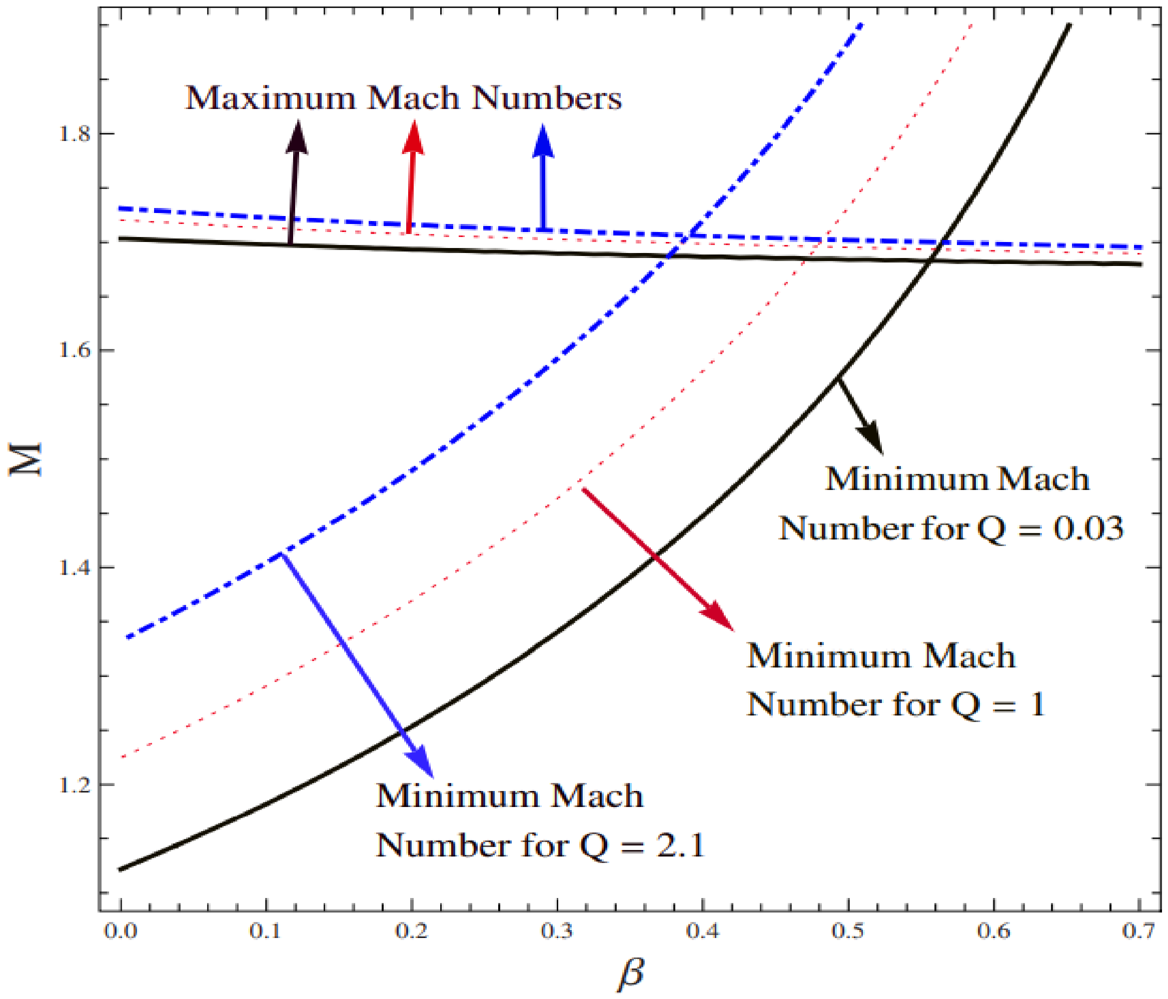
$$\boxed{M^2 > \frac{Q\,v}{(1-\beta)\mu}.}$$

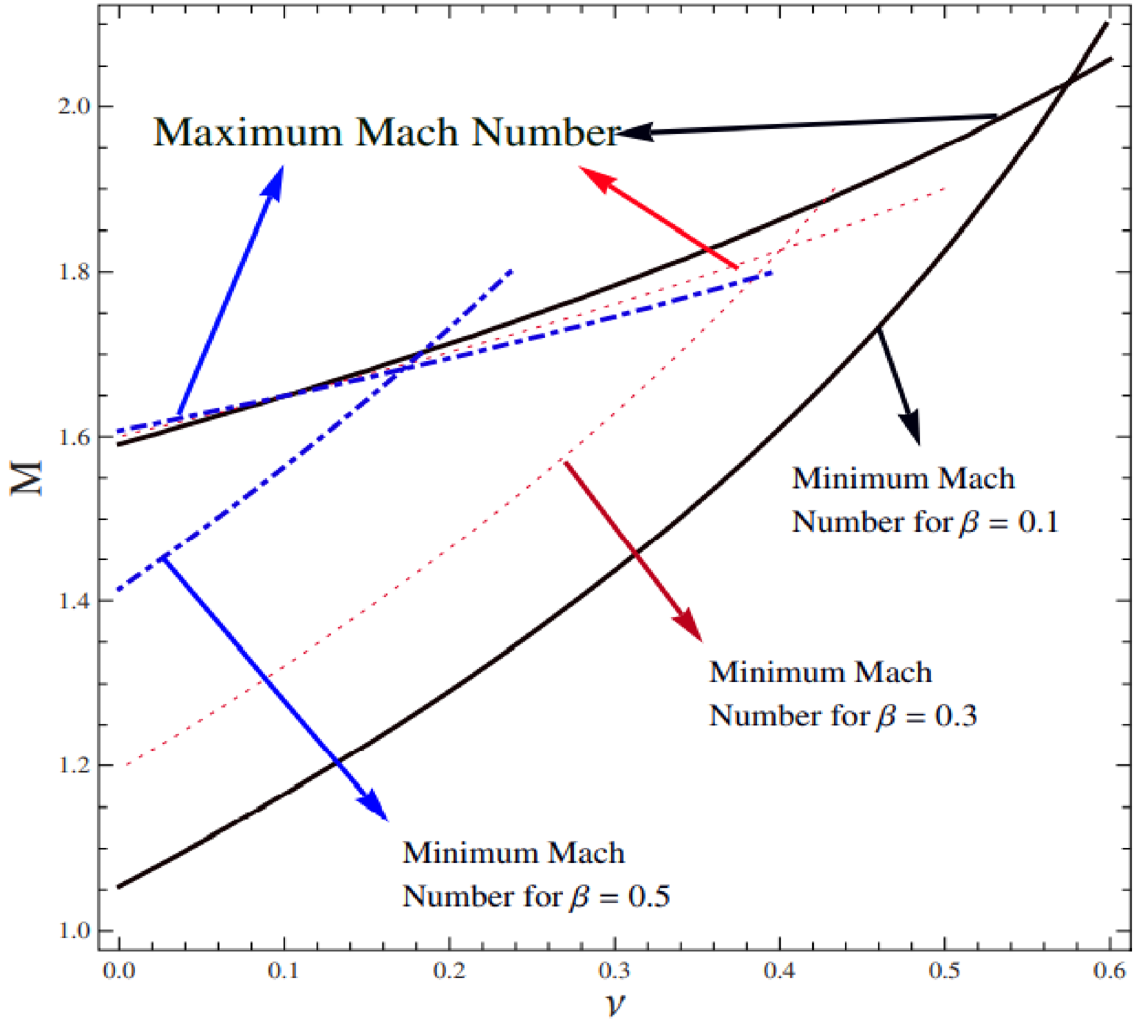
$\longrightarrow$ **[Minimum Mach number]**

(ii) Nonlinear IAWs exist only when $V(\Phi_{Max}) \geq 0$, where the maximum potential Φ_{Max} is determined by $\Phi_{Max} \approx \frac{M^2}{2}$ this implies the inequality.

$$\boxed{M^2[Q + \upsilon\,] - \upsilon\sqrt{(1+Q)} + \mu Q(1+3\beta) \geq Q\mu\left[1 + \beta\left(\frac{1}{4}M^4 - \frac{3}{2}M^2 + 3\right)\right]e^{M^2/2}}$$

$\longrightarrow$ **[Maximum Mach number]**

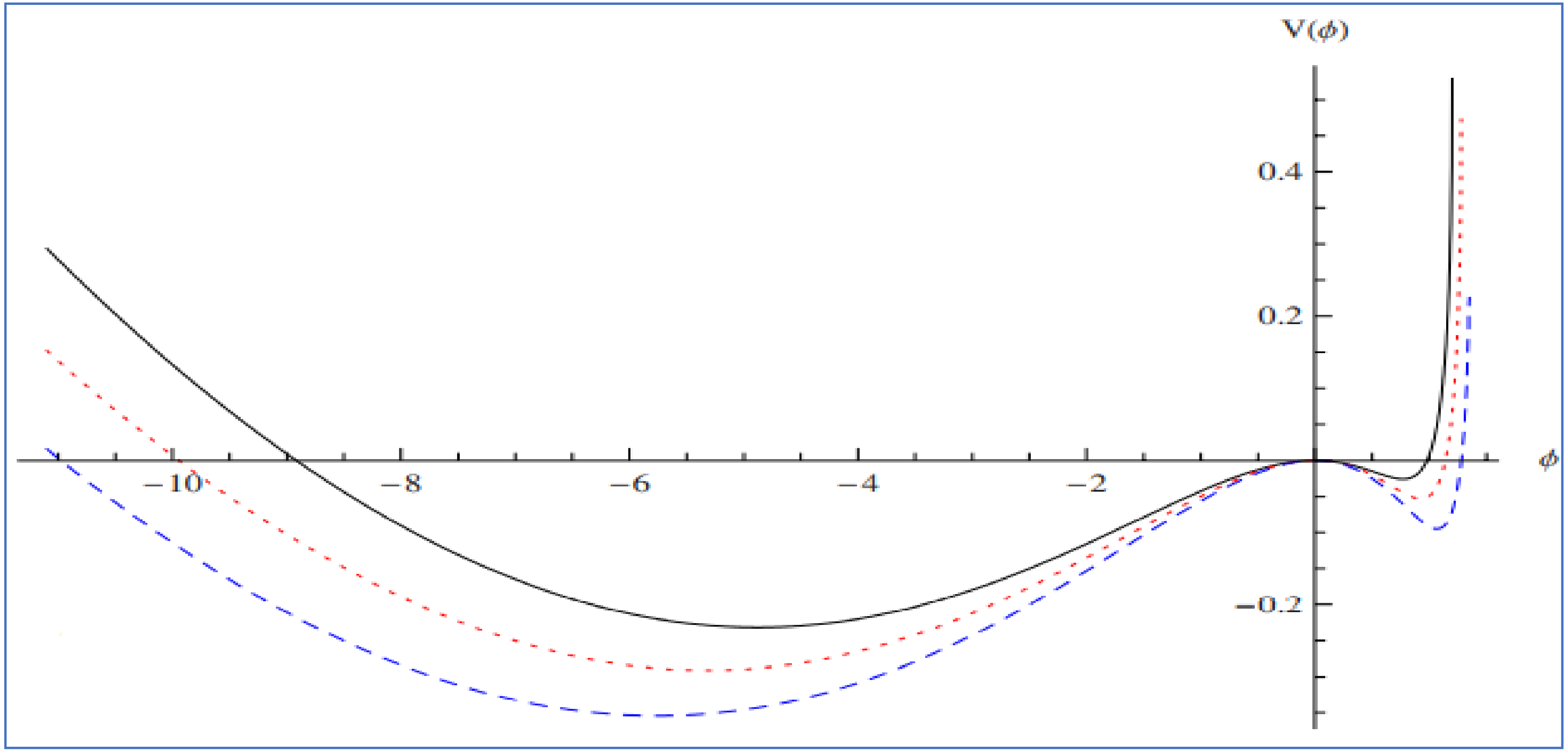




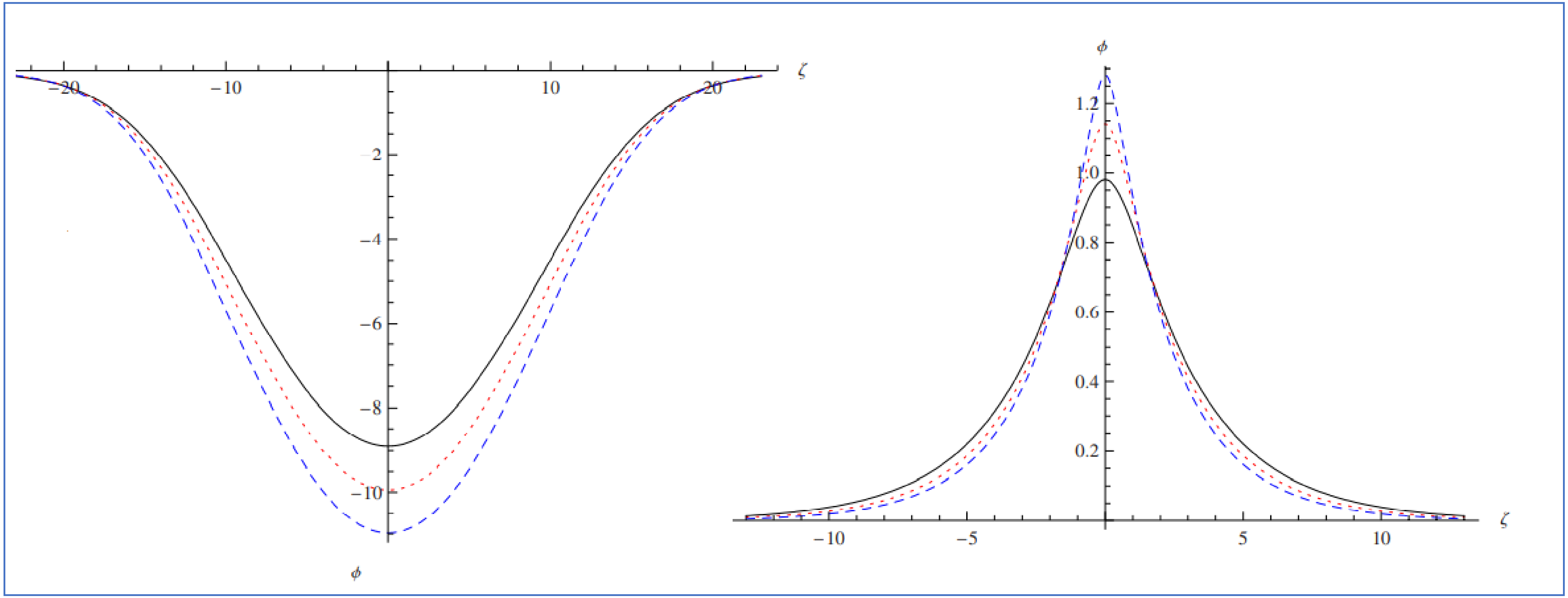
The fig. shows minimum and maximum Mach number Vs the non-thermality parameter for different values of Q,and

minimum and maximum Mach number Vs the density ratio *ν* for different values of non-thermality parameter β.

The Following figures show the effect of Mach number M on the large amplitude IAWs for (H^+, O_2^-):



The fig. shows the Sagdeev potential curve for different values of M, M=1.55 (solid line), M=1.6(dotted line), M=1.65(dotted-dashed line). Q=0.03,ν=0.4,β=0.1.

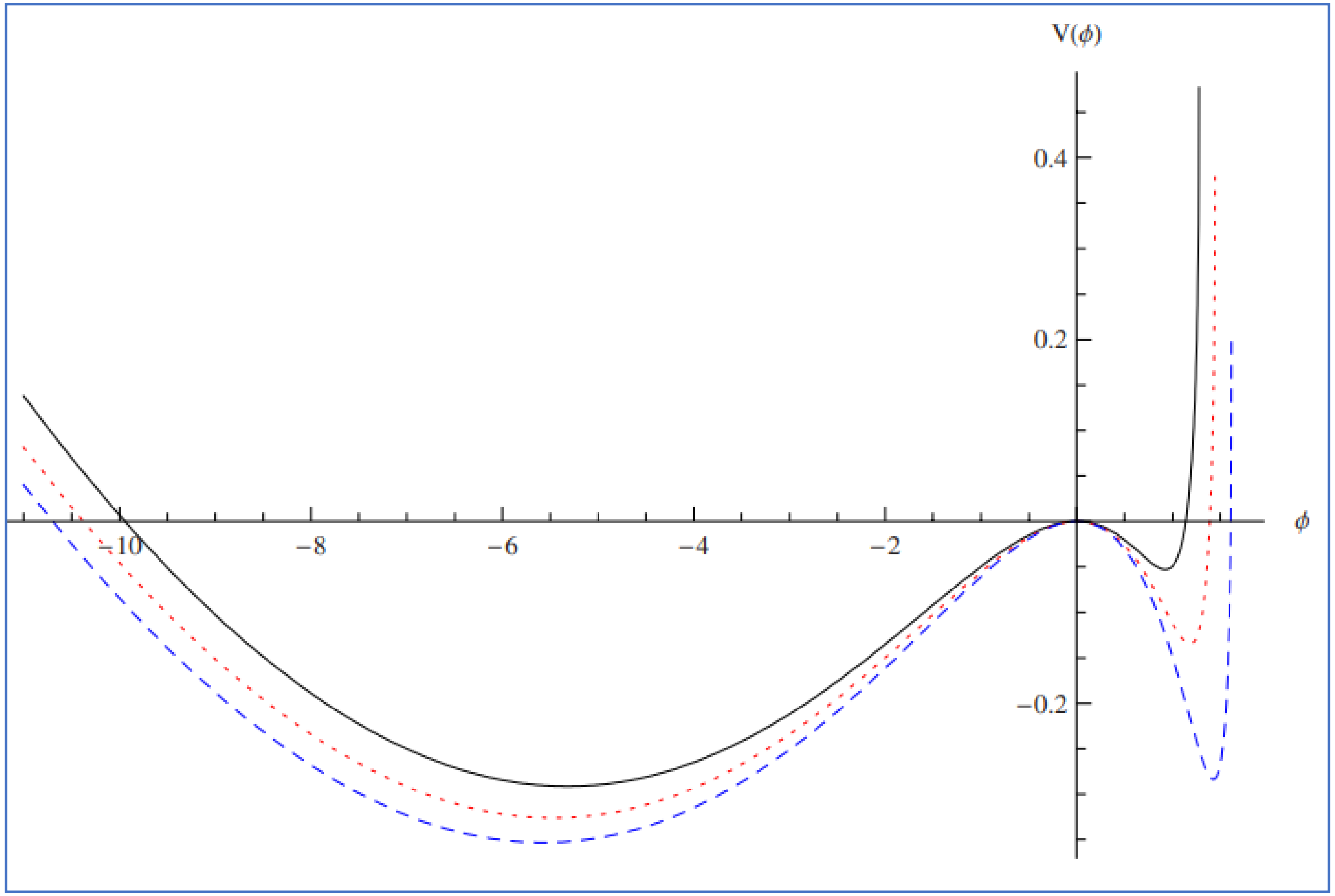


The fig. shows the profile of the positive ion-acoustic solitary waves, and the profile of the negative ion-acoustic solitary waves for different values of M, M=1.55 (solid line), M=1.6(dotted line), M=1.65(dotted-dashed line.

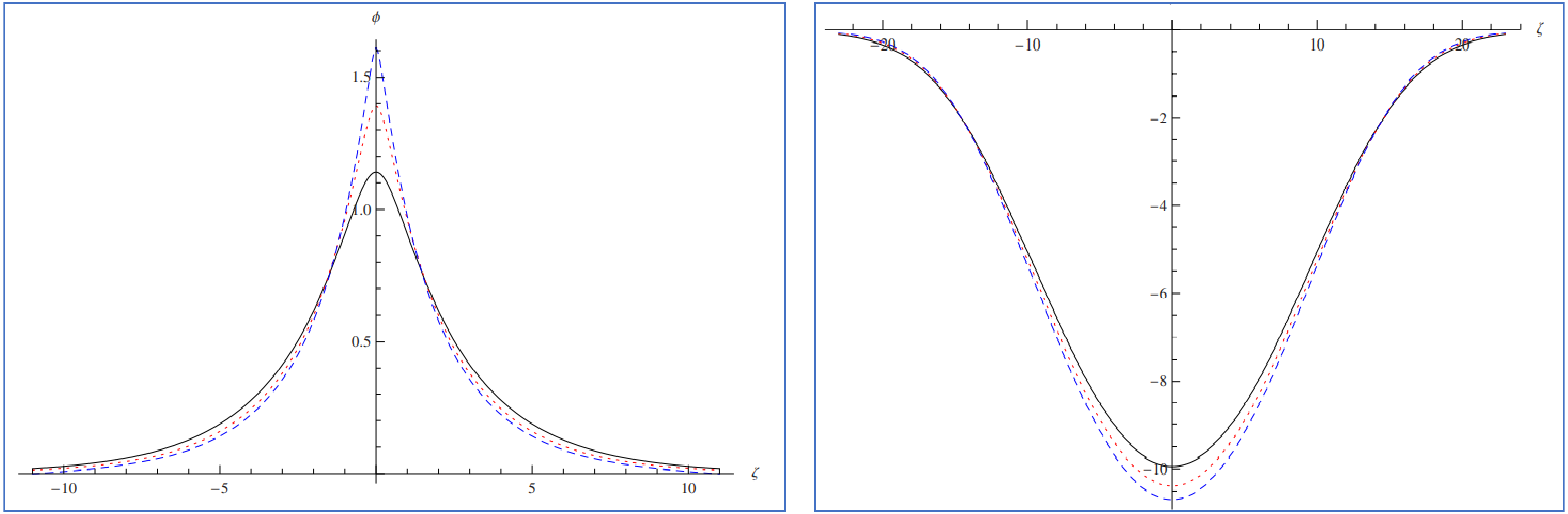
It is clear that increasing the Mach number increases the amplitude but decreases the width.

It is noticeable that faster solitary pulses will be taller and narrower, while slower ones will be shorter and wider.

The Following figures show the effect of density ratio ν on the large amplitude IAWs for (H^{+}, O_{2}^{-}):



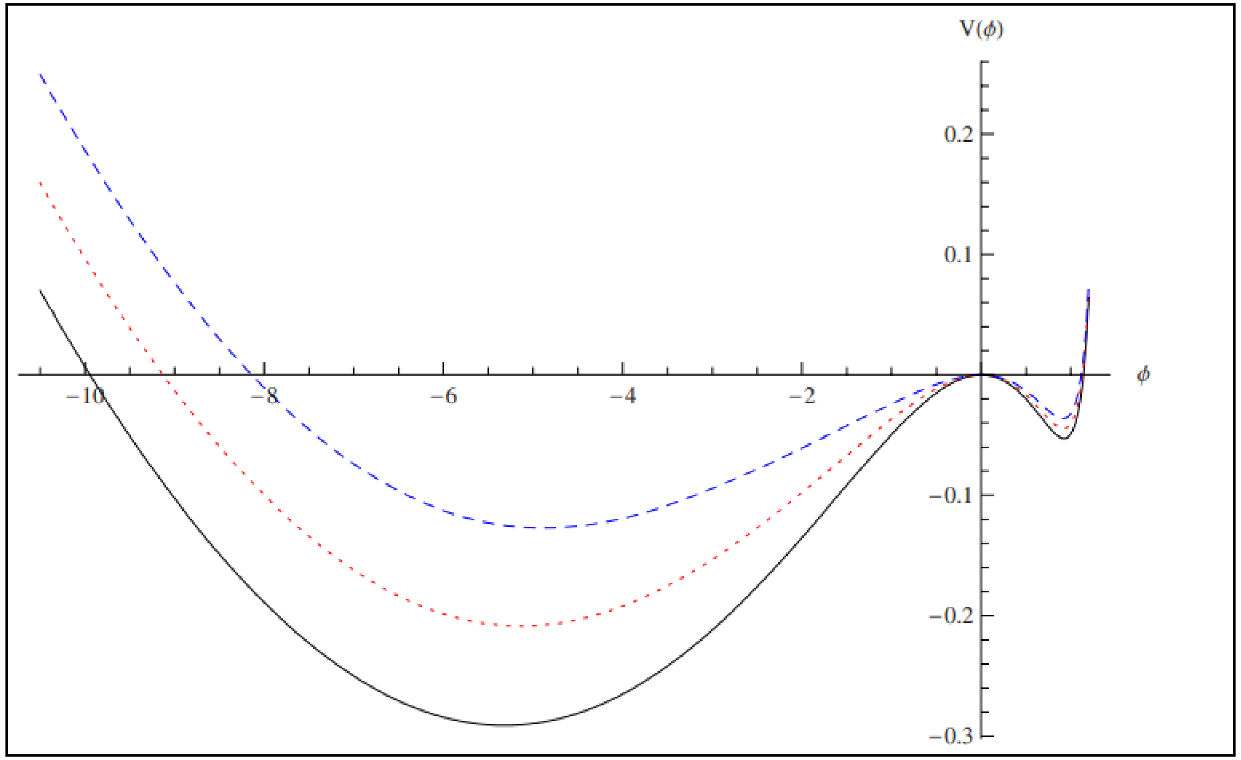
The fig. shows the Sagdeev potential curve for different values of ν, ν= 0.4 (solid line), ν= 0.42(dotted line), ν= 0.44(dotted-dashed line).
Q=0.03, 0.4,β=0.1.



The fig. shows the profile of the positive ion-acoustic solitary waves, and the profile of the negative ion-acoustic solitary waves for different values of v, v= 0.4 (solid line), v= 0.42(dotted line), v= 0.44(dotted-dashed line).

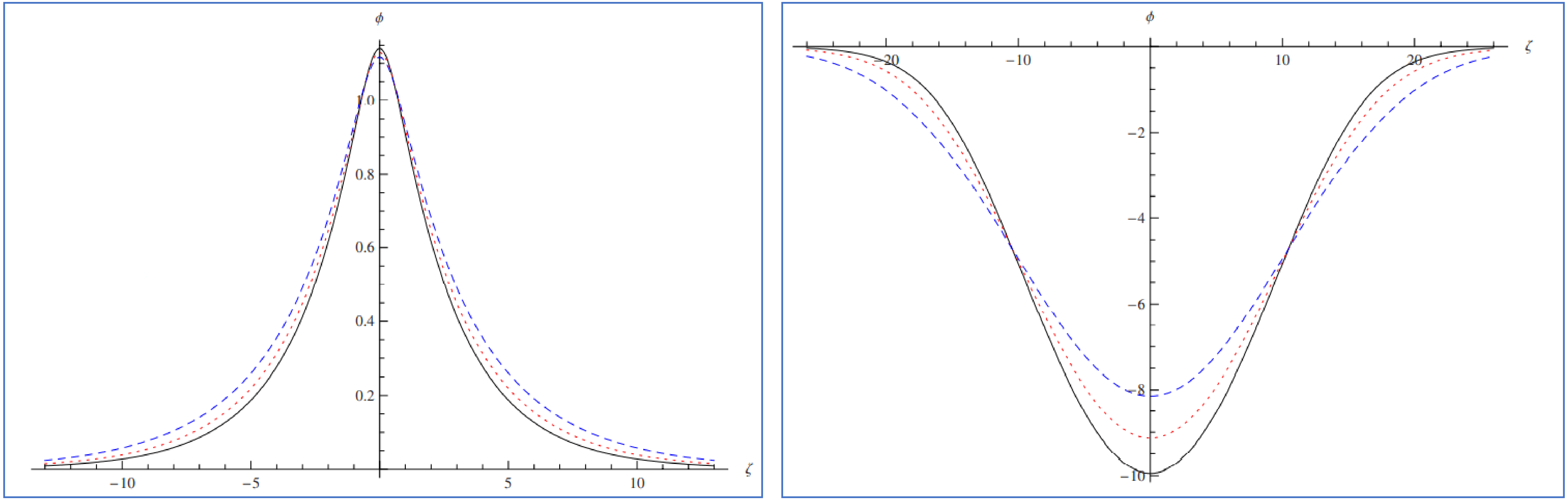
Q=0.03, 0.4,β=0.1.

The Following figures show the effect of the nonthermal parameter β on the large amplitude IAWs for (H^+, O_2^-):



The fig. shows the Sagdeev potential curve for different values of β, β = 0.1 (solid line), β = 0.15(dotted line), β = 0.2 (dotted-dashed line).

Q=0.03, 0.4, v =0.4,M=1.6



The fig. shows the profile of the positive ion−acoustic solitary waves, and the profile of the negative ion−acoustic solitary waves for different values of β, β = 0.1 (solid line), β = 0.15(dotted line), β = 0.2 (dotted-dashed line).

Q=0.03, 0.4, ν =0.4,M=1.6.

summary

- **we have presented a study of the fully nonlinear ion-acoustic solitary waves in a plasma with two distinct ion species (i.e., positive and negative ions) and nonthermal electrons.**

- **By employing the two-fluid equations for the ions and a nonthermal electron distribution, we have derived the energy integral with a new Sagdeev potential that is used to examine the existence regions of the solitary pulses.**

summary

- **The solitary excitations are strongly depending on the mass ratio of the positive-to-negative ions(Q), the density ratio of the negative-to-positive ions (v) , and the nonthermal electron parameter(β) .**

- **Numerical solution of the energy integral equation shows that both positive and negative solitary pulses exist together**

summary

- **the faster solitary pulses are taller and narrower.**

- **increasing the nonthermal electron parameter β decreases the amplitude but increases the pulse width.**


thank
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