ON THE STUDY OF WAVE-PARTICLE INTERACTION EFFECTS IN A DUSTY PLASMA

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Outline

- Introduction
- Aim
- Physical Model
- Linear Analysis
- Non-linear Analysis
- Discussion
- Conclusion

Introduction

The wave particle interaction plays a crucial role in the structure and dynamics of various space and laboratory plasma system

....Why?

- Plasma controlled by long-range electromagnetic waves .
- Applications

(space plasmas) formation magneto pause boundary
(astrophysics plasmas) charged particle acceleration in relativistic regimes
(laboratory plasmas) plasma heating in magnetic fusion plasmas

- What happens between the charged particle and the wave in the plasma?

1. **($V_T > V_{Ph}$)**

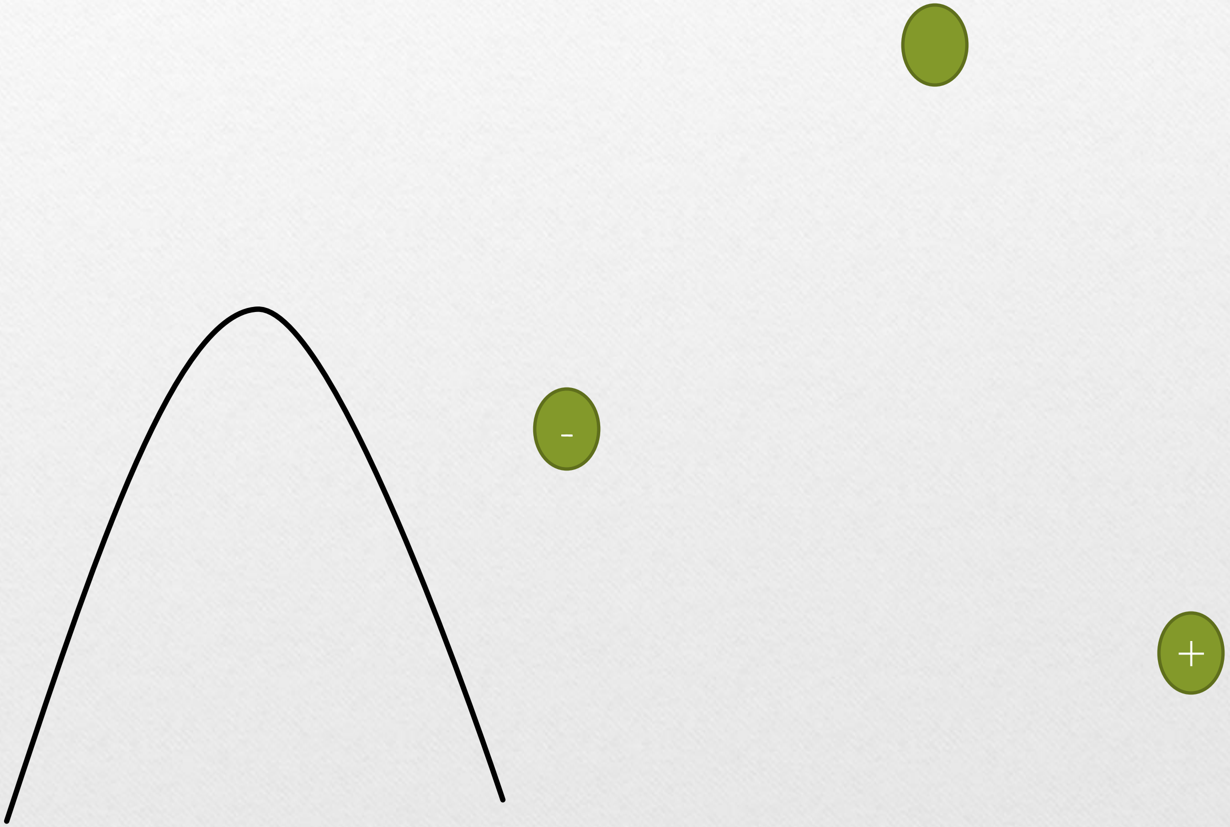
   Passing particles (Free particle)

2. **($V_T \leq V_{Ph}$)**

   Resonance particles

   - **(Resonance Trapped particle)**
   - **(Resonance Reflected particle)**

WPIs



Phase-space of Resonant charges

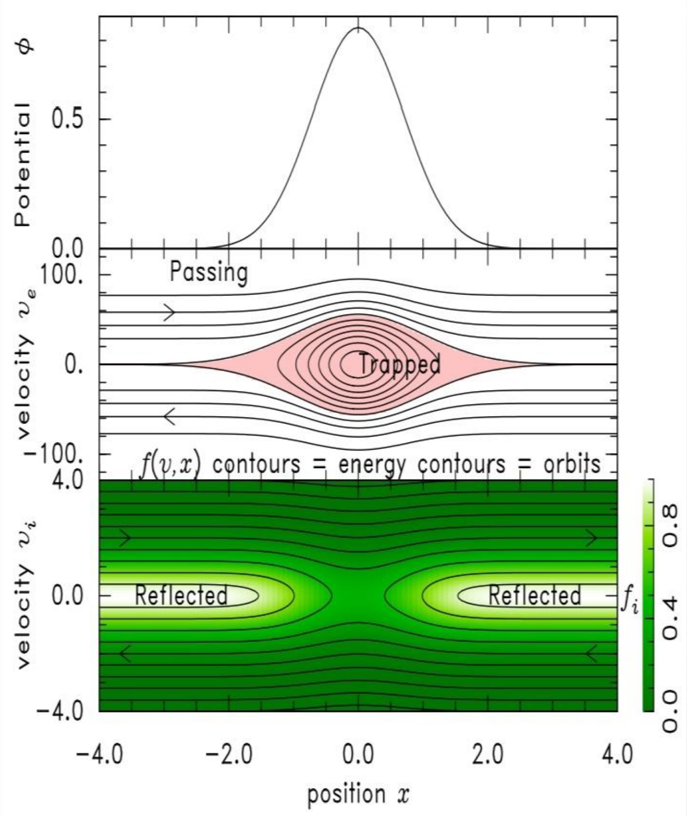


FIG. 1. Schematic of a slow electron hole and the corresponding electron and ion phase-space density contours.

Wave-particle interaction scenario with two different charged particles (SEADL,SIADL)

Distribution Functions

$$f_e^{\kappa_e}(v,\phi) = \frac{\Gamma[\kappa_e]}{\sqrt{2\pi}(\kappa_e - \frac{3}{2})^{1/2}\Gamma[\kappa_e - \frac{1}{2}]} \begin{cases} (1 + \frac{\frac{v^2}{2} - \phi}{\kappa_e - \frac{3}{2}})^{-\kappa_e}, \mid v \mid > 2\phi, \\ (1 + \beta_e \frac{\frac{v^2}{2} - \phi}{\kappa_e - \frac{3}{2}})^{-\kappa_e}, \mid v \mid \leq 2\phi. \end{cases}$$

$$f_i^{\kappa_i}(u,\phi) = \frac{\Gamma[\kappa_i]}{\sqrt{2\pi}(\kappa_i - \frac{3}{2})^{1/2}\Gamma[\kappa_i - \frac{1}{2}]} \begin{cases} (1 + \frac{\frac{u^2}{2} - \theta(\psi - \phi)}{\kappa_i - \frac{3}{2}})^{\kappa_i}, \mid u \mid > 2\theta(\psi - \phi), \\ (1 + \alpha_i \frac{\frac{u^2}{2} - \theta(\psi - \phi)}{\kappa_i - \frac{3}{2}})^{-\kappa_i}, \mid u \mid \leq 2\theta(\psi - \phi). \end{cases}$$

$$\boldsymbol{f_e^{\kappa_e}(v,\phi) = f_{fe}^{\kappa_e}(v,\phi) + f_{te}^{\kappa_e}(v,\phi), \quad f_i^{\kappa_i}(v,\phi) = f_{fi}^{\kappa_i}(u,\phi) + f_{ri}^{\kappa_i}(u,\phi)}$$

Aim

Study of the WPIs(**Trapping +Reflection**) and **Superthermality** of two different charges (**electron, ion**) effects on **DAW**':

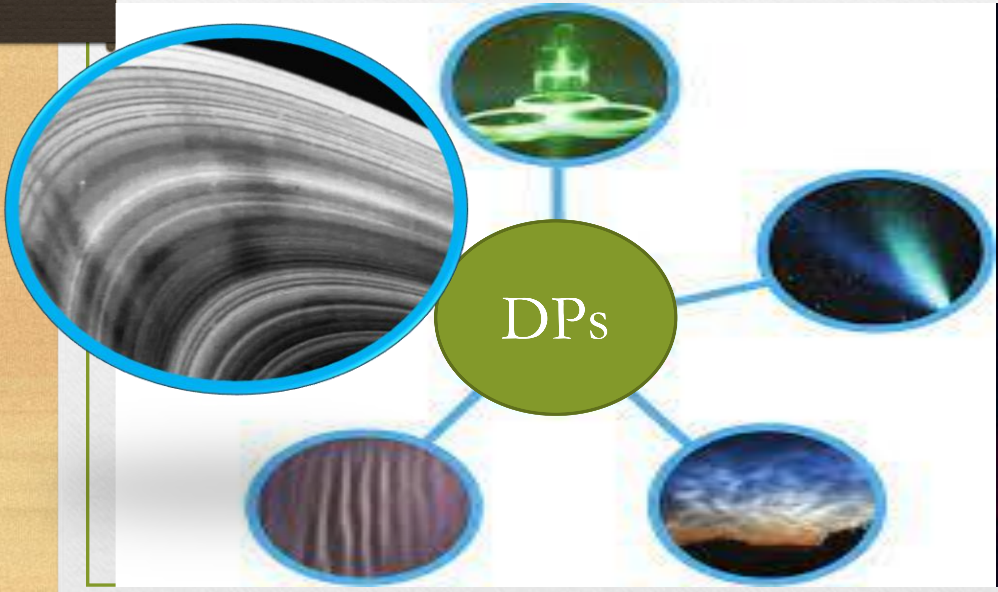
1. Existence
2. No of modes
3. Polarity
4. Profile
5. Propagation speed

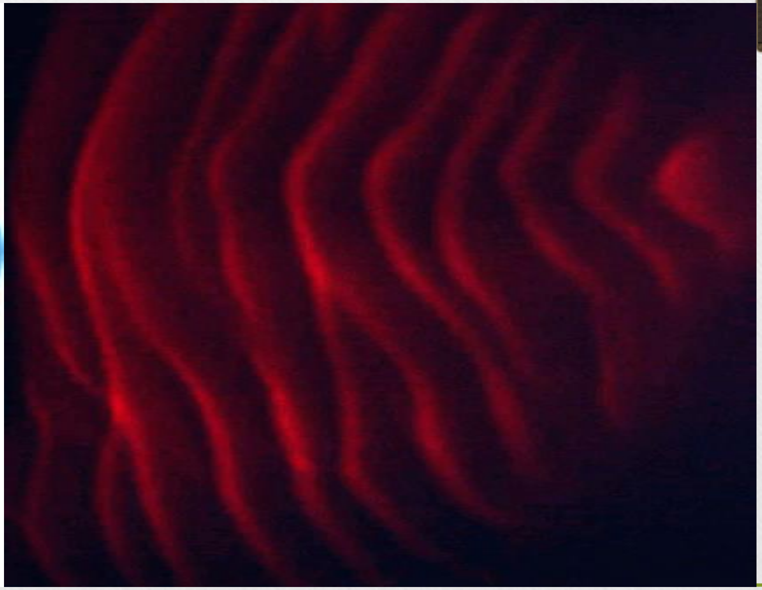
WPIs Cases: { Case A (TE+RI)
Case B (TI+RE)

Modelling

Plasma system:

Un-magnetized collision-less adiabatic OPDP system consisting of positive dust, negative dust, nonthermal electrons and nonthermal ions.





Model Equations

$$\frac{\partial n_n}{\partial t} + \frac{\partial(n_n u_n)}{\partial x} = 0$$

$$\frac{\partial u_n}{\partial t} + u_n \frac{\partial u_n}{\partial x} = \frac{\partial \phi}{\partial x} - \sigma_n n_n \frac{\partial n_n}{\partial x},$$

$$\frac{\partial n_p}{\partial t} + \frac{\partial(n_p u_p)}{\partial x} = 0$$

$$\frac{\partial u_p}{\partial t} + u_p \frac{\partial u_p}{\partial x} = -\nu \frac{\partial \phi}{\partial x} - \sigma_p n_p \frac{\partial n_p}{\partial x},$$

$$\frac{\partial^2 \phi}{\partial x^2} = n_n - \delta_p n_p + \delta_e n_e - \delta_i n_i$$

general mathematical form for the number density

$n_e \simeq 1 + c_{e1}\phi + c_{e2}\phi\ 3/2 + c_{e3}(\psi\ 3/2 - (\psi + \phi)\ 3/2) + c_{e4}\phi\ 2$

$n_i \simeq 1 + c_{i1}\phi + c_{i2}(-\phi)\ 3/2 + c_{i3}(\psi\ 3/2 - (\psi - \phi)\ 3/2) + c_{i4}\phi\ 2$

$$c_{e1} = \frac{2\kappa_e - 1}{2\kappa_e - 3}\ , \qquad c_{e2} = \frac{8\sqrt{2/\pi}(\beta_e - 1)\kappa_e\Gamma[\kappa_e]}{3(2\kappa_e - 3)^{3/2}\Gamma[\kappa_e - \frac{1}{2}]},$$

$$c_{e3} = -\frac{8\sqrt{2/\pi}(\alpha_e - 1)\kappa_e\Gamma[\kappa_e]}{3(2\kappa_e - 3)^{3/2}\Gamma[\kappa_e - \frac{1}{2}]}, \qquad c_{e4} = \frac{4\kappa_e{}^4 - 1}{2(2\kappa_e - 3)^2}$$

$$c_{i1} = \theta\left(\frac{2\kappa_i - 1}{2\kappa_i - 3}\right), \qquad c_{i2} = \theta^{3/2}\left(\frac{8\sqrt{\frac{2}{\pi}}(\beta_i - 1)\kappa_e\Gamma[\kappa_i]}{3(2\kappa_i - 3)^{\frac{3}{2}}\Gamma\left[\kappa_i - \frac{1}{2}\right]}\right),$$

$$c_{i3} = \theta^{3/2}\left(\frac{8\sqrt{2/\pi}(\alpha_i - 1)\kappa_i\Gamma[\kappa_i]}{3(2\kappa_i - 3)^{3/2}\Gamma[\kappa_i - \frac{1}{2}]}\right), \qquad c_{i4} = \theta^2\left(\frac{4\kappa_i{}^4 - 1}{2(2\kappa_i - 3)^2}\right)$$

Linear Wave Analysis

$\boldsymbol{LDR}$ $\qquad \omega^4 + a_1\omega^2 + a_0 = 0$

$Where;$

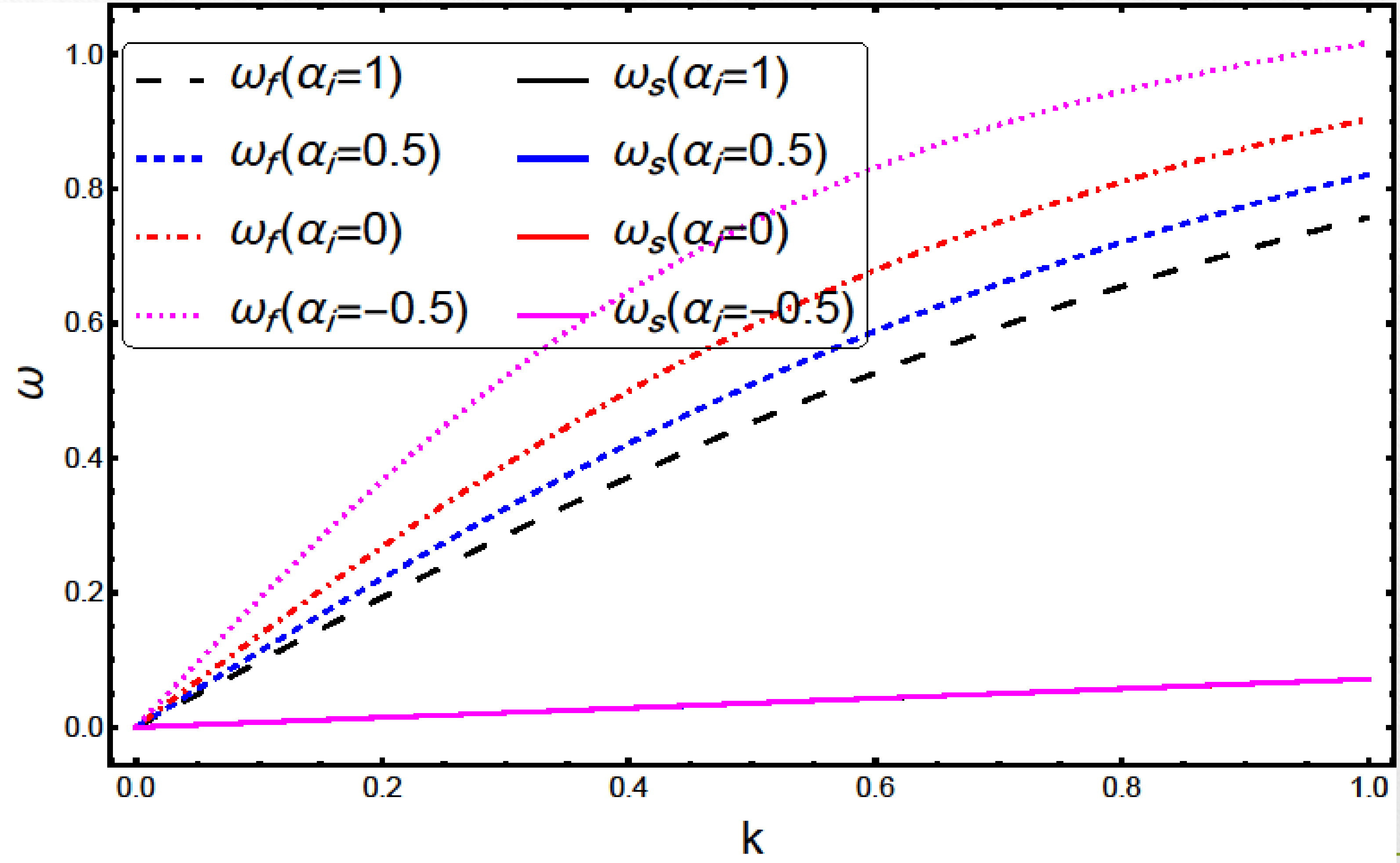
$$a_1 = -\left(\sigma n + \sigma p + \frac{1 + \nu\delta p}{\kappa^2 + ce\delta e - ci\delta i}\right)\kappa^2,$$

$$a_0 = \left(\sigma n\sigma p + \frac{\sigma p + \nu\delta p\sigma n}{\kappa^2 + ce\delta e - ci\delta i}\right)\kappa^4$$

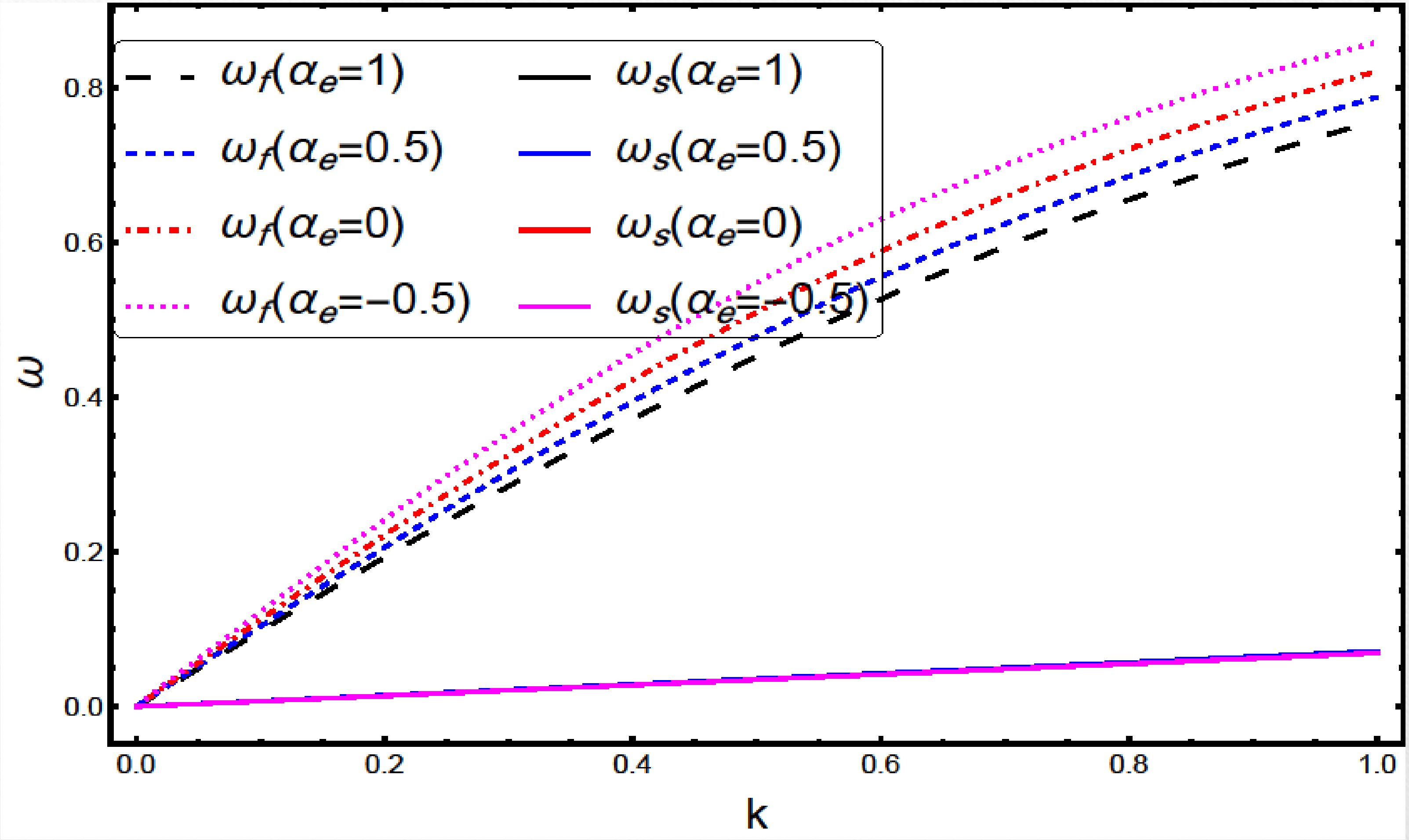
$$c_e = \left(c_{e1} - \frac{3}{2}c_{e3}\psi^{1/2}\right),$$

$$c_i = \left(c_{i1} + \frac{3}{2}c_{i3}\psi^{1/2}\right).$$

Case A
($\alpha_e = 1$)



Case B
$(\alpha_i = 1)$



Non-Linear Wave Analysis (RPT)

Stretched coordinates $\xi = \epsilon^{1/2}(x - \lambda t), \quad \tau = \epsilon^{3/2} t.$

Expanding the independent in powers of ϵ

$$n = 1 + \epsilon n^{(1)} + \epsilon^{3/2} n^{(2)} + \epsilon^{2} n^{(3)} +,$$

$$u = \epsilon u^{(1)} + \epsilon^{3/2} u^{(2)} + \epsilon^{2} u^{(3)} + ,$$

$$\phi = \epsilon \phi^{(1)} + \epsilon^{3/2} \phi^{(2)} + \epsilon^{2} \phi^{(3)} +$$

To the next higher order of ϵ, we obtain a group of Eqs., which lead to the following modified Schamel-Kdv-equation(SKdV)

$$\frac{\partial \phi}{\partial \tau} + \left(A_1\phi + A_2\phi^{1/2} + A_3(-\phi)^{1/2}\right)\frac{\partial \phi}{\partial x} + B\frac{\partial^3 \phi}{\partial x^3} = 0$$

$$A_1 = \left(-\frac{3\lambda^2+\sigma_n}{(\lambda^2-\sigma_n)^3} + \frac{3\lambda^2+\sigma_p}{(\lambda^2-\sigma_p)^3}\nu^2\delta_p - 2\delta_e\left(c_{e4} - \frac{3}{8}c_{e3}\psi^{-1/2}\right) + 2\delta_i\left(c_{i4} - \frac{3}{8}c_{i3}\psi^{-1/2}\right)\right) B$$

$$A_2 = -\frac{3}{2}\delta_e c_{e2} B,$$

$$A_3 = -\frac{3}{2}\delta_i c_{i2} B,$$

$$B = \frac{1}{2\lambda}\left(\frac{1}{(\lambda^2-\sigma_n)^2} + \frac{\nu\delta_p}{(\lambda^2-\sigma_p)^2}\right)^{-1}$$

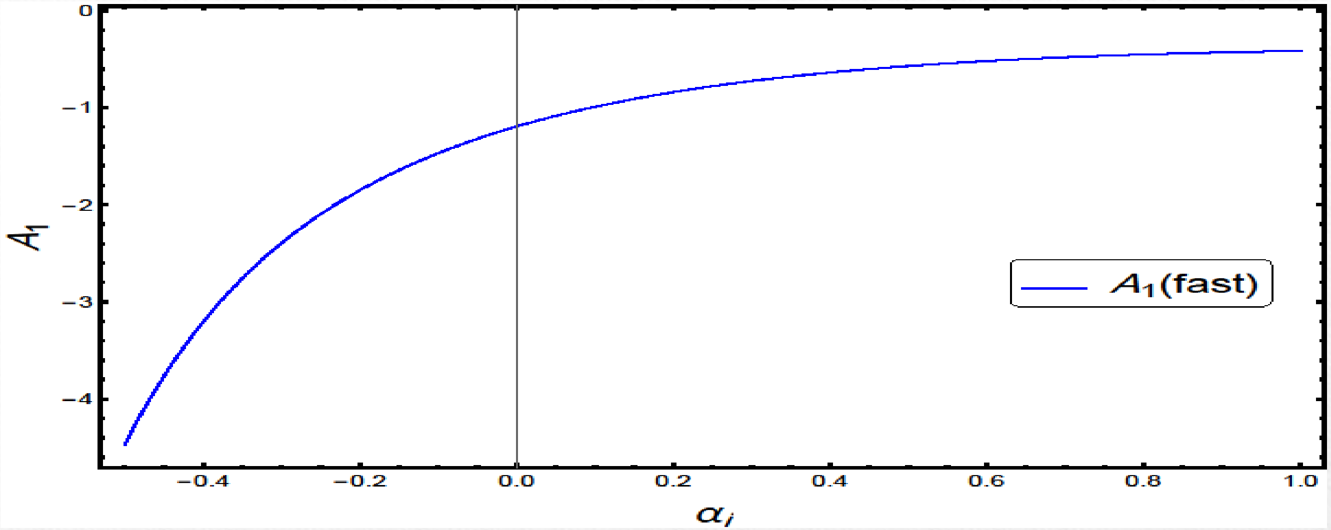
Case A

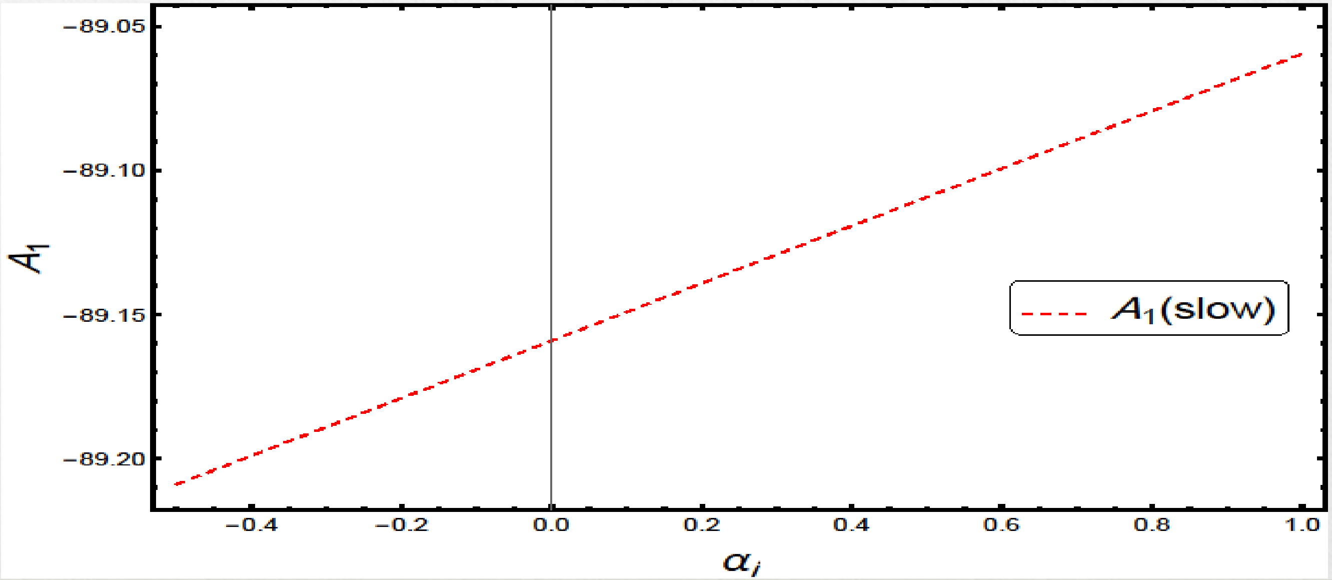
$$(\boldsymbol{\beta_e < 1, \alpha_i < 1; \beta_i = 1, \alpha_e = 1})$$

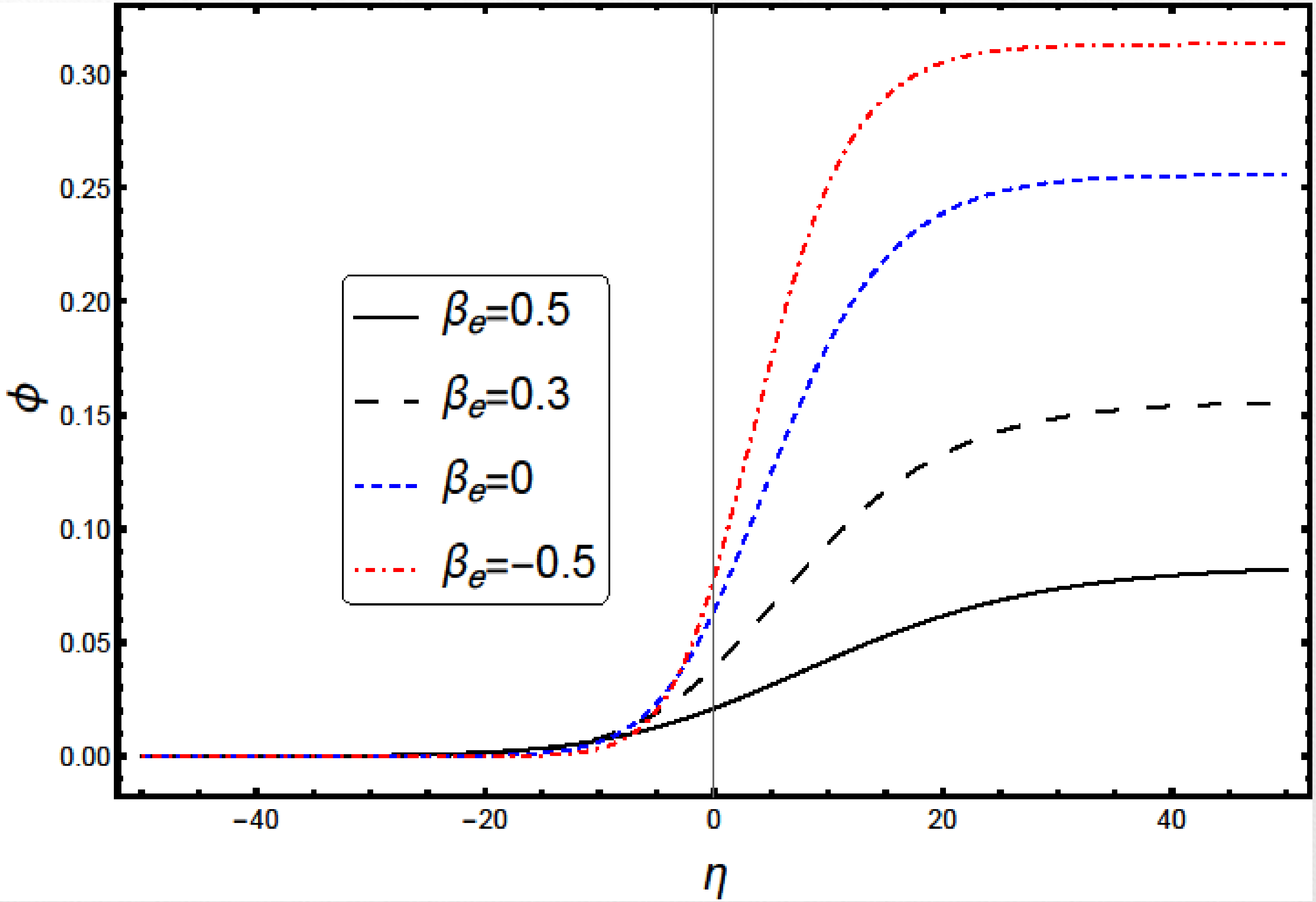
$$\frac{\partial\varphi}{\partial\tau} + \left(A_1\varphi + A_2\varphi^{\frac{1}{2}}\right)\frac{\partial\varphi}{\partial\boldsymbol{\xi}} + B\,\frac{\partial^3\varphi}{\partial\boldsymbol{\xi}^3} = 0$$

$$\varphi = \varphi_m(1 \pm \tanh[\frac{\xi - M\tau}{W}])^2$$

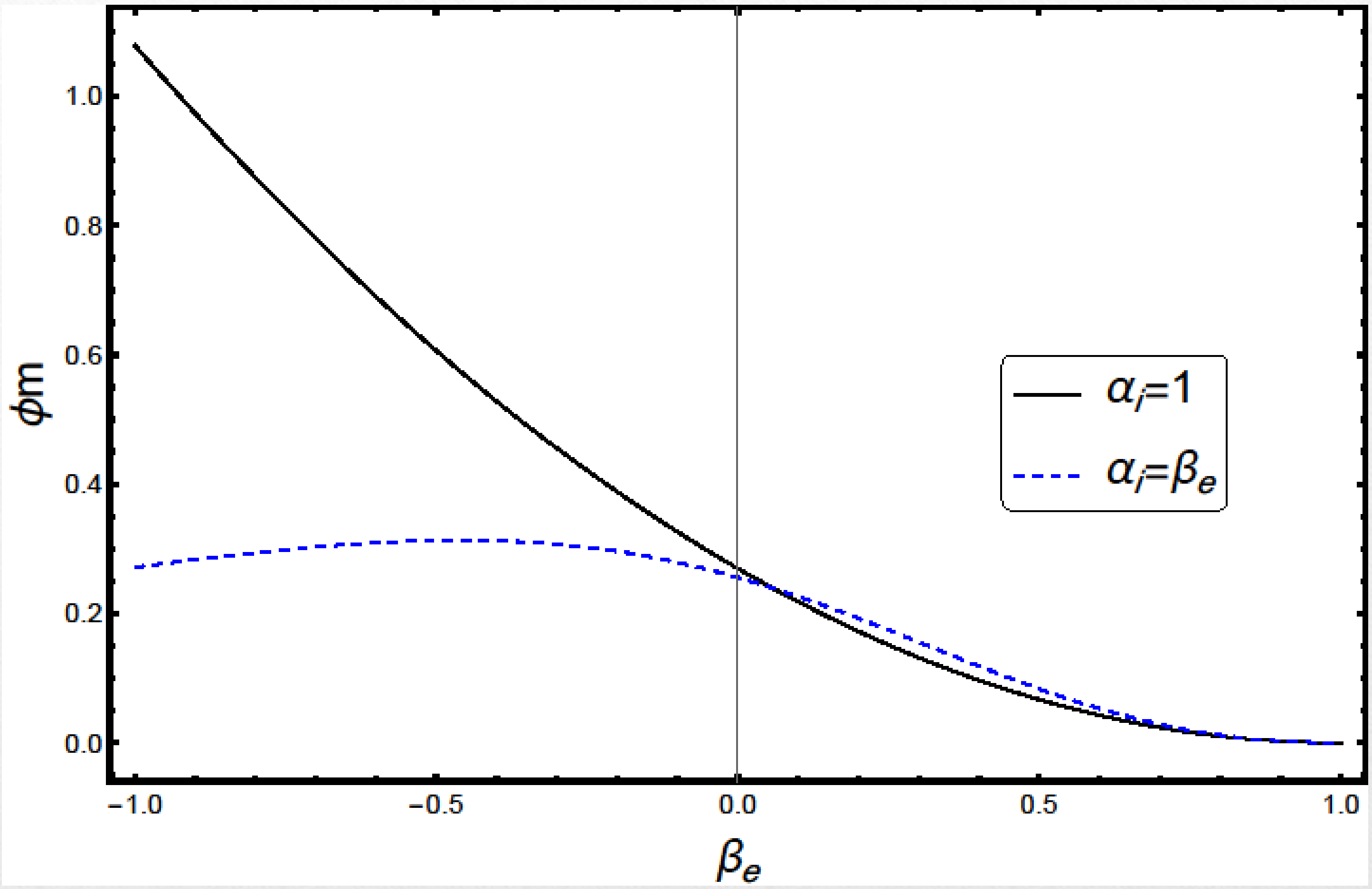
$$\varphi_m = \frac{4A_2^2}{25A_1^2}, \quad W = \frac{5}{A_2}\sqrt{-3BA_1}$$


0
−1
−2
−3
−4
A_1
A_1(fast)
−0.4
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
α_i

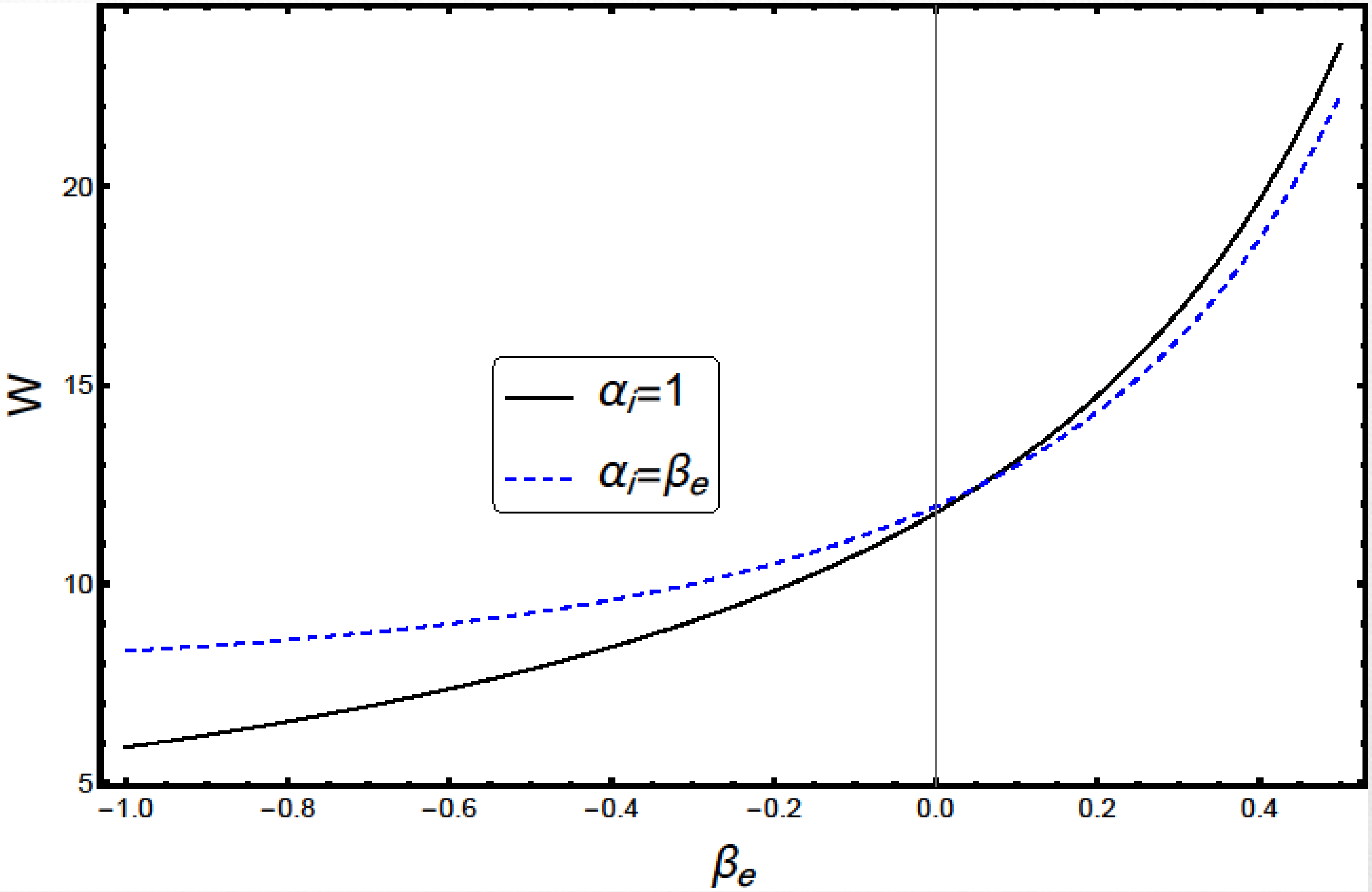

−89.05
−89.10
−89.15
−89.20
A_1
A_1(slow)
−0.4
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
α_i



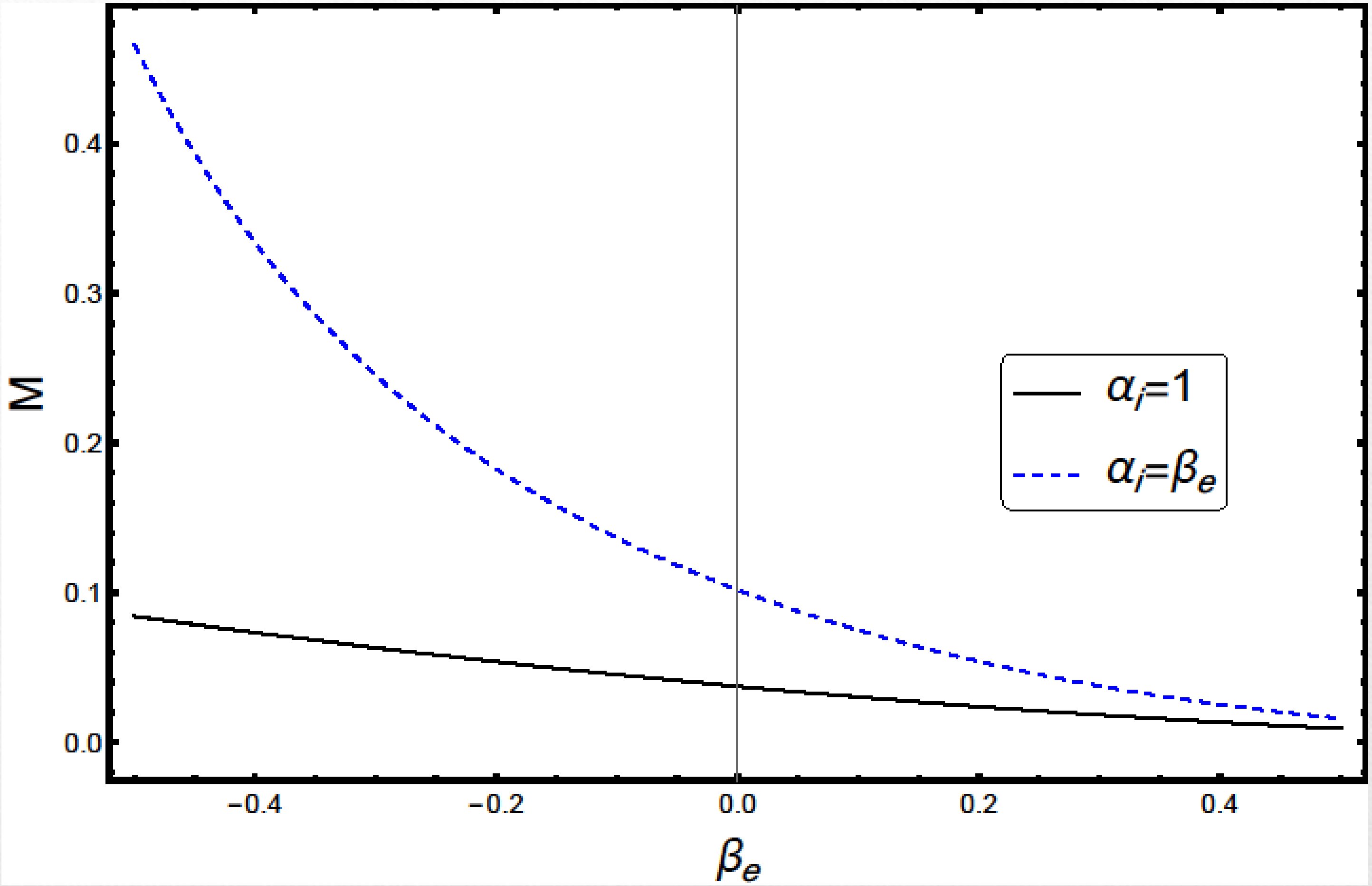
0.30
0.25
0.20
0.15
0.10
0.05
0.00
ϕ
−40
−20
0
20
40
η
βe=0.5
βe=0.3
βe=0
βe=−0.5



1.0
0.8
0.6
0.4
0.2
0.0
ϕm
−1.0
−0.5
0.0
0.5
1.0
β_e
α_i=1
α_i=β_e



W
20
15
10
5
−1.0
−0.8
−0.6
−0.4
−0.2
0.0
0.2
0.4
β_e
α_i=1
α_i=β_e



0.4
0.3
0.2
0.1
0.0
M
−0.4
−0.2
0.0
0.2
0.4
β_e
α_i=1
α_i=β_e

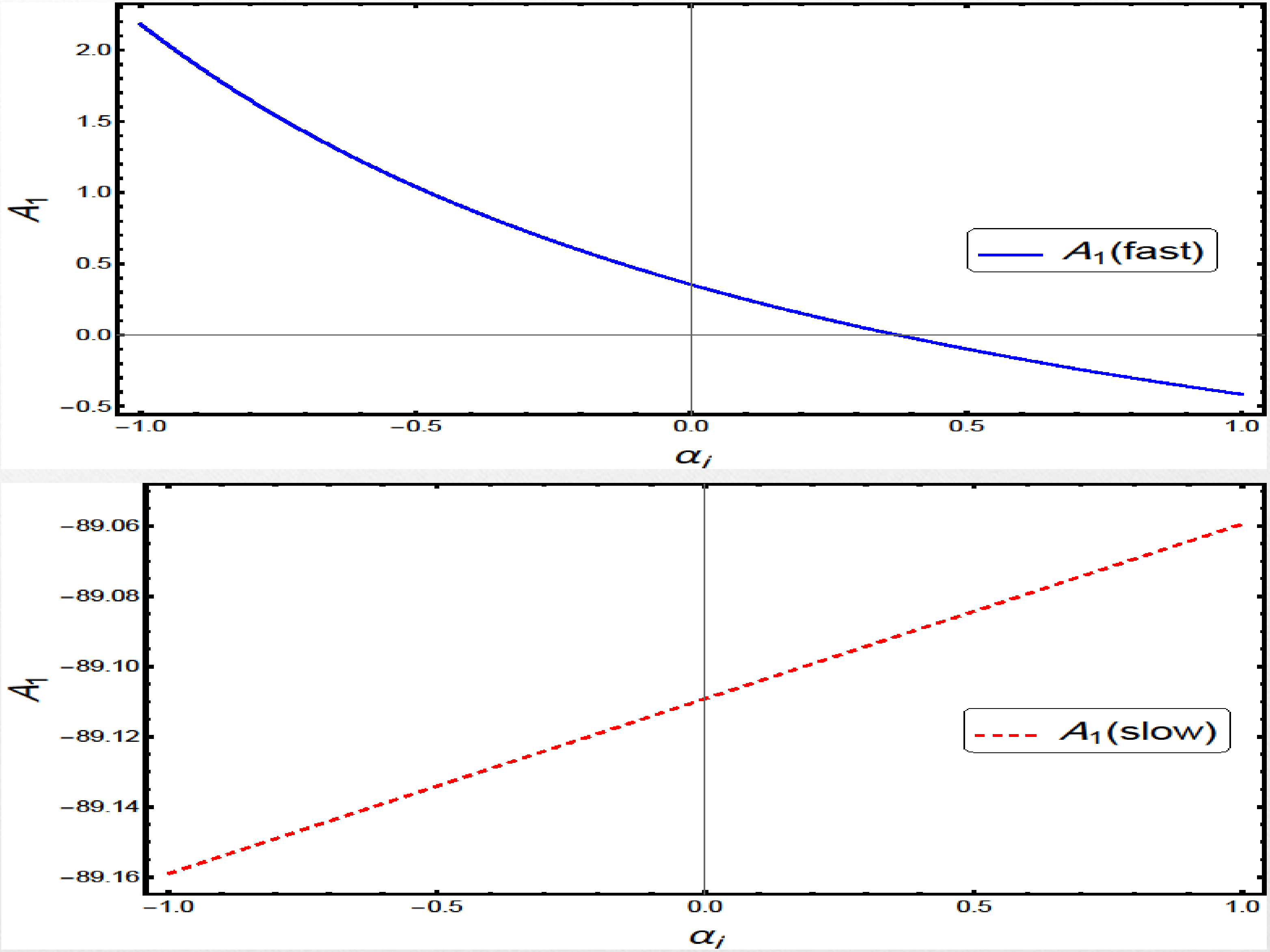
Case B

$$(\beta_i < 1, \alpha_e < 1; \beta_e = 1, \alpha_i = 1)$$

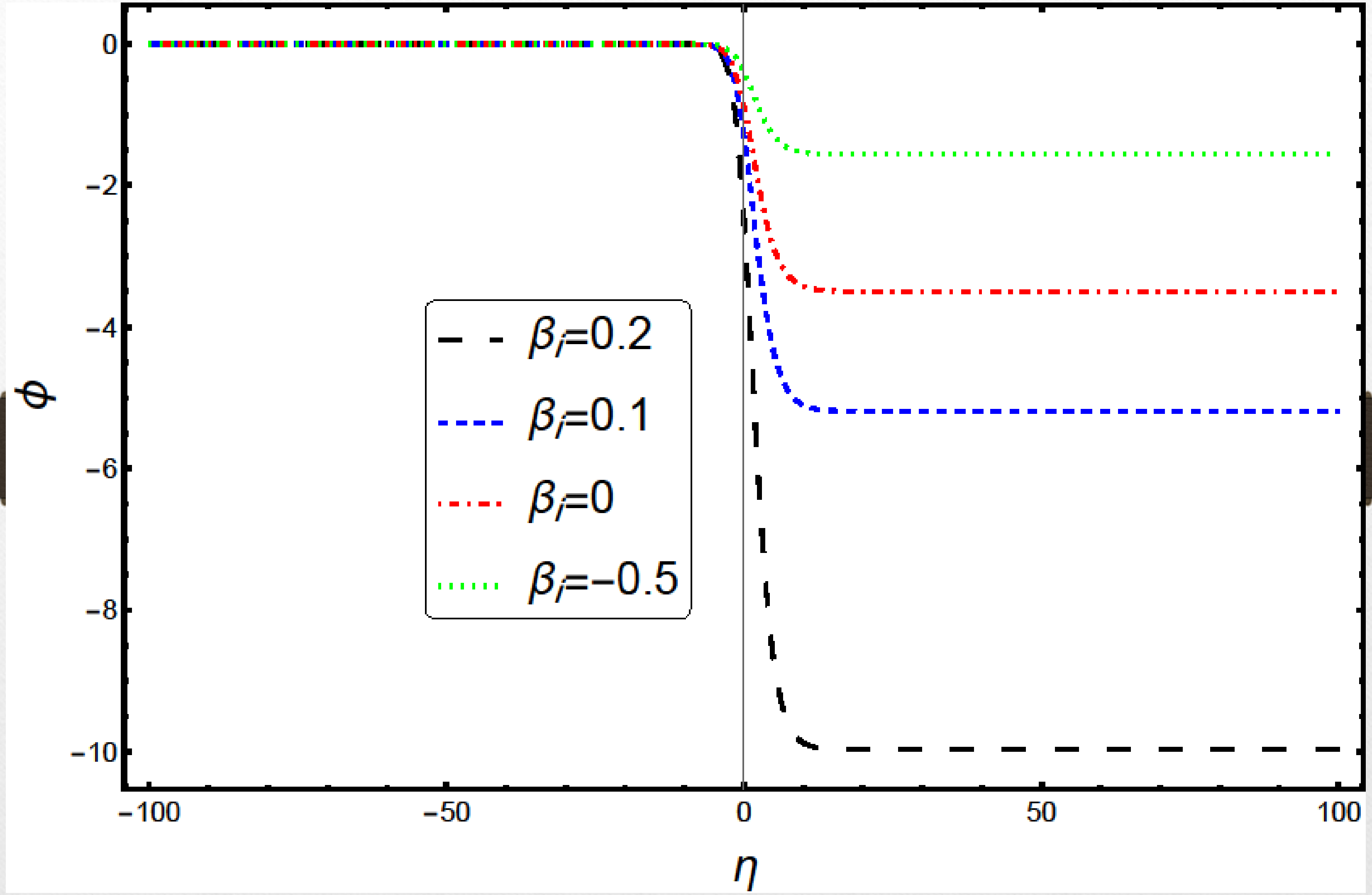
$$\frac{\partial\varphi}{\partial\tau}+\left(A_1\varphi+A_3(-\varphi)^{\frac{1}{2}}\right)\frac{\partial\varphi}{\partial\boldsymbol{\xi}}+B\,\frac{\partial^3\varphi}{\partial\boldsymbol{\xi}^3}=0$$

$$\varphi=\varphi_m(1\pm\tanh[\frac{\xi-\mathrm{M}\tau}{\mathrm{W}}\,])^2$$

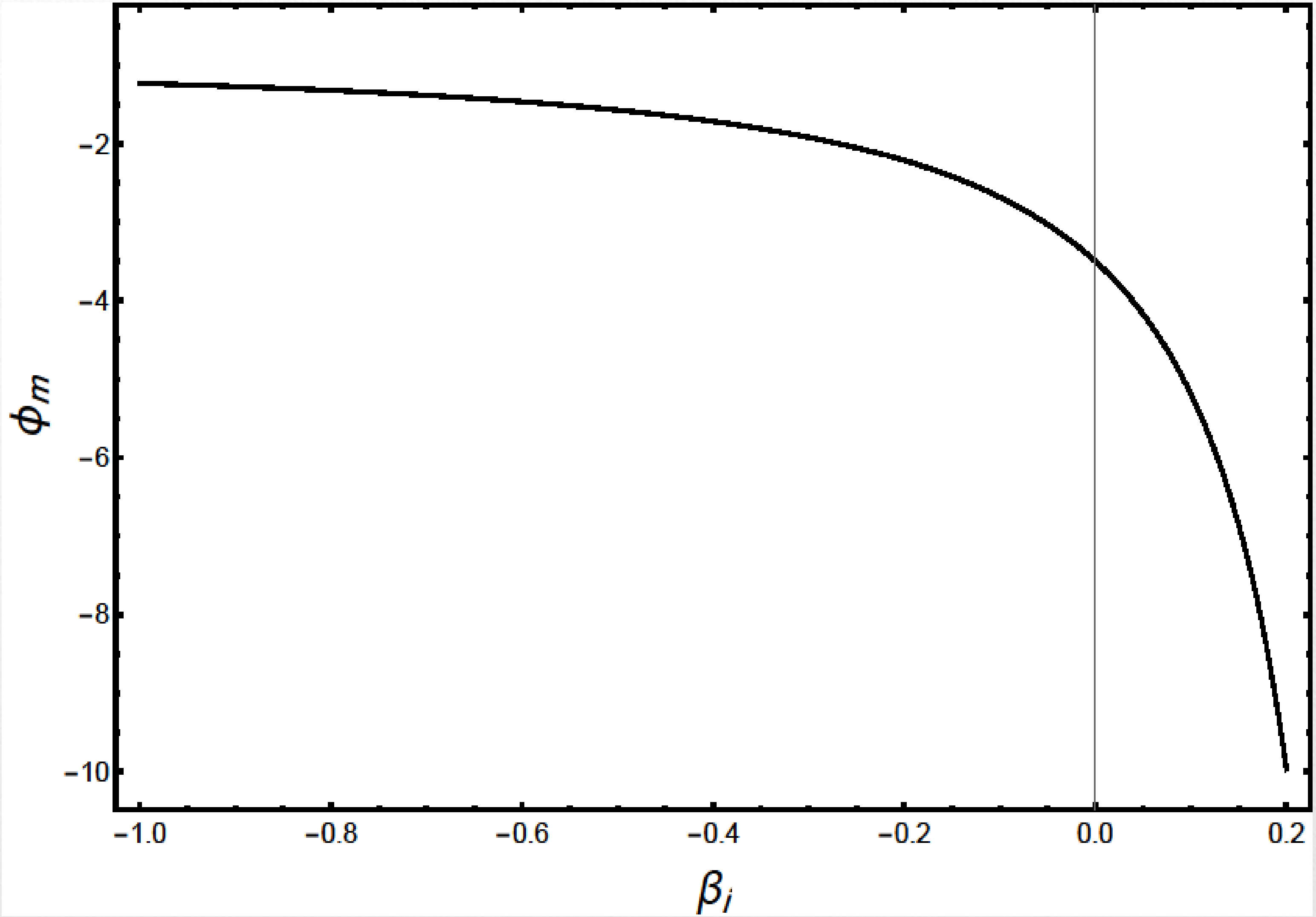
$$\varphi_m=-\frac{4A_3^2}{25A_1^2},\quad \mathrm{W}=\frac{5}{A_3}\sqrt{3BA_1}$$



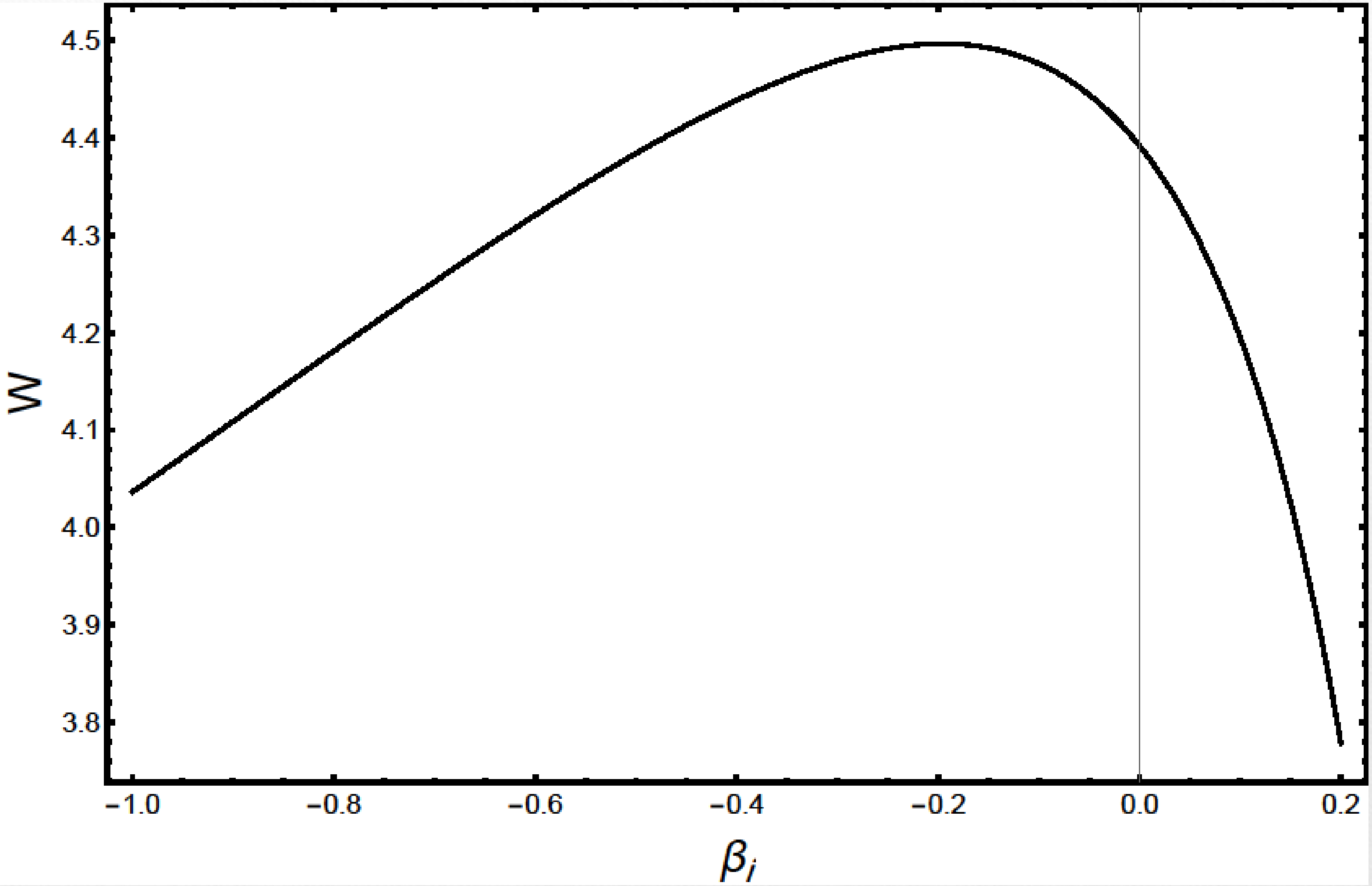
2.0
1.5
1.0
0.5
0.0
−0.5
A_1
A_1(fast)
−1.0
−0.5
0.0
0.5
1.0
α_i
−89.06
−89.08
−89.10
−89.12
−89.14
−89.16
A_1
A_1(slow)
−1.0
−0.5
0.0
0.5
1.0
α_i



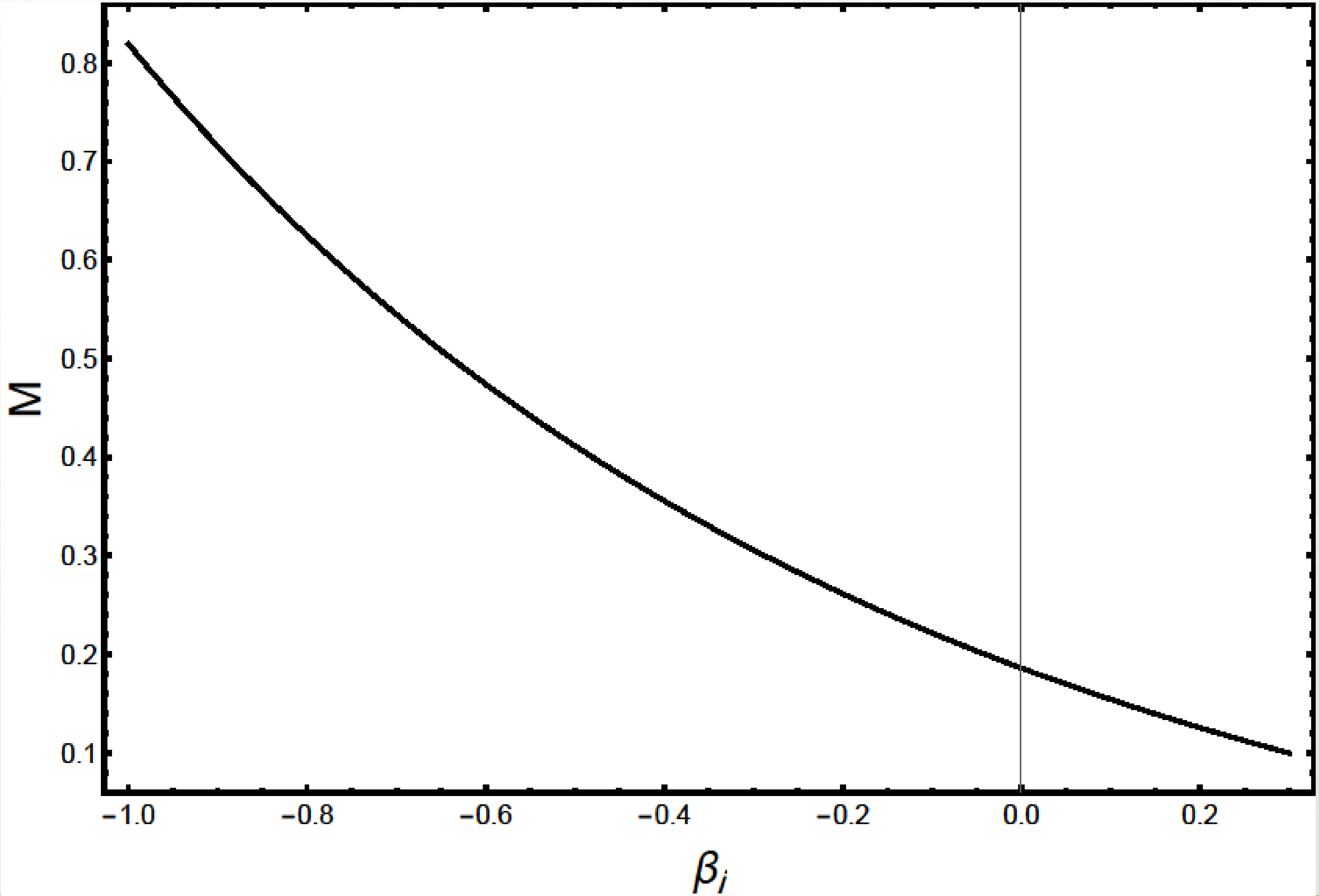
0
−2
−4
−6
−8
−10
ϕ
−100
−50
0
50
100
η
β_i=0.2
β_i=0.1
β_i=0
β_i=−0.5



ϕ_m
-2
-4
-6
-8
-10
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
0.2
β_i



4.5
4.4
4.3
4.2
4.1
4.0
3.9
3.8
W
−1.0
−0.8
−0.6
−0.4
−0.2
0.0
0.2
β_i



0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
M
−1.0
−0.8
−0.6
−0.4
−0.2
0.0
0.2
β_i

Conclusions

	Case **A**	Case **B**
1. Existence	DADL	DADL
2. No. modes	fast, slow	fast
3. Polarity	Positive	Negative
4. Profile	Smaller Amp., Wider width	Larger Amp., Wider width
5. Speed	Slower Speed	Slower Speed

Thanks