n-acoustic Solitary and Sho

Dusty Plasn

The Abdus Salam International Centre for Theoretical Physics

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- Presence of micron sized dust grains is ubiquitous in naturally occurring and man-made plasma systems[1]

- When the dust particles are exposed to the plasma environment, they are getting charged by collecting plasma particles hitting on their surfaces

- For typical lab plasma, $Z_d = 10^2\text{-}10^4$

- Plasma system maintains quasineutrality condition, i.e., $n_i = n_e + Z_d n_d$

- Plasma exhibits Debye shielding of the particle

$$\lambda_D = \frac{\lambda_{De}\lambda_{Di}}{\sqrt{\lambda_{De}^2 + \lambda_{Di}^2}}$$

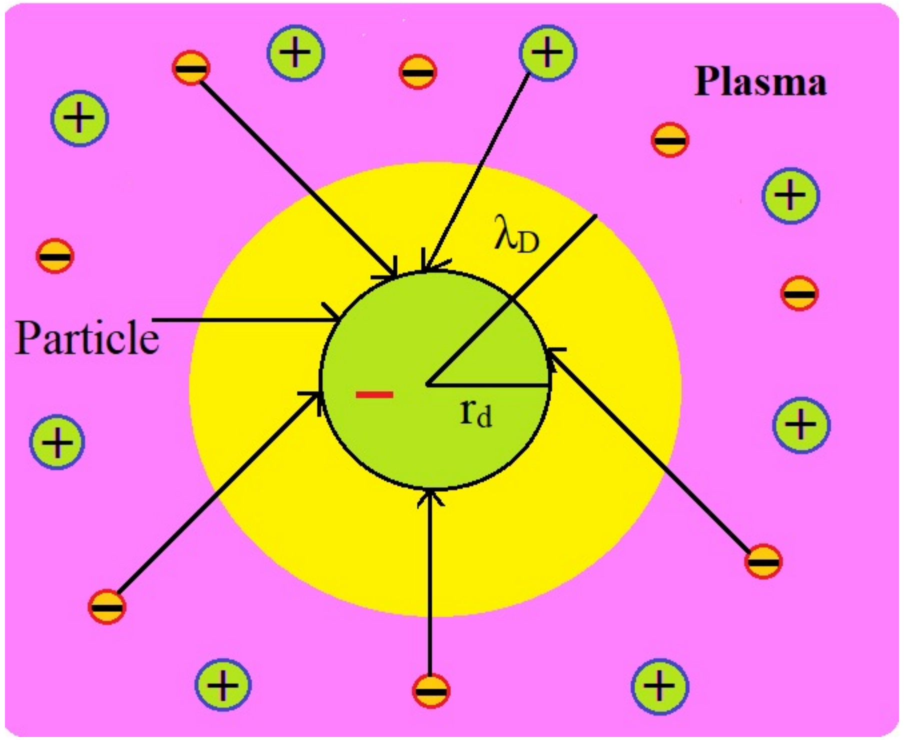

Figure: Schematic diagram of dusty plasma and dust charging process.

[1](Shukla and Mamun, 2002)

- Dust charge fluctuations affect linear and non-linear wave characteristics[2]

- In addition, events happening in cosmic environments such as planetary rings, dust wave instabilities in astrophysical plasmas and Earth's magnetosphere

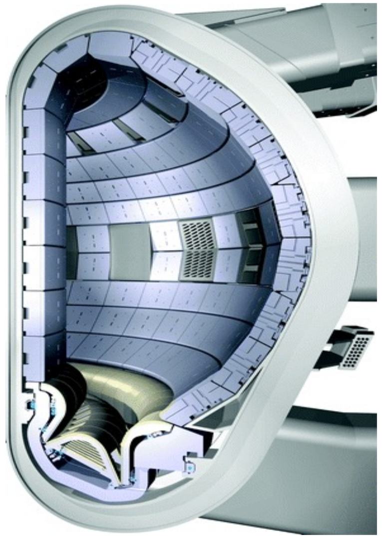

Figure: Divertor part of fusion device[3]

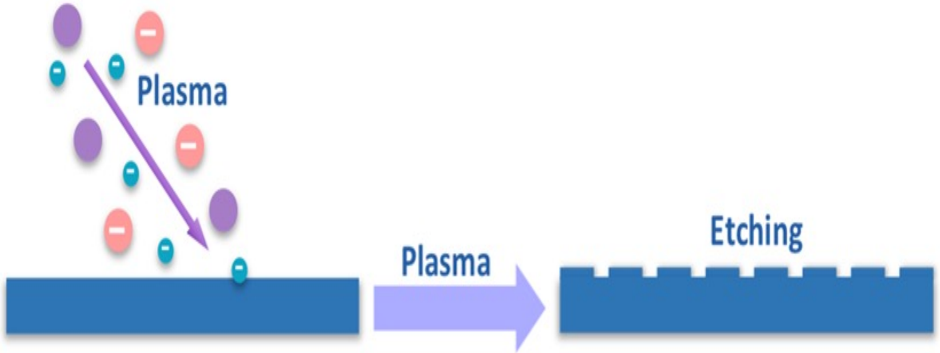

Figure: Plasma etching for semiconductor processing[4]

Figure: Saturn rings[5]

[2] (Das et al., 2017) [3](https://f4e.europa.eu/mediacorner/newsview.aspx) [4](http://www.grinp.com/plasma/chemistry.html) [5](https://dornsife.usc.edu/news/stories/3063/a-brief-astronomical-history-of-saturns-amazing-rings

Motivation

Continuity equation: $\frac{\partial n_i}{\partial t} + \nabla.(n_i \vec{v}_i) = S_i - S_l$

Momentum equation: $m_i n_i \left(\frac{\partial \vec{v}_i}{\partial t} + (\vec{v}_i.\nabla)\vec{v}_i \right) = -en_i \nabla \phi + en_i (\vec{v}_i \times \vec{B}) - m_i n_i \nu_i \vec{v}_i - \nabla.\overline{P}$

Poisson's equation: $\varepsilon_0 \nabla^2 \phi = en_e - en_i - q_d n_{d0}$

Quasineutrality condition: $en_{e0} = en_{i0} + q_{d0} n_{d0}$

Density distribution for electrons: $n_e = n_{e0} \left\{ 1 + (q-1) \frac{e\phi}{k_B T_e} \right\}^{(3q-1)/(2q-2)}$

Dust charge equation: $\frac{dq_d}{dt} = I_{Ti} + I_e$

Ion current: $I_{Ti} = \pi r_d^2 e n_i \left(\frac{8 k_B T_i}{\pi m_i} \right)^{\frac{1}{2}} \left[1 - \frac{e q_d}{r_d k_B T_i} + 0.4 \left(\frac{e q_d}{r_d k_B T_i} \right)^2 \frac{\lambda_D}{\lambda_{in}} \right]$

Electron current: $I_e = -\pi r_d^2 e n_{e0} \left(\frac{8 k_B T_e}{\pi m_e} \right)^{\frac{1}{2}} B_q \left[1 + (q-1) \frac{e q_d}{r_d k_B T_e} + (q-1) \frac{e\phi}{k_B Te} \right]^{\frac{2q-1}{q-1}}$

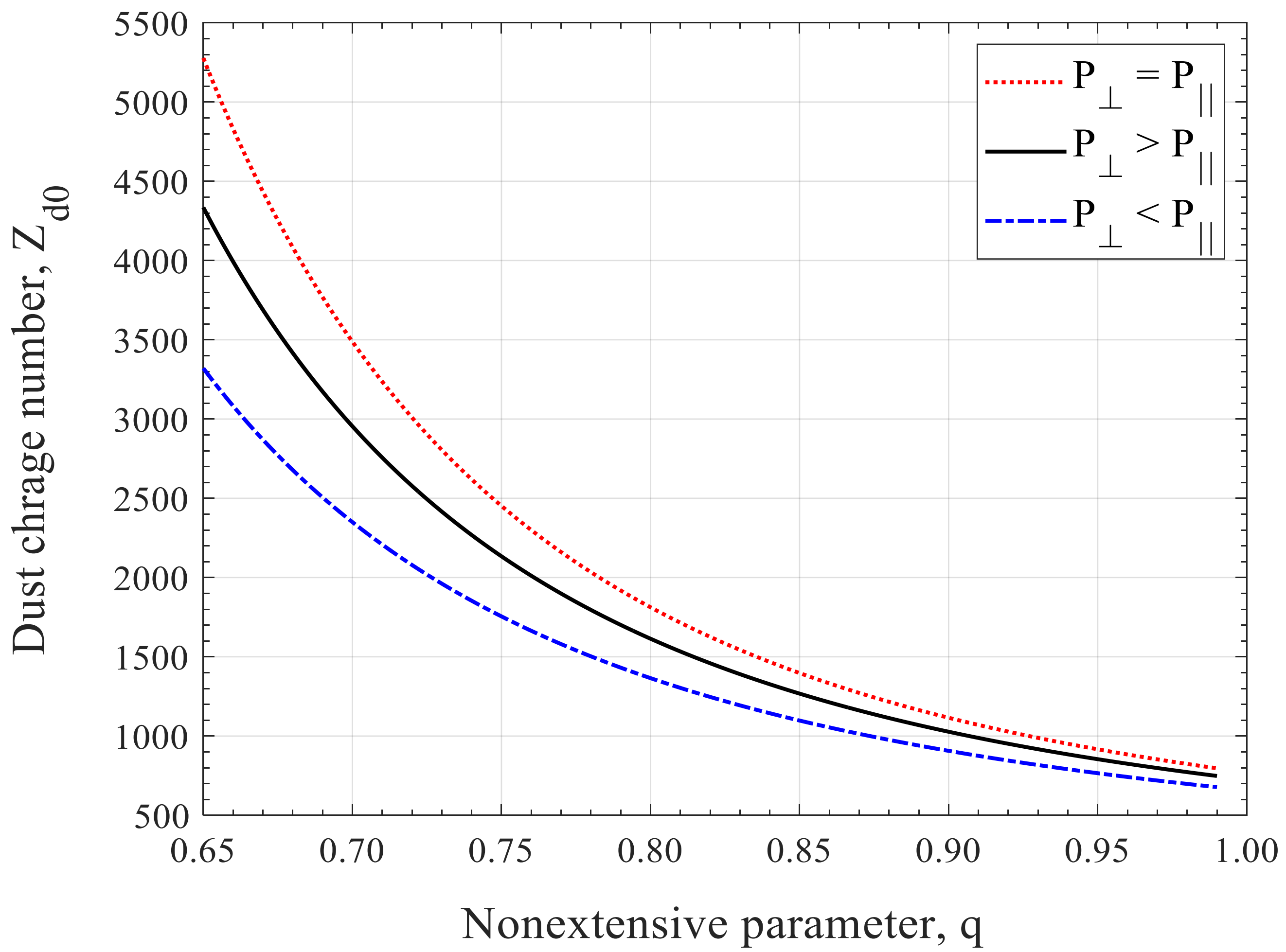

Figure: The variation of the equilibrium dust-charge number is shown against the nonextensive parameter q for different values of the anisotropic pressure: $P_\perp = P_\parallel = 0.5$, $P_\perp(0.3) > P_\parallel(0.1)$, and $P_\perp(0.1) < P_\parallel(0.3)$.

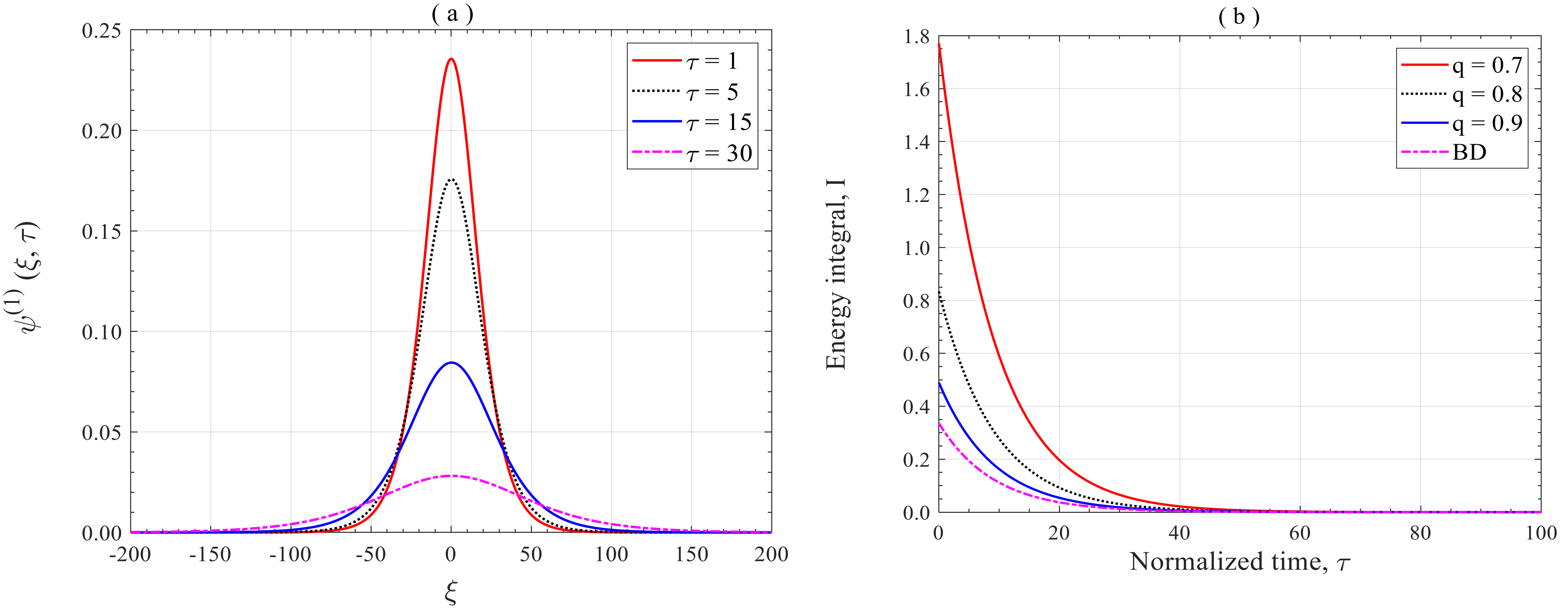

Figure: Profiles of the DIA soliton [subplot (a)] and the soliton energy [subplot (b)] are shown at different times (τ) and for different values of q as in the legends.

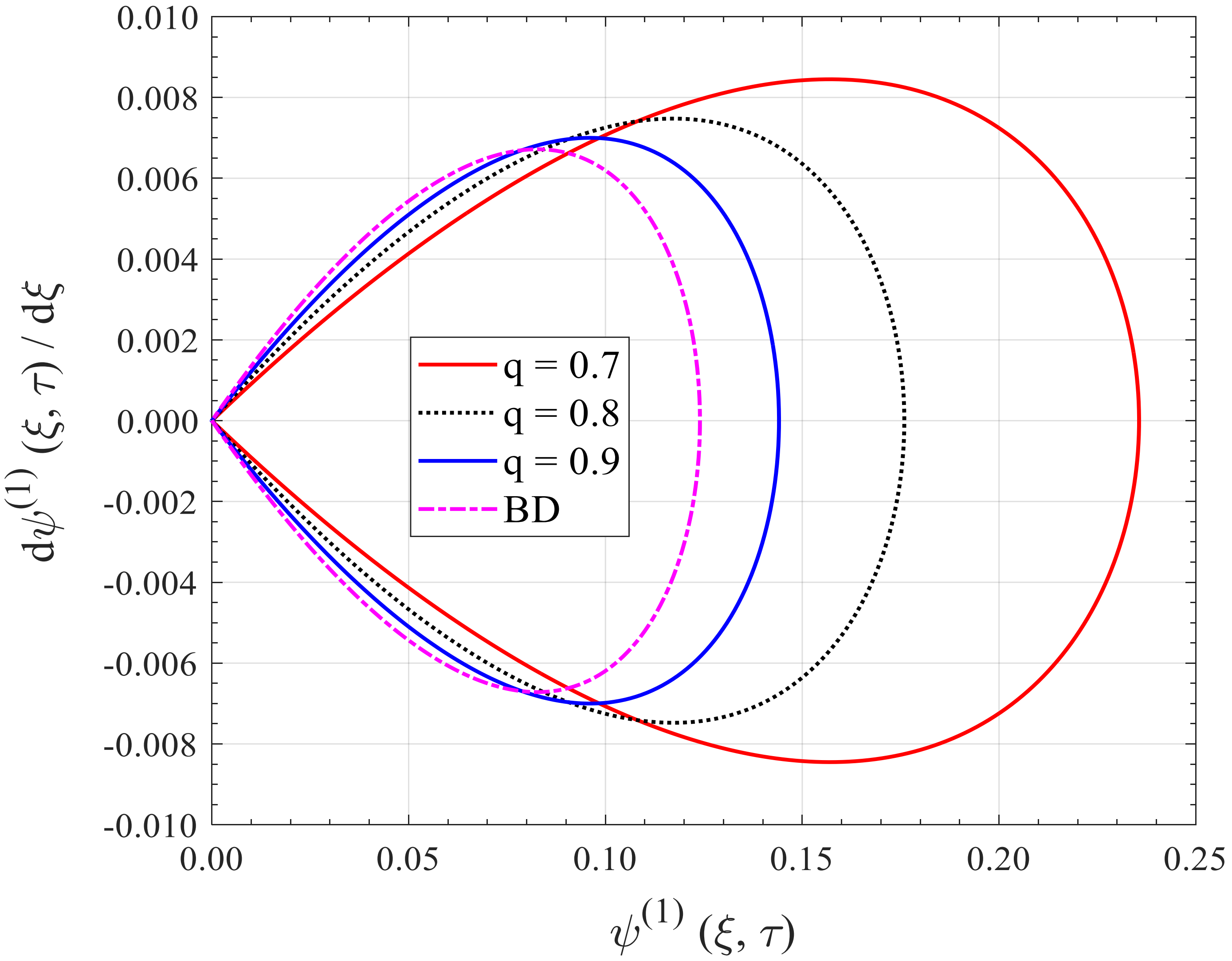

Figure: Phase portraits are shown for different values of the nonextensive parameter q.

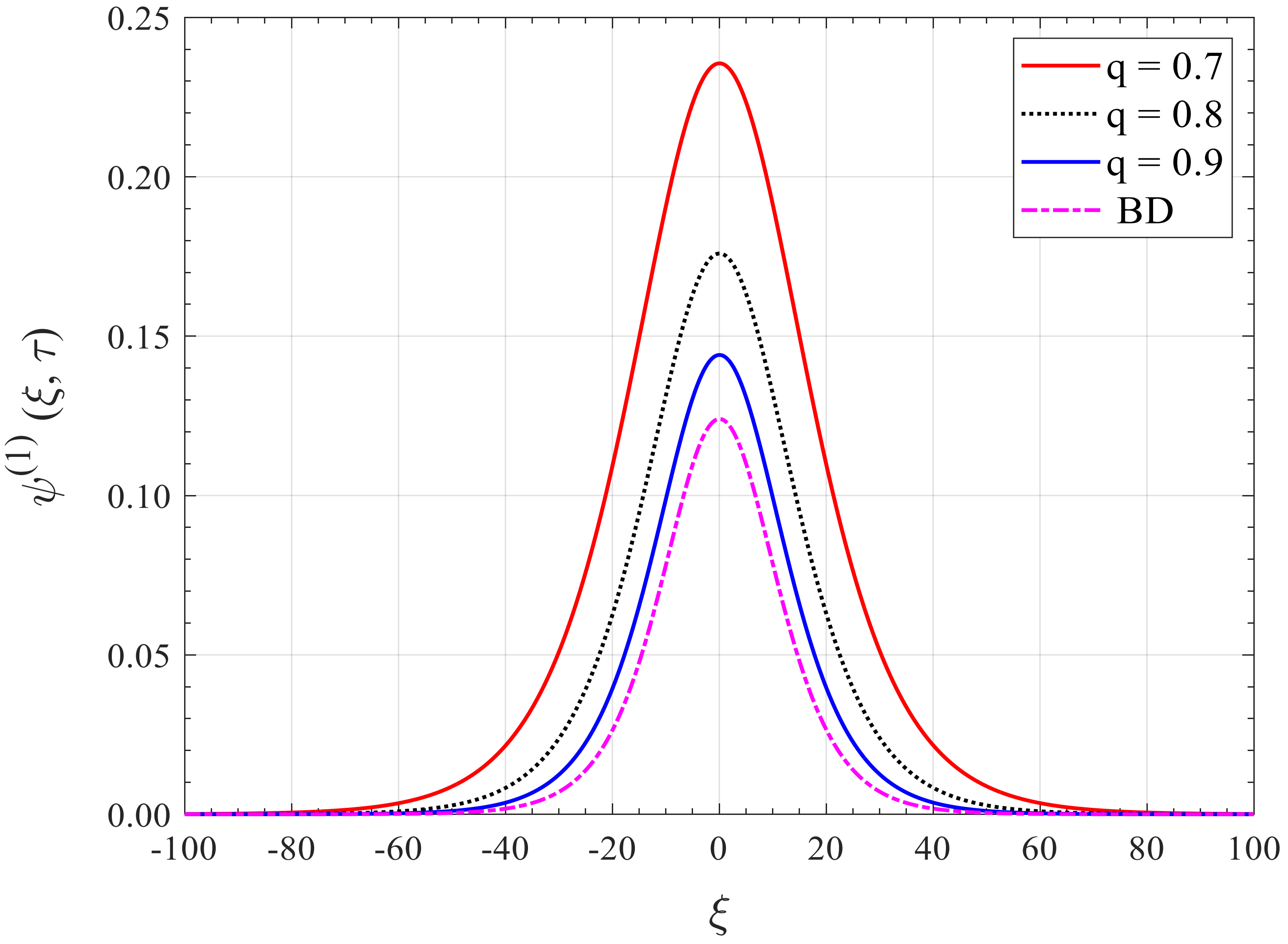

Fig. Profiles of the damped DIA soliton are shown for different values of the nonextensive parameter q.

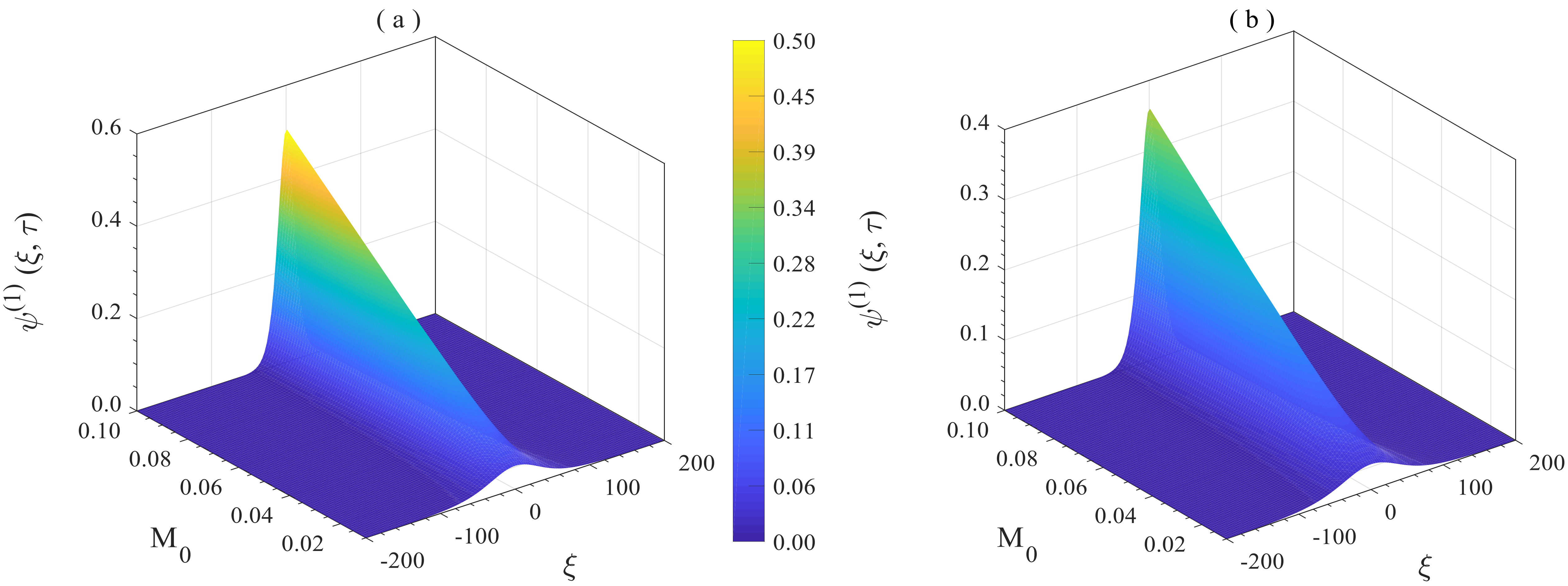

Fig. Profiles of the damped DIA solitons are shown in absence [subplot (a)] and presence [subplot (b)] of collision enhancement ion current.

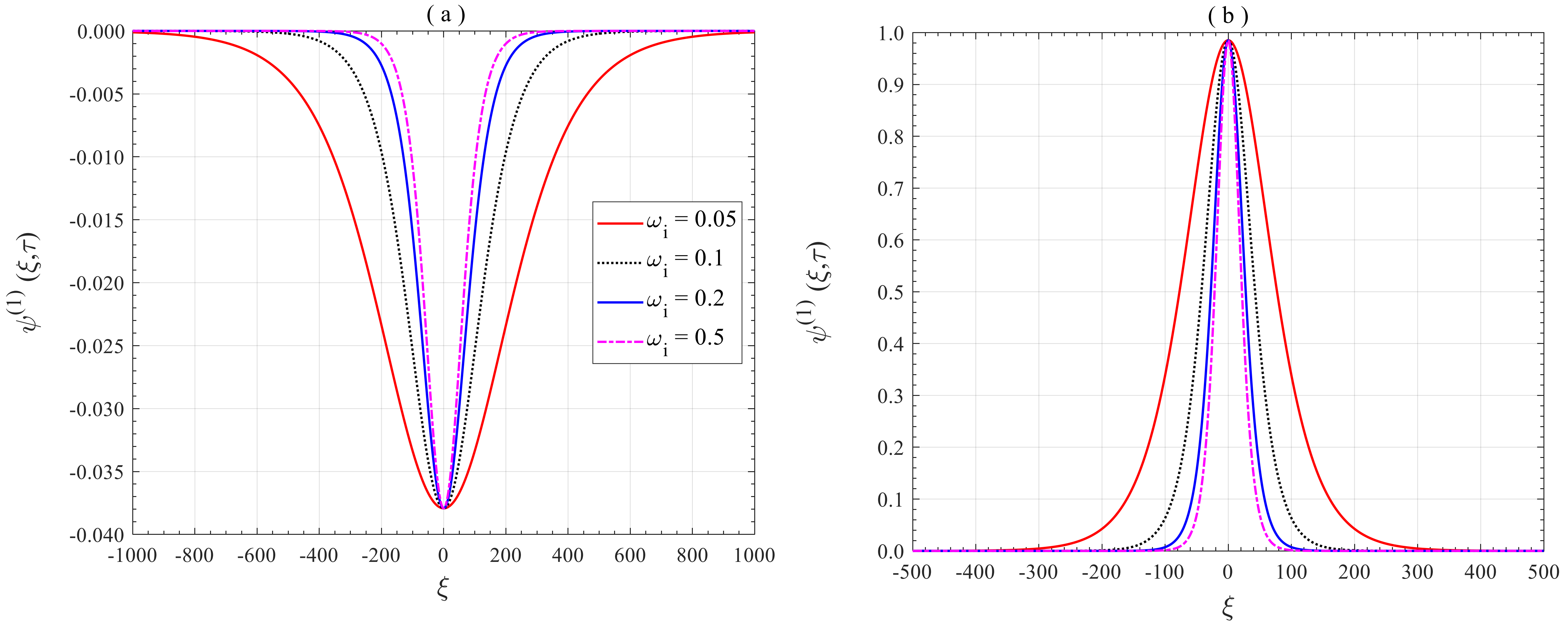

Figure: Profiles of the rarefactive [subplot (a) for q=0.8] and compressive [subplot (b) for q=0.98] DIA solitons are shown for different values of the ion gyrofrequency ω_i as in the legend.

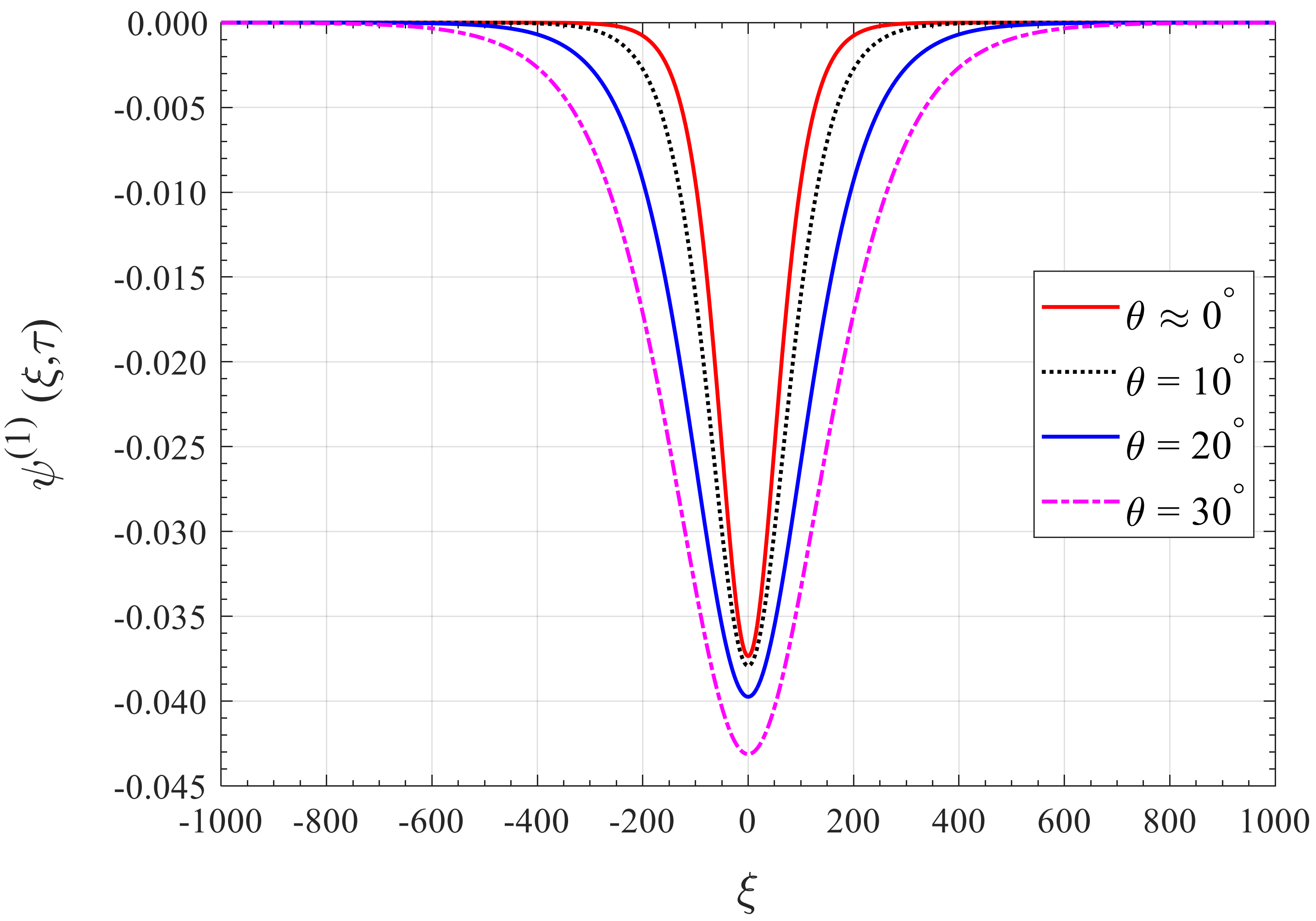

Figure: Effects of the obliqueness of wave propagation on the profiles of rarefactive DIA solitons are shown for different values of θ.

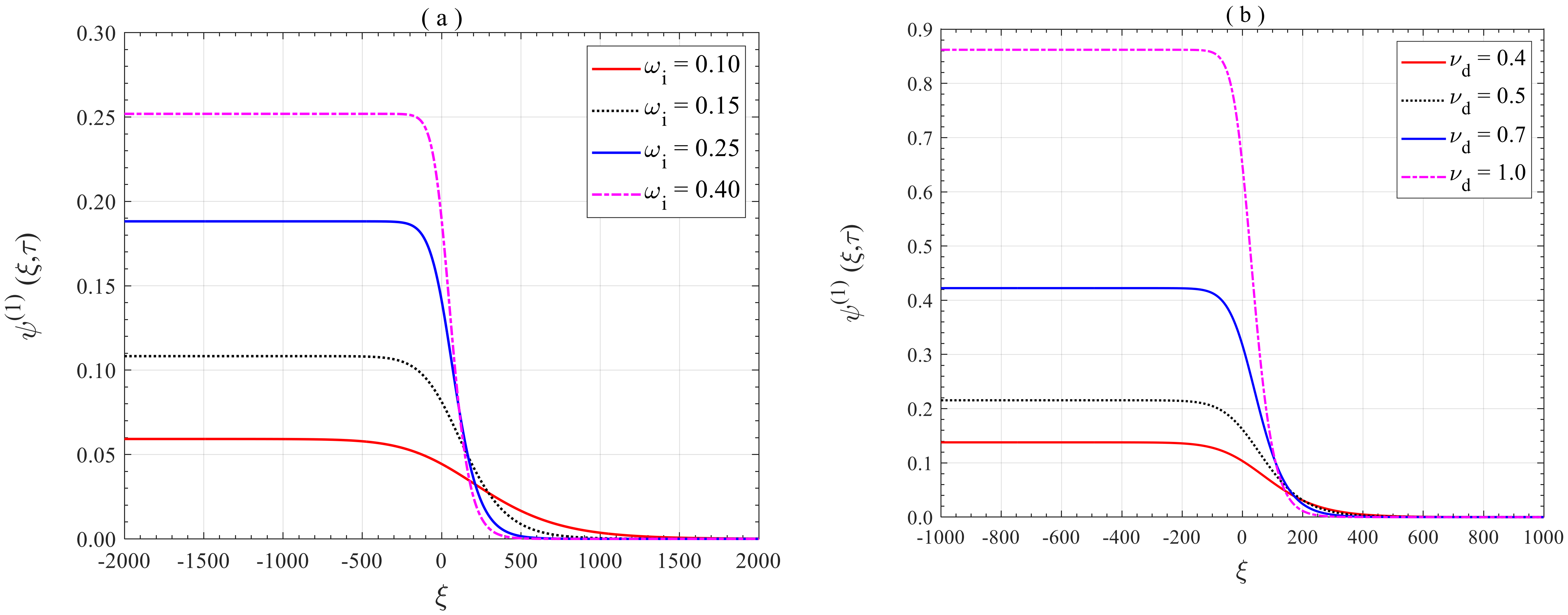

Figure: Monotonic shock profiles for different values of the (a) ion gyrofrequency, and (b) dust charge fluctuation rate with q=0.8.

Conclusion

- At equilibrium, the dust-charge number can achieve a maximum value in collisionless isotropic nonthermal dusty plasmas with super extensive electrons. The effects of the ion pressure anisotropy and the ion-neutral collision are to reduce the dust-charge number significantly.
- The DIA solitary waves get damped due to the effects of the adiabatic dust-charge variation and ion-dust and ion-neutral collisions.
- The increment of q-nonextensive parameter leads to the decrement of soliton amplitude and width,
- A deviation from the limit of adiabatic dust-charge variation, i.e., either (i) $\nu_{ch} < \omega_{pd}$ or (ii) $\nu_{ch} > \omega_{pd}$, relevant for space plasmas, can lead to the evolution of either (i) DIA damped solitary waves or (ii) DIA shocks.
- The qualitative features of the damped DIA solitons by the effects of the magnetic field (ω_i) and the propagation angle θ remain similar to those for laboratory plasmas.
- A transition of DIA shocks from rarefactive to compressive types can occur as we approach from nonthermal states (with superextensive electrons) to thermal ones (with Boltzmann distributed electrons).
- It is noted that the effects of the magnetic field (ω_i) and the dust-charge fluctuation rate (ν_d) on the profiles of DIA shocks are similar.

References

Shukla, P. K., & Mamun, A. A. (2002). *Introduction to dusty plasma physics*, (1st ed.) Bristol and Philadelphia, IoP Publishing.

Chen, F. F. (2016). *Introduction to Plasma Physics and Controlled Nuclear Fusion.* (3rd ed.) Switzerland, Springer.

Douglass, A., Land, V., Matthews, L., & Hyde, T. (2011). Dust particle charge in plasma with ion flow and electron depletion near plasma boundaries. *Physics of Plasmas*, *18*(8), 083706.

Acknowledgements

- Prof. Raju Khanal (Supervisor)
- Dr. Suresh Basnet (Co-supervisor)
- Prof. Amar P. Misra, Visva-Bharati University, India
- Prof. Ralf Kaiser, ICTP
- Mahendra Multiple Campus, TU, Dang
- University Grants Commission, Nepal for the PhD fellowship (PhD-78/79-S&T-17)
- Plasma and Nuclear Lab members, CDP, TU
- The Abdus Salam International Center for Theoretical Physics, ICTP, Trieste, Italy
- International Atomic Energy Agency, IAEA
- Friends and Family

Thank You.