Pramana – J. Phys. (2019) 92:49
https://doi.org/10.1007/s12043-018-1713-z
© Indian Academy of Sciences

Non-planar electron-acoustic waves with hybrid Cairns–Tsallis distribution

SONA BANSAL[1,2,*] and MUNISH AGGARWAL[3]

[1]I.K. Gujral Punjab Technical University, Kapurthala 144 601, India
[2]Sikh National College, Banga 144 505, India
[3]Department of Applied Science, Lyallpur Khalsa College of Engineering, Jalandhar 144 001, India
*Corresponding author. E-mail: sonabansal34@gmail.com

MS received 26 June 2018; revised 21 August 2018; accepted 4 September 2018;
published online 15 February 2019

Abstract. Non-planar electron-acoustic waves having Cairns–Tsallis distributed hot electrons are investigated under multiple temperature electrons model in unmagnetised plasma. In this model, Korteweg–de Vries (KdV) equation is obtained in the cylindrical/spherical coordinates. On the basis of the solutions of KdV equation, variation of solitary wave features (amplitude, velocity and width) with different plasma parameters are analysed. Dispersion and nonlinear coefficients obtained depend on the particle density α, non-extensive parameter q, electron temperature ratio θ and non-thermal parameter γ. Combined effect of all these plasma parameters significantly changes the properties of the solitary waves in non-planar geometry. It is observed that increasing the number of non-thermal electrons in the medium increases the amplitude, velocity as well as width of the non-planar waves whereas with the increase in temperature, the velocity of waves decreases and this impact is dominant in spherical waves. This two-parameter (γ, q) distribution model (C–T) is applicable to a wide range of observed plasmas, i.e. auroral region and magnetosphere of the Earth.

Keywords. Electron-acoustic waves; non-planar geometry; Cairns–Tsallis distribution; reductive perturbation method.

PACS Nos 52.27.Lw; 52.35.Fp; 52.35.Sb; 52.35.Tc; 52.35.Mw; 52.27.Ep

1. Introduction

Experimental and theoretical analyses of nonlinear electron-acoustic waves having two-electron population known as cold and hot electrons in magnetised and unmagnetised plasma have been studied by numerous researchers [1–5]. Electron-acoustic waves (EAWs) have received a great deal of attention because of their potential importance in interpreting electrostatic component of the broadband electrostatic noise (BEN) observed in the cusp region of the terrestrial magnetosphere [6], in geomagnetic tail [7] and in the dayside auroral acceleration region [8–10]. The EAWs have also been used to interpret various wave emissions in different regions of the Earth's magnetosphere [8,9].

Researchers used Maxwellian distribution to explain various situations in astrophysical environments [11–14]. The presence of energetic electrons known as non-thermal electrons in a number of astrophysical space environment indicates that the particle distribution plays an important role in the characterisation of space plasmas. Cairns *et al* [15,16] were the first to recognise the non-thermal distribution of the electrons. Non-thermal model was expressed in terms of γ which measures the deviation of particles from Maxwellian distribution. For example, when $\gamma = 0$, we shall get the well-known Maxwellian distribution. Then, Tsallis [17] characterised the non-extensive distribution of particles for the systems with long-range interactions, e.g. plasmas and gravitational systems having non-equilibrium stationary states. Parameter q describes the degree of non-extensivity with $q \rightarrow 1$ corresponds to Maxwellian distribution. Some investigators have used the generalised non-extensive statistics to explain the number of astrophysical and space scenarois [18–23].

Tribeche *et al* [24] introduced a new distribution known as hybrid Cairns–Tsallis distribution. This distribution is the combination of both Cairns non-thermal distribution and Tsallis non-extensive distribution. This two-parameter (γ, q) distribution model is applicable to a wide range of observed plasmas, i.e. auroral region and magnetosphere of Earth. Amour *et al* [25] used this model to study the electron-acoustic solitons and showed that this model supports rarefactive EA waves. Williams *et al* [26] re-examined the Cairns–Tsallis distribution for ion-acoustic solitons. They showed the validity of the model for restricted range of non-extensive parameter q and non-thermal parameter γ, i.e. $0 \leq \gamma \leq 0.25$ and $0.6 < q \leq 1$. Bouzit *et al* [27] studied the contribution of both non-thermal and non-extensive parameters on the instability domains of the solitons. Abid *et al* [28] applied this hybrid model to study dust grain charging process in plasma with electrons, positive/negative ion and negatively charged dust grains. Bala *et al* [29] investigated the combined effect of non-thermal and non-extensive parameter on ion-acoustic dressed soliton dynamics. Recently, Merriche and Tribeche [30] had studied the problems of modulational instability of rouge wave propagation in the presence of non-thermal non-extensive plasma and shown that it is very important to study the combined effect of non-thermal and non-extensive distribution to explain various plasma modes. This distribution provides better fit in the data of space observations. As in many astrophysical and space environment, the solitons are not always unbounded (infinite), it becomes important to study the plasma waves in non-planar geometry (cylindrical/spherical).

A lot of research has been done to study non-planar plasma waves in the last few years [31–34]. Sabry *et al* [35] investigated the non-planar ion-acoustic waves in an unmagnetised plasma with two-electron temperature distributions to study their modulational instability period which was not present in the planar geometry. Javidan and Pakzad [36] examined the behaviour of electron-acoustic waves with superthermal electrons in cylindrical and spherical coordinates. They found that the presence of superthermal particles quantitatively effects the existence region of the solitons in spherical geometry. El-Labany *et al* [37] studied the non-planar electron-acoustic waves in unmagnetised plasma with non-thermal distributed hot electrons and showed the influence of various plasma parameters on the analytical phase shift. Very recently, non-planar electron waves with vortex-like distribution of hot electrons had been studied by Demiray and El-Zahar [38]. The main purpose of their study was to use the analytical approximation method to solve the KdV equation and compare it with numerical solution. They successfully justified their results in good agreement with numerical solutions. Till now, a very few studies has been done on this new hybrid C–T distribution. Now, we shall study the non-planar electron-acoustic waves with hybrid Cairns–Tsallis distribution in a two-population electron plasma which is a more realistic state of the plasma.

In this research paper, EA solitary waves are investigated with two different populations of electrons in cylindrical/spherical geometries. The paper is organised as: Basic equations are presented in §2 and non-planar KdV equation is derived using perturbation method in §3. Section 4 deals with the solution and results. The conclusions of the results are given in §5.

2. Basic equations

Let us consider an unmagnetised plasma consistent with stationary ions, cold electrons and Cairns–Tsallis distributed hot electrons. Such a model in non-planar geometry for electron-acoustic waves is governed by [39,40]

$$\frac{\partial n_c}{\partial t} + \frac{1}{r^m}\frac{\partial}{\partial r}(r^m n_c u_c) = 0 \tag{1}$$

$$\frac{\partial u_c}{\partial t} + u_c\frac{\partial u_c}{\partial r} + \frac{3\alpha(1+\alpha)^2}{\theta} n_c \frac{\partial n_c}{\partial r} = \alpha\frac{\partial \phi}{\partial r} \tag{2}$$

$$\frac{1}{r^m}\frac{\partial}{\partial r}\left(r^m\frac{\partial \phi}{\partial r}\right) = \frac{1}{\alpha}n_c + n_h - \left(1+\frac{1}{\alpha}\right). \tag{3}$$

Here, $m = 0, 1, 2$ for planar, cylindrical and spherical geometry respectively. n_c and n_h are the number densities of cold and hot electron species which are normalised by their equilibrium values n_{c0} and n_{h0}. Here, $\alpha = n_{h0}/n_{c0}$ and $\theta = T_h/T_c$. The spatial variables are normalised by hot electron Debye length $\lambda_{\mathrm{D}} = (k_{\mathrm{B}}T_h/4\pi n_{h0}e^2)^{1/2}$ whereas temporal variables by the inverse of cold electron plasma frequency $\omega_{pc}^{-1} = (m/4\pi n_{c0}e^2)^{1/2}$. Cold electron fluid velocity u_c and electrostatic wave potential ϕ are normalised by $C_e = (K_{\mathrm{B}}T_h/\alpha m)^{1/2}$ and $K_{\mathrm{B}}T_h/e$ respectively. Here, K_{B} is the Boltzmann's constant, e is the electron charge and m is its mass.

Hybrid Cairns–Tsallis distribution which is the product of Cairns and Tsallis distribution is given by [24]

$$f_{\mathrm{CT}}(v_e) = C_{q\gamma}\left[1+\gamma\frac{v_e^4}{v_{te}^4}\right]\left[1-(q-1)\frac{v_e^2}{2v_{te}^2}\right]^{1/(q-1)}, \tag{4}$$

where

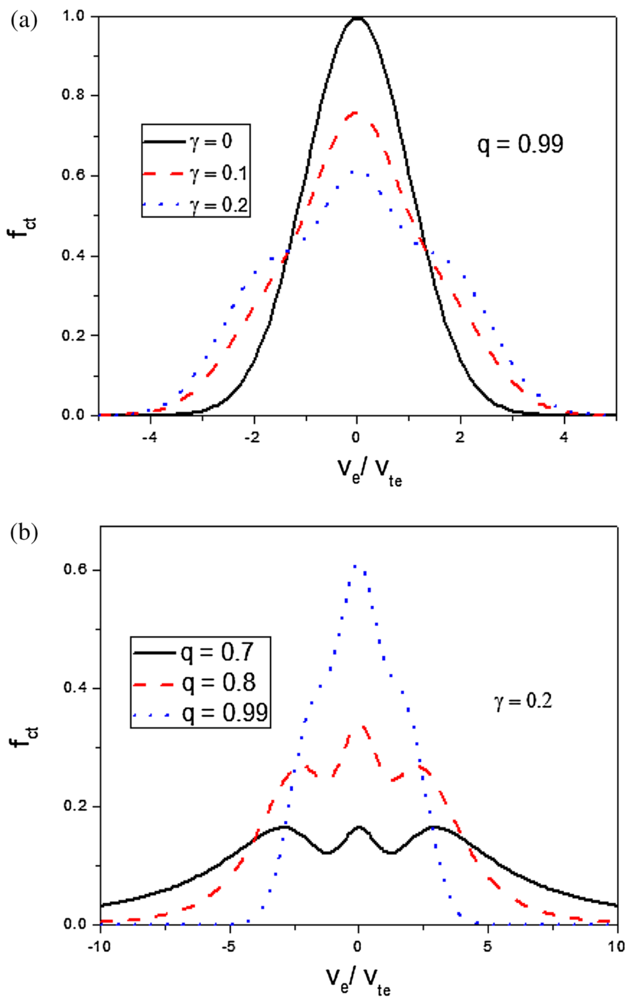

Figure 1. Plot of Cairns–Tsallis distribution function for (**a**) $\gamma = 0, 0.1$ and 0.2 at $q = 0.99$ ($q \to 1$) and (**b**) $q = 0.7, 0.8$ and 0.99 at $\gamma = 0.2$.

$$C_{q\gamma} = \frac{1}{2\pi v_{te}} \left[\frac{\Gamma\left(\frac{1}{1-q}\right)(1-q)^{5/2}}{\Gamma\left(\frac{1}{1-q} - \frac{5}{2}\right)\left[3\gamma + \left(\frac{1}{1-q} - \frac{3}{2}\right)\left(\frac{1}{1-q} - \frac{5}{2}\right)(1-q)^2\right]} \right], \quad \text{for} -1 < q \leq 1 \tag{5}$$

$$C_{q\gamma} = \frac{1}{2\pi v_{te}} \left[\frac{\Gamma\left(\frac{1}{1-q} + \frac{5}{2}\right)(1-q)^{5/2}\left(\frac{1}{q-1} + \frac{5}{2}\right)\left(\frac{1}{q-1} - \frac{3}{2}\right)}{\Gamma\left(\frac{1}{q+1} + 1\right)\left[3\gamma + \left(\frac{1}{q-1} + \frac{3}{2}\right)\left(\frac{1}{q-1} + \frac{5}{2}\right)(q-1)^2\right]} \right], \quad \text{for } q \geq 1. \tag{6}$$

Here, $v_{te} = (T_e/m_e)^{1/2}$ is the thermal velocity of electron, $C_{q\gamma}$ is the normalisation constant, γ is the non-thermal parameter representing the number of energetic electrons in the medium and q is the non-extensive parameter.

In figure 1a, Cairns–Tsallis distribution function $f_{\mathrm{CT}}(v_e)$ is plotted as a function of v_x/v_{te} at a fixed value of non-extensive parameter $q = 0.99$ ($q \to 1$) for different values of non-thermal parameter γ to show the deviation from Maxwellian distribution. It is observed that the effect of non-thermal parameter γ is prominent on the shoulders of the distribution and for $\gamma = 0$, the velocity distribution curve approaches the Maxwellian. Figure 1b depicts the variation of distribution curve for different values of q at $\gamma = 0.2$. It is clear from the plot that for $q = 0.99$ ($q \to 1$), the curve approaches pure Cairns distribution. We note that when $q \to 1$ and $\gamma = 0$, eq. (1) reduces to Maxwellian distribution. On integrating eq. (4), we shall get the Cairns–Tsallis distribution for the hot electrons, taken from the model of Amour *et al* [25],

$$n_h = [1 + (q-1)\phi]^{\frac{1}{q-1}+\frac{1}{2}}[1 + \beta_1\phi + \beta_2\phi^2], \tag{7}$$

where

$$\beta_1 = -16q\gamma/(15q^2 - 14q + 12\gamma + 3)$$

and

$$\beta_2 = -16(2q-1)q\gamma/(15q^2 - 14q + 12\gamma + 3).$$

Using the above value in eq. (3), we get

$$\frac{\partial^2\phi}{\partial r^2} = \frac{1}{\alpha}n_c + 1 + c_1\phi - c_2\phi^2 - \left(1 + \frac{1}{\alpha}\right), \tag{8}$$

where

$$c_1 = \frac{15q^3 + q^2 - (11 + 20\gamma) + 12\gamma + 3}{2\left(15q^2 - 14q + 12\gamma + 3\right)},$$

$$c_2 = \frac{\left(q^2 - 2q - 12\gamma - 3\right)(5q-3)(3q-1)}{8\left(15q^2 - 14q + 12\gamma + 3\right)}.$$

3. Cylindrical/spherical KdV equation

To study the small-amplitude shock waves in a plasma, let us assume the stretched coordinates as $\tau = \epsilon^{3/2}t$ and $\xi = \epsilon^{1/2}(r - \lambda t)$, where ϵ is a small parameter and the wave speed λ is normalised by C_e. The dependent variables n_c, u_c and ϕ are expanded as follows:

$$n_c = 1 + \epsilon n_{1c} + \epsilon^2 n_{2c} + \cdots , \tag{9}$$

$$u_c = \epsilon u_{1c} + \epsilon^2 u_{2c} + \cdots , \tag{10}$$

$$\phi = \epsilon \phi_1 + \epsilon^2 \phi_2 + \cdots . \tag{11}$$

Substitute (9)–(11) into (1), (2), (8) and collect the lowest coefficients of ϵ as

$$n_{1c} = -\alpha c_1 \phi_1 \tag{12}$$

$$u_{1c} = -\alpha c_1 \lambda \phi_1 \tag{13}$$

$$\lambda^2 = \frac{3\alpha\,(1+\alpha)^2}{\theta} + \frac{1}{c_1}. \tag{14}$$

Equation (14) gives the relation between frequency and wave number known as dispersion relation of the solitary waves. Now, equate the coefficients of higher-order of ϵ from both sides of (1), (2) and (8), we obtain

$$-\lambda \frac{\partial n_{2c}}{\partial \xi} + \frac{\partial u_{2c}}{\partial \xi} + \frac{\partial}{\partial \xi}(n_{1c}u_{1c}) + \frac{\partial n_{1c}}{\partial \tau} + \frac{m u_{1c}}{\lambda \tau} = 0 \tag{15}$$

$$-\lambda \frac{\partial u_{2c}}{\partial \xi} + u_{1c}\frac{\partial u_{1c}}{\partial \xi} + \frac{\partial u_{1c}}{\partial \tau} + \frac{3\alpha(1+\alpha)^2}{\theta}\frac{\partial n_{2c}}{\partial \xi} + \frac{3\alpha(1+\alpha)^2}{\theta} n_{1c}\frac{\partial n_{1c}}{\partial \xi} = \alpha \frac{\partial \phi_2}{\partial \xi} \tag{16}$$

$$\frac{\partial^2 \phi_1}{\partial \xi^2} = \frac{1}{\alpha} n_{2c} + c_1 \phi_2 - c_2\,(\phi_1)^2 . \tag{17}$$

Now, rearranging eqs (15)–(17) and using eqs (12)–(14) to eliminate the first-order terms, we finally get the KdV equation for EA waves in non-planar geometry as

$$\frac{\partial \phi}{\partial \tau} + \frac{m}{2\tau}\phi + P\phi \frac{\partial \phi}{\partial \xi} + Q\frac{\partial^3 \phi}{\partial \xi^3} = 0, \tag{18}$$

where $\phi_1 = \phi$. P and Q are the coefficients of nonlinearity and dispersion given by

$$P = -Q\left(-2c_2 + \alpha\left(3\lambda^2 + \frac{3\alpha(1+\alpha)^2}{\theta}\right)c_1^3\right) \tag{19}$$

$$Q = \frac{1}{2c_1^2\lambda}. \tag{20}$$

Equation (18) is known as KdV equation in cylindrical/spherical coordinates. The value of m can be 0 (planar), 1 (cylindrical) and 2 (spherical waves). Now, if we set $\gamma = 0$ and $\theta = 0$, our results reduce to ref. [41] obtained by Pakzad. In the next section, we shall study the effect of these parameters on the propagation charactristics of solitary waves in different geometries.

4. Numerical analysis and discussion

To solve eq. (18) numerically, we shall assume that at large values of τ (say $\tau = -14$), the term $m/2\tau$ becomes too small and can be neglected. At this stage, stationary solution of eq. (18) obtained by the tanh method [42] can be used as the initial condition, i.e.

$$\phi = \phi_m \mathrm{sech}^2\left(\frac{\xi - u_0\tau}{\delta}\right), \tag{21}$$

where $\phi_m = (3u_0/P)$ is the amplitude and $\delta = \sqrt{4Q/u_0}$ is the width of the soliton. The second term of the left-hand side of eq. (18), $m/2\tau$, becomes dominant only at small values of τ and can be ignored at large values of τ (say $\tau = -14$). At large values of τ, the profile of the cylindrical and spherical waves approaches the plasma waves in planar geometry, but as the value of τ decreases, these three types of waves (flat, cylindrical and spherical) differ significantly from each other. Equations (19) and (20) show that the coefficients P and Q are complicated functions of plasma parameters. Therefore, the effect of parameters on the amplitude, width and velocity of the waves is studied with the help of graphs for different values of parameters q, γ, α and θ. In our work, only rarefactive solitons are possible as nonlinear coefficient $P < 0$. The plasma parameters from ref. [43] have been choosen to study the effect of non-thermal extensivity, geometry, temperature and density on the solitary wave properties. Figures 2–4 show how the effects of different plasma parameters modify the EA wave structures with multiple temperature electrons.

In the persent problem, our main aim is to analyse the effect of various physical parameters γ (degree of non-thermality), θ (temperature ratio), α (density) and q (non-extensivity) on the propagation of EA waves in unmagetised non-planar palsma. For this purpose, we have plotted potential ϕ vs. ξ. To keep the value of the second term of eq. (18), $m/2\tau$, constant in both cylindrical and spherical geometries, we have taken $m = 1$, $\tau = -1$ in cylindrical case and $m = 2$, $\tau = -2$ in spherical case so that $m/\tau = -1$ because the presence of the second term m/τ of expression (18) shows the difference between planar and non-planar geometries. If $m/2\tau = 0$, then our equation reduces to KdV Burger equation in flat geometry. Figures 2a and 2b present the evolution of non-planar electron-acoustic waves for three different values of q, i.e., $q = 0.7, 0.8, 0.9$ when $m/\tau = -0.5, -0.67$ and -1. The other plasma parameters are $\alpha = 2$, $\theta = 200$ and $\gamma = 0.2$. Figure 2 depicts the change in the properties of solitary waves with q. It is clear from figures 2a and 2b that the width and amplitude of the solitary wave decrease with increase in q in both cylindrical and spherical geometries but the

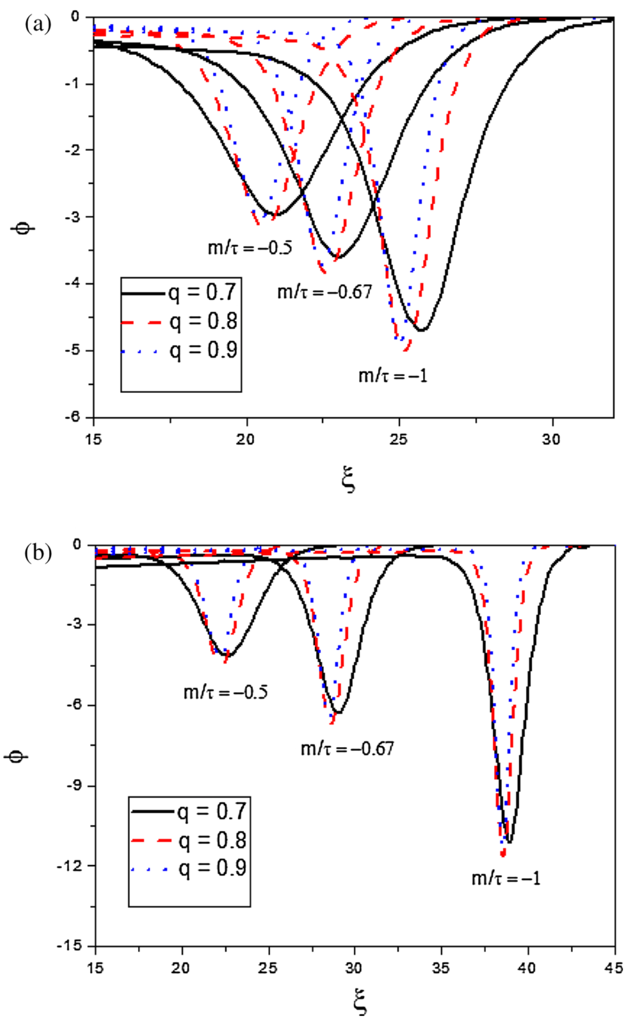

Figure 2. Variation of ϕ with ξ for $q = 0.7, 0.8$ and 0.9 at $\alpha = 2$, $\gamma = 0.1$ and $\theta = 200$ in (**a**) cylindrical ($m = 1$) and (**b**) spherical geometries ($m = 2$).

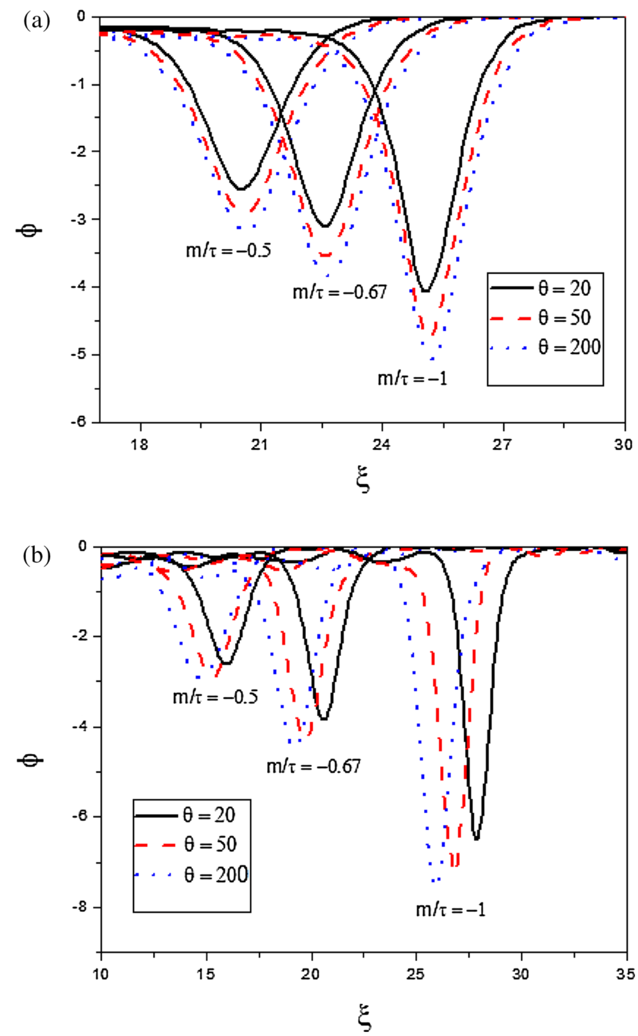

Figure 3. Variation of ϕ with ξ for $\theta = 200$, 50 and 20 with $\alpha = 2$, $\gamma = 0.1$ and $q = 0.8$ in (**a**) cylindrical ($m = 1$) and (**b**) spherical geometry ($m = 2$).

effect is more dominant for spherical waves than for cylindrical waves.

However, it is worth discussing here the effect of temperature ratio (θ) as it plays a significant role on the properties of EA waves. To study the influence of θ on the soliton properties, a graph is plotted between ϕ and ξ for three different values of θ, i.e., $\theta = 20$, 50 and 200 as illustrated in figures 3a and 3b in different geometries. From the figure, it is depicted that the increase in the electron temperature ratio increases the wave width as well as amplitude. θ has significant effect on amplitude, width and velocity of the waves. It is very interesting to note here that the velocity of the solitary wave decreases with increase of temperature for the same value of m/τ in spherical coordinates as shown in figure 3b. It means that electron-acoustic waves slow down with increasing temperature when $m = 2$ (spherical geometry). Also as one goes to higher values of m/τ, velocity, amplitude and width of the wave increases and this is more noticeable in spherical coordinates compared to cylindrical one.

The solutions of eq. (18) have been plotted in figurse 4a and 4b for cylindrical and spherical geometries respectively to study the combined effect of non-thermal non-extensive parameter. Figure 4 shows that an increase in non-thermal γ ($\gamma = 0$, 0.05, 0.1) leads to an increase in the width and amplitude. Other plasma parameters are $q = 0.8, \theta = 200$ and $\alpha = 2$. However, wave amplitude and steepness are found to be more pronounced in figure 4b. There is a slight increase in the velocity of waves in both geometries with non-thermal parameter γ. It is observed that increasing the number of non-thermal electrons in the medium increases the amplitude, velocity as well as width of the non-planar waves but the impact is dominant in

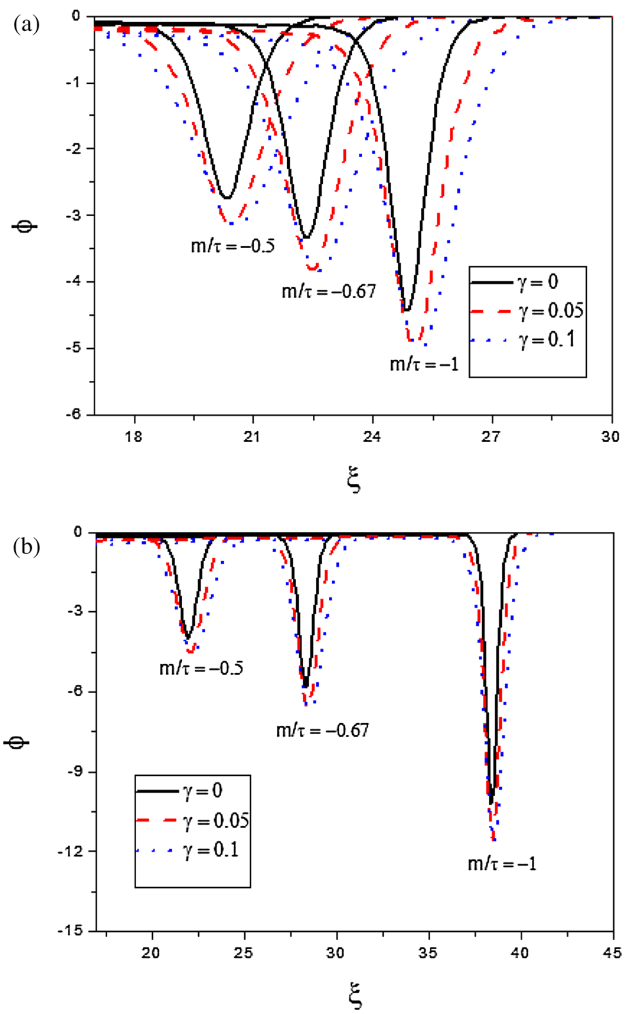

Figure 4. Variation of ϕ with ξ for $\gamma = 0, 0.05$ and 0.1 with $\theta = 200$, $\alpha = 2$ and $q = 0.8$ in (**a**) cylindrical ($m = 1$) and (**b**) spherical geometry ($m = 2$).

spherical waves. Further, it is clear from the figure that in spherical coordinates, the velocity and amplitude of the soliton increase more rapidly than in the cylindrical one at large values of m/τ.

5. Conclusions

We have investigated the non-planar waves in hybrid non-thermal non-extensive plasma. In this paper, we have used the reductive perturbation method to derive a KdV equation (18) in unmagnetised plasma to investigate the features (size and shape) of EA waves. Results of the KdV equation confirm that the nonlinear wave profile is strongly modified by the non-thermal non-extensive, temperature and density. Figures 1–4 show the physical behaviour of solitary wave profiles with different plasma parameters q, θ and γ in cylindrical and spherical goemetries. Our results show that increase in values of θ and γ increases the amplitude and width but increase in values of non-extensive parameter q decreases the amplitude and width of the waves. It is very interesting to note here that the velocity of the solitary wave decreases with increase of temperature parameter for the same value of m/τ in spherical coordinates as shown in figure 3b. It means that electron-acoustic waves slow down with increasing temperature when $m = 2$ (spherical geometry). Furthermore, we found that the effect is more pronounced in spherical coordinates. If we assume $\theta = 0$ and $\gamma = 0$, then results of our paper are consistent with [41]. This two-parameter (γ, q) distribution model is applicable to a wide range of observed plasmas, i.e. auroral region and magnetosphere of the Earth. Results could be helpful to analyse the features of solitons and their physical processes in complex astrophysical plasma.

Acknowledgements

Sona Bansal and Munish Aggarwal are thankful to Punjab Technical University, Kapurthala (India) for their support.

References

[1] K Watanabe and T Taniuti, *J. Phys. Soc. Jpn* **43**, 1819 (1977)
[2] M Y Yu and P K Shukla, *Phys. Plasmas* **29**, 1409 (1983)
[3] R L Tokar and S P Gary, *Geophys. Res. Lett.* **11**, 1180 (1984)
[4] S P Gary and R L Tokar, *Phys. Fluids* **28**, 2439 (1985)
[5] R L Mace and M A Helberg, *Phys. Plasmas* **43**, 239 (1990)
[6] W C Feldman *et al*, *Geophys. Res. Lett.* **88**, 15 (1983)
[7] S D Bale, P J Kellogg, D E Larson, R P Lin, K Goetz and R P Lepping, *Geophys. Res. Lett.* **25**, 2929 (1983)
[8] G S Lakhina, S V Singh, A P Kakad, F Verheest and R Bharuthram, *Nonlinear Process. Geophys.* **15**, 903 (2008)
[9] S V Singh and G S Lakhina, *Planet. Space Sci.* **49**, 107 (2001)
[10] D Schriver and M Ashour-Abdalla, *Geophys. Res. Lett.* **16**, 8 (1989)
[11] N Dubouloz, R Pottelete, M Malingre and R A Treumann, *Geophys. Res. Lett.* **18**, 155 (1991)
[12] N Dubouloz, R A Treumann, R Pottelete and M Malingre, *Geophys. Res. Lett.* **98**, 17 (1993)
[13] R L Mace, S Baboolal, R Bharuthram and M A Hellberg, *J. Plasma Phys.* **45**, 323 (1991)

[14] R L Mace and M A Helberg, *Phys. Plasmas* **8**, 2649 (2001)
[15] R A Cairns, A A Mamun, R Bingham, R Bostrom, R O Dendy, C M C Nairn and P K Shukla, *Geophys. Rev. Lett.* **22**, 2709 (1995)
[16] R A Cairns, R Bingham, R O Dendy, C M C Nairn, P K Shukla and A A Mamun, *J. Geophys. Res.* **5**, C6-4 (1995)
[17] C Tsallis, *J. Stat. Phys.* **52**, 479 (1988)
[18] F Satin, *Phys. Scr.* **71**, 443 (2005)
[19] M Tribeche, L Djebarni and R Amour, *Phys. Plasmas* **17**, 042114 (2010)
[20] R Amour and M Tribeche, *Phys. Plasmas* **17**, 063702 (2010)
[21] A S Bains, M Tribeche and T S Gill, *Phys. Plasmas* **18**, 022108 (2011)
[22] M Shahmansouri and H Alinejad, *Astrophys. Space Sci.* **344**, 463 (2013)
[23] U Abdelsalam, F Allehiany, W M Moslem and S K El-Labany, *Pramana – J. Phys.* **86**, 3 (2015)
[24] M Tribeche, R Amour and P K Shukla, *Phys. Rev. E* **85**, 037401 (2012)
[25] R Amour, M Tribeche and P K Shukla, *Astrophys. Space Sci.* **338**, 287 (2012)
[26] G Williams, I Kourakis, F Verheest and M A Hellberg, *Phys. Rev. E* **88**, 023103 (2013)
[27] O Bouzit, L A Gougam and M Tribeche, *Phys. Plasmas* **21**, 062101 (2014)
[28] A A Abid, M Z Khan, S I Yap, H Tercas and S Mahmood, *Phys. Plasmas* **23**, 013706 (2016)
[29] P Bala, T S Gill, A S Bains and H Kaur, *Indian J. Phys.* **91**, 1625 (2017)
[30] A Merriche and M Tribeche, *Ann. Phys.* **376**, 436 (2017)
[31] B Sahu and R Roychoudhury, *Phys. Plasmas* **10**, 4162 (2009)
[32] W Massod, N Imtiaz and M Siddiq, *Phys. Scr.* **80**, 015501 (2009)
[33] M Eghbali, B Farokhi and M Eslamifar, *Pramana – J. Phys.* **88**: 1 (2016)
[34] M Amina, S A Ema and A A Mamun, *Pramana – J. Phys.* **88**: 6 (2017)
[35] R Sabry, S K El-Labany and P K Shukla, *Phys. Plasmas* **15**, 122310 (2008)
[36] K Javidan and H R Pakzad, *Indian J. Phys.* **87**, 83 (2012)
[37] S K El-Labany, M Shalaby, R Sabry and L S El-Sherif, *Astrophys. Space Sci.* **340**, 101 (2014)
[38] H Demiray and E R El-Zahar, *Phys. Plasmas* **25**, 042102 (2018)
[39] T K Baluku, M A Helberg, I Kourakis and N S Saini, *Phys. Plasmas* **17**, 053702 (2010)
[40] S Bansal, M Aggarwal and T S Gill, *J. Astrophys. Astron.* **39**, 27 (2018)
[41] H R Pakzad, *Astrophys. Space Sci.* **337**, 217 (2012)
[42] W Malfliet, *J. Comput. Appl. Math.* **164**, 529 (2004)
[43] A Merriche and M Tribeche, *Physica A* **421**, 463 (2015)