# Formation of Nonlinear Solitary Vortical Structures by Drift and Ion-Acoustic Waves in Electron-Positron-Ion Plasmas

L.Z. Kahlon[1], I. Javaid[1], T.D. Kaladze[2]
[1] Physics Department, Forman Christian College (A Chartered University), Ferozpur Road, 54600 Lahore, Pakistan; lailakahlon@fccollege.edu.pk ; lailakahlon192@gmai.com
[2]I. Vekua Institute of Applied Mathematics of Tbilisi State University, Tbilisi, Georgia
[3]E. Andronikashvili Institute of Physics, I. Javakhishvili Tbilisi State University, 0128 Tbilisi, Georgia

Many laboratory and astrophysical medium frequently form the three-component plasma containing electrons, positrons, and ions (EPI plasma). The study of low-frequency long wavelength drift and ion-acoustic waves (DIAWs) is of great interest because of its applications to many laboratory, space, and astrophysical systems. Such interest of DIAWs is connected with the consequence of their existence forming nonlinear solitary vortical structures [1, 2].

In the presented manuscript, we are going to discuss the formation of nonlinear solitary vortical structures on the low-frequency coupled large-scale electrostatic drift and ion-acoustic waves (DIAWs) in the EPI plasma. Such description requires examination of nonlinear equations involving the dispersion and non-homogeneity of plasma. In addition, we consider temperatures of electrons and positrons to be arbitrary. As in the laboratory plasma experiments, large-scale drift waves ($k_{\perp}\rho \leq 1$, where $\rho$ is the ion Larmor radius defined at the electron temperature) are mainly observed; we will keep our attention to the large-scale solitary nonlinear structures and derive the generalized HM equation for the coupled drift and ion-acoustic waves in EPI plasmas.

To describe the nonlinear propagation of electrostatic drift and ion-acoustic waves (DIAWs), the generalized Hasegawa-Mima equation containing both vector (Jacobian) and scalar (Korteweg-de Vries type) nonlinearities is obtained for electron-positron-ion (EPI) plasmas. In addition, density and temperature non-homogeneities of electrons and positrons are taken into account. Appropriate set of 3D equations consisting of generalized Hasegawa-Mima equation for the electrostatic potential and equation of parallel to magnetic field motion of ions are obtained to describe the formation of coherent dipole and large-scale monopole vortices.

We have shown that the dynamics of low-frequency waves studied in usual EI plasmas is generally modified in EPI plasmas. Density and temperature inhomogeneity of electrons and positrons is taken into account. The generalized HM equation containing both vector and scalar nonlinearities valid for arbitrary sizes of structures is obtained. We have shown that due to the existence of positrons in the plasma the sign of the derivative $Zn'_{io}(x)= n'_{eo}(x) - n'_{po}(x)$ may change, which in turn enriches the class of solutions of the generalized HM equation. The appropriate dispersion equation and propagation frequency of drift and ion-acoustic waves (DIAWs) are obtained.

The new nonlinear self-organization mechanism of formation of LF large-scale electrostatic drift and ion-acoustic vortical structures in EPI plasmas is discussed. TThe generalized equation contains additional new scalar nonlinearities of KdV type as compared to the classical HM equation with respect of drift waves. The new type mechanism of the formation of solitary drift vortical structures due to the mutual action of scalar and vector nonlinearities. The standard HM equation contains only the vector nonlinearity which is valid only for the small-scale structures and predicts the existence of only dipolar vortices. By containing scalar nonlinearities, the generalized HM Equation describes solitary monopole type vortices. Monopolar solitary structures were first observed in laboratory modeling of solitary Rossby vortices [3]. By Kaladze et al. [4], it was numerically shown that the presence of the scalar nonlinearity plays the role of instability forming monopole vortical structures of definite polarity as a result of breaking large-scale dipole ones. The dynamics of large-scale drift vortical structures in EPI plasmas was discussed by Kaladze et al. [5]. Kaladze et al. [4] showed that in ionospheric E-layer, large-scale ULF coupled Rossby-Khantadze electromagnetic (EM) waves can be self-organized into localized (solitary) dipole nonlinear structures propagating along the latitudinal circles (parallels) against the background of the mean flow.

Finally, the numerical estimate made for the laboratory parameters [6], magnetic induction B ~1T, ion cyclotron frequency $\omega_{ci}{\sim}10^8 s^{-1}$, ion Larmor radius $\rho \sim 0.1$ cm, and the scale of inhomogeneity $L_{n,T}{\sim}10\ cm$. Then if we consider that vortical structures are propagating at the velocity $U \approx \beta_n$, we find the typical size of vortical structures $a \approx \rho$.

**References:**

[1] M.J. Rees, in The Very Early Universe, ed. by G. M. Gibbons, S. W. Hawking, S. Siklas. (Cambridge University Press, Cambridge, 1983)
[2] A. Mushtaq, H.A. Shah, Phys. Plasmas 12, 072306 (2005)
[3] L.Z. Kahlon, I. Javaid, Chin. Phys. Lett. 34(12), 123201 (2017)
[4] T.D. Kaladze, L.V. Tsamalashvili, L.Z. Kahlon, J. Plasma Phys. 77, 813 (2011)
[5] T.D. Kaladze, M. Shad, H.A. Shah, Phys. Plasmas 16, 024502 (2009)
[6] S.I. Popel, S.V. Vladimirov, P.K. Shukla, Phys. Plasmas 2, 716 (1995).