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Zonal flow generation by small-scale drift-ion-acoustic waves in electron–positron–ion plasmas

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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) has great attention due to its applications to many laboratory, space, and astrophysical systems. This problem received much attention due to the possibility of the formation of spatially three-dimensional different nonlinear solitary structures (vortices and zonal flows) in multicomponent plasmas. Such interest of DIAWs is connected with the generation of sheared zonal flow spontaneously arising in laboratory plasmas as a consequence of the secondary instability of plasma due to the nonlinear interaction between the primary oscillations. Note that the existence of spatially isolated sheared zonal flows is an integral property of many planetary atmospheres and laboratory plasmas controlling anomalous transport of heat and particles across the magnetic surfaces of plasma confinement systems due to the energy transport toward large-scale structures as a result of inverse energy cascade [1, 2, 3].

In the present work, we investigate the possibility of generation of the zonal flow for low-frequency coupled electrostatic DIAWs in an electron–positron–ion plasma and its corresponding growth rate is analyzed both analytically and numerically. We will draw our attention to the small-scale ($k_{\perp}\rho \geq 1$, where ρ is the ion Larmor radius defined at the electron temperature) solitary structures. The parametric interaction formulation is used to investigate the instabilities of zonal flows driven by a monochromatic wave packet of primary modes.

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 [3]. 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 where vector nonlinearity is taken into account for short-scale DIAWs [4].

We have shown that the dynamics of low-frequency waves studied in usual EI plasmas [5] is generally modified in EPI plasmas [3, 6]. 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 modified parametric approach is developed for the monochromatic primary modes. Accordingly, the interaction of a pump drift-ion-acoustic waves, two satellites of the pump waves (sideband waves), and a sheared zonal flow is studied. The driving mechanism of this instability is the Reynold stress and the mean electromotive force. The obtained results are applied to laboratory plasma experiments, that were considered for the case when $k_{\perp}\rho \geq 1$. The corresponding expressions for the growth rate are found.

This study shows that the parametric instability presented here is a sufficient nonlinear mechanism to drive large-scale zonal flows in EPI laboratory plasmas. The results obtained in the present study may be applied to the large-scale inhomogeneities in density of the universe and also to the astrophysical EPI jets where ions concentrations are taken as small fractions of the electron–positron plasma number densities.

Finally, the mathematical results and graphical analysis in this paper highlight the importance of effects that have not been taken into account in earlier works. In the numerical work, we analyze the dependence of growth rate on different parameters zonal wave vector, presence of positron and scale length. It is shown that how the presence of positron enhances the growth rate.[7]

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