AAPPS-DPP2024, Nov3-8, 2024, Grand Swiss-Bel Hotel, Malacca, Malaysia

Solitons and Shocks in Ion Temperature Gradient Driven Mode

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The ion temperature gradient (ITG) mode has been the subject of extensive research due to its plausible relevance to anomalous particle and thermal transport in laboratory-scale experiments. Plasma is intrinsically nonlinear, and the diversity of waves in the system can give rise to structures such as vortices, solitons, and shocks, which play an important role in transport phenomena [1]. Recently, Adnan *et al.* [1] explored the dynamics of low-frequency electrostatic excitations of an inhomogeneous plasma and discussed the role of scalar and vector nonlinearities, which contribute to the formation of nonlinear structures, such as solitons and vortices. Studying these structures is also important in exploring space plasma regions, for instance, Earth's auroral region, solar atmosphere, and other astrophysical plasma [2]. These structures have a lifetime longer than their period of internal rotation and are important for heat, mass, and momentum transport. The study focuses on ion temperature gradient (ITG) driven solitons and shocks in a plasma with gradients in equilibrium number density and ion temperature. In the linear regime, it is observed that both the ion temperature and the ratio of gradient scale lengths, ηi = Ln/LT, influence the real frequency and growth rate of the ITG wave instability. In the nonlinear regime, a Korteweg-de Vries (KdV) type equation is derived for the ITG mode, leading to the discovery of solitary wave solutions, specifically compressive solitons. The amplitude and width of these solitons are found to be sensitive to the parameter ηi = Ln/LT. Additionally, a Burgers-type equation is derived in the presence of dissipation, which admits shock wave solutions. This research may aid in understanding low-frequency electrostatic modes in inhomogeneous electron-ion plasma with density and ion temperature gradients. For illustration, the model is applied to tokamak plasma.

The ion temperature gradient (ITG) driven modes, the trapped electrons modes, and pressure gradient ballooning modes are the most effective sources for instabilities in realistic tokamaks (weak collisional) and are thus responsible for ion anomalous transport in the magnetically confined system. Plasma turbulence enhances the diffusion of heat, momentum, and particles across magnetic surfaces. We argue that theoretical justifications and experimental advances are also required to understand simulation results. It facilitates us to construct reduced models to allow meaningful experimental tests and comparisons. Our results may provide a good qualitative description of the observations of nonlinear solitary and shock waves driven by the ITG mode in magnetically confined plasmas.

We have presented a theoretical study of soliton and shock formation driven by ion temperature gradient mode for the first time in a magnetized inhomogeneous plasma. We found analytically that the resulting mode equations for both of these nonlinear structures show the ηi = Ln/LT effect exclusively. The parametric results show the ηi = Ln/LT influence on the amplitude and the width of the solitons and the propagation of shock waves. We observed that by increasing the ion-to-electron temperature ratio, the dispersive effect is dominant, and the soliton gets less localized, while the ηi = Ln/LTeffect on the structure showed that the amplitude of the soliton decreases, and the width retains its initial position. It is noticeable that the shock profile reveals the effect of temperature and ηi = Ln/LT, but in the case of magnetic field strength variation, the shock profile shifts but steepness remains the same.

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