Chapter 8

Interaction of Beam-Driven Electron-Acoustic Solitons in Auroral Region

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ABSTRACT

The interaction of beam driven solitons is studied in an unmagnetized plasma, comprising (r,q) distributed hot electrons, cold inertial electrons, warm electron beam and static ions. For this purpose, fluid equations are solved to obtain four distinct roots of linear dispersion relation which vary with beam speed. For small-amplitude limit, the standard Korteweg-de Vries (KdV) equation is derived that admits soliton solution and critical condition gives rise to modified KdV equation (mKdV). The overtaking interaction of KdV and mKdV solitons is studied by Hirota method, while the head-on collision (HOC) by the Poincare-Lighthill-Kuo (PLK) technique. The analytical expressions of phase shifts are examined for the plasma parameters, namely density, temperature, and velocity of beam electrons. In contrast to Hirota method, the PLK method provides the linear sum of the solitons at the point of interaction. However, despite this limitation, PLK technique is only analytical technique available to study HOC. The relevance of this model is interesting to understand tripolar electric field structures in Earth's Auroral region, which may be associated to the interaction of EASWs in space plasmas.

1. INTRODUCTION

In this chapter, we take into account the *hydrodynamic* or *fluid* model for plasma system, which consists of a mixture of electrons and ions along with energetic electron beam particles, intermediated by the electromagnetic field. For this model the separate set of equations for density, momentum and energy

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conservation for all the constituent particles is utilized. The electron waves are produced on the time scale of electron motion, so are high frequency waves as compared to the ion waves. We particularly study the nonlinear wave interaction of electron acoustic waves in this chapter driven by electron beam particles. The nonlinear wave interaction is a significant phenomenon as it plays a vital role for the transport of energy and momentum in a plasma system.

1.1 Electron Acoustic Waves

The Electron Acoustic Waves (EAWs) are the high frequency electrostatic waves found in various regions of space. They have been detected by many satellite missions, including S3-3 and THEMIS in auroral region (Temerin et al., 1982; Angelopoulos et al., 2008), POLAR in polar cusp (Gary & Tokar, 1985), Viking and FAST satellites in polar cusp boundary layer (Bostrom et al., 1989; Ergun et al., 1998; Pottelette et al., 1999), GEOTAIL in plasma sheet boundary layer (Matsumoto et al., 1994), CLUSTER in Earth's magnetosphere/magnetopause (Pickett et al., 2005; Graham et al., 2015), etc. The broadband electrostatic noise (BEN) has been observed in bow shock, magnetotail, auroral region, polar cusp and other regions of the Earth's magnetosphere (Singh & Lakhina, 2001). In BEN, there is a large asymmetric bipolar electric field component parallel to the magnetic field, which is found in the range from a few *mV/m* to 100*mV/m*. The large amplitude electric field component has successfully been interpreted in terms of EAWs in various regions of magnetosphere (Dubouloz et al., 1991; Lakhina et al., 2011; Dillard et al., 2018). The existence of these waves has been reported by the Magnetospheric Multi-scale (MMS) during asymmetric magnetic reconnection at Earth magnetopause (Ergun et al., 2016).

The pre-requisite for the generation of stable EAWs is the presence of two temperature electron populations in a plasma system. The cold electrons provide the necessary inertia and the thermal pressure of hot electrons furnish the essential restoring force for the wave. The quasi-neutrality is ensured by the presence of ions which act stationary for these high frequency waves. The phase velocity of the EAW lies intermediate between the thermal speed of hot electrons and the thermal speed of cold electrons. The EAWs were first predicted by Fried and Gould (1961) while studying the dispersion relation of linearized longitudinal waves in hot, collisionless, unmagnetized plasma. They anticipated the presence of this mode in plasmas, however, unlike Langmuir mode and ion acoustic waves, this mode is heavily Landau damped. Later, Watanabe established that this mode becomes less weakly damped in the presence of cold and hot electrons. Gary and Tokar (1985) presented the necessary conditions on plasma parameters for the formation of EAWs. presented the necessary conditions on plasma parameters for the formation of EAWs. They established that the temperature of cold electrons ($\mathrm{T_c}$) must be much lower than the temperature of hot electrons ($\mathrm{T_h}$), and the minimum percentage of the hot electrons density ($\mathrm{n_h}$) must be 20 percent of the total electron density ($n_e=n_c+n_h$), mathematically equivalent to $T_c \leq 10T_h$ and $0.2<n_c/n_e<0.8$, respectively.

The presence of two temperature electrons has been detected in terrestrial and planetary magnetospheres as well as the laser-plasma corona (Bezzerides et al., 1978; Mozer et al., 1979; Lakhina et al., 2018), which allows the investigation of EAWs in these regimes. The existence of two electron temperatures is also justified for the regions where there is diffusion of particles emerging from different regions of space. One such frequent situation occurs when the energetic particles of the solar wind interact with various regions of magnetosphere. The electron-electron collisions in such space plasmas are low, so that the high frequency mode appears before the electrons attain the thermal equilibrium. The magnetic

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