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Nonlinear Magnetosonic Waves with Modified Temperatures Based on Non-Extensive q- Distribution and Generalized (r,q) Distribution

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This study investigates the propagation characteristics of obliquely propagating nonlinear fast and slow magnetosonic wave modes in a hot, dissipative plasma medium where particle populations deviate from classical Maxwellian behavior. In particular, the plasma is modeled using generalized nonthermal velocity distributions, specifically the non-extensive q-distribution and the more generalized (r,q)-distribution, which are frequently observed in astrophysical, space, and laboratory plasma systems characterized by long-range interactions and nonequilibrium dynamics. To account for the thermal properties of such non-Maxwellian plasmas, modified expressions for the temperature are derived that appropriately incorporate the features of the non-extensive and (r,q)-generalized statistics. These modified temperatures provide a physically consistent framework for analyzing wave phenomena in plasmas where standard thermodynamic assumptions no longer apply. The analysis employs the reductive perturbation technique (RPT) to derive the governing equations for the nonlinear evolution of magnetosonic wave modes. Initially, the linear dispersion relation (LDR) is obtained, which highlights how non-extensive parameters and viscosity influence the basic wave propagation characteristics. Subsequently, the nonlinear evolution equations for the fast and slow magnetosonic modes are derived in the form of the Korteweg-de Vries (KdV) equation and the Kadomtsev-Petviashvili-Burgers (KPB) equation. The KdV equation captures the dynamics of small-amplitude solitary structures, while the KPB equation accounts for two-dimensional effects and dissipative mechanisms that lead to shock-like structures in the plasma.

The contemporary investigations explores in detail the role of various plasma parameters on the dispersion and nonlinear evolution of magnetosonic waves. These parameters include the non-extensive index q, which quantifies the degree of deviation from Maxwellian equilibrium, and the spectral indices (r,q), which control the shape and tail properties of the generalized distribution function. Furthermore, the influence of kinematic viscosity is included to reflect realistic dissipative effects commonly present in warm or hot astrophysical plasmas. Results reveal that both the linear and nonlinear behaviors of fast and slow magnetosonic waves are significantly modified by the nonthermal characteristics of the plasma. Specifically, the LDR is sensitive to changes in q and (r, q), altering phase speeds and wave dispersion properties. In the nonlinear regime, soliton structures governed by the KdV equation and shock profiles described by the KPB equation are also highly dependent on the non-Maxwellian parameters and viscosity. The amplitude, width, polarity, and stability of these structures vary considerably, suggesting that nonthermal features and dissipative effects must be accounted for to accurately model wave dynamics in such plasma environments. This investigation thus provides a deeper and more generalized theoretical understanding of magnetosonic wave modes under realistic, non-equilibrium plasma conditions. These results are relevant for interpreting space plasma observations (e.g., in the solar wind, magnetosphere, and astrophysical jets), as well as for designing experiments in controlled laboratory plasmas where nonthermal features are deliberately introduced or naturally arise.