Kinetic theory of acoustic-like modes in nonextensive pair plasmas

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Abstract The low-frequency acoustic-like modes in a pair plasma (electron-positron or pair-ion) is studied by employing a kinetic theory model based on the Vlasov and Poisson’s equations with emphasizing the Tsallis’s nonextensive statistics. The possibility of the acoustic-like modes and their properties in both fully symmetric and temperature-asymmetric cases are examined by studying the dispersion relation, Landau damping and instability of modes. The resultant dispersion relation in this study is compatible with the acoustic branch of the experimental data (Oohara et al. in Phys. Rev. Lett. 95:175003, 2005) in which the electrostatic waves have been examined in a pure pair-ion plasma. Particularly, our study reveals that the occurrence of growing or damped acoustic-like modes depends strongly on the nonextensivity of the system as a measure for describing the long-range Coulombic interactions and correlations in the plasma. The mechanism that leads to the unstable modes lies in the heart of the nonextensive formalism yet, the mechanism of damping is the same developed by Landau. Furthermore, the solutions of acoustic-like waves in an equilibrium Maxwellian pair plasma are recovered in the extensive limit ($q \rightarrow 1$), where the acoustic modes have only the Landau damping and no growth.

Keywords Pair plasmas · Kinetic theory of plasma waves: waves, oscillations, and instabilities in plasmas

1 Introduction

Studying the pair plasmas has been an important challenge for many plasma physicists in two past decades. As we know, the difference between the electron and ion masses in an ordinary electron-ion plasma (in general, multi-component plasma with both light and heavy particles) gives rise to different time-space scales which are used to simplify the analysis of low- and high-frequency modes. Such time-space parity disappears when studying a pure pair plasma which consisting of only positive- and negative-charged particles with an equal mass, because the mobility of the particles in the electromagnetic fields is the same. Pair plasmas consisting of electrons and positrons have attracted an especial of interest because of their significant applications in astrophysics. In fact, electron-positron plasmas play an important role in the physics of a number of astrophysical situations such as active galactic nuclei (Begelman et al. 1984; Miller and Witta 1987), pulsar and neutron star magnetosphere (Goldreich and Julian 1969; Max and Perkins 1972; Michel 1982), solar atmosphere (Tandberg-Hansen and Emslie 1988), accretion disk (Orsoz et al. 1997), black holes (Daniel and Tajima 1998), the early universe (Misner et al. 1973; Gibbons et al. 1983) and many others. For example, the detection of circularly polarized radio emission from the jets of the archtypal quasar 3C297, indicates that electron-positron pairs are an important component of the jet plasma (Wardle et al. 1998). Similar detections in other radio sources suggest that, in general, extragalactic radio jets are composed mainly of an electron-positron plasma (Wardle et al. 1998). Furthermore, it has been suggested that the creation of electron-positron plasma in pulsars is essentially by energetic collisions between particles which are accelerated as a result of electric and magnetic fields in such systems (Sturrock 1971; Michel 1982, 1991).