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ORIGINAL ARTICLE

Low frequency collective modes in dense relativistic-degenerate strongly coupled plasma

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Abstract It is shown that low frequency electrostatic ion mode couples with electromagnetic shear Alfven mode in a dense plasma containing strongly coupled non-degenerate ion and relativistic degenerate electron fluids. By employing the appropriate fluid equations, a linear dispersion equation is obtained which shows modifications due to ion correlations and electron relativistic degeneracy. The results are discussed in the ultra-relativistic and weak-relativistic limits and implications of the results in dense degenerate plasmas of astrophysical origin (e.g., white dwarf stars) are pointed out with possible consequences.

Keywords Collective ion modes · Coupling · Degeneracy pressure · Relativistic-degenerate plasma

Under extreme conditions, the behaviour of matter is not conventional Chndrasekhar (1931, 1935, 1939), Lai (2001). Superdense matter constitutes degenerate plasma realized in numerous natural phenomena and laboratory with broad range of parameters. Such plasmas are predominantly found in compact astrophysical objects (e.g., matter of white and brown dwarfs, neutron stars, magnetars etc.), deep layers of the giant planets in the solar system (e.g., Jovian planets) and aimed to be produced in the next generation of laser-based plasma compression schemes Lai (2001), Hansen et al. (2004), Fortov et al. (2006), Shapiro and Teukolsky (2004), Shukla and Eliasson (2010). It is well known that the density, magnetic field and temperature of such plasmas vary over a wide range of values. For example, in white dwarfs, neutron stars and laser-compressed superdense plasmas, the electrons become degenerate and represent an ideal Fermi gas. On the other hand, ion component is nonideal in general with appreciable particle correlations. It may be in the form of ionic liquid, crystalline structure or some other model representation typical for ionic matter. The plasma density can exceed the solid state density by many orders, magnetic field is estimated to be varying from few kilogauss to few gigagauss (petagauss) in white dwarfs (neutron stars) and temperatures can be as high as in fusion plasma Lai (2001), Shapiro and Teukolsky (2004), Shukla and Eliasson (2010), Potekhin et al. (1999). Average inter-fermion distance becomes comparable to or less than the thermal de Broglie wave length and quantum degeneracy and relativity effects are ubiquitous. Quantum effects associated with lighter species (electrons, positrons, holes etc.) are more pronounced due to their smaller mass. Heavier species (ions) may behave classically or quantum mechanically depending upon the degeneracy parameter $\sim n\lambda_B^3$, where n and λ_B is the particle number density and thermal de Broglie wavelength, respectively. At extremely high densities, the electron Fermi energy $\epsilon_{Fe}[= \hbar^2/2m_e(3\pi^2 n_e)^{2/3}]$ can be much larger than thermal energy $\sim k_B T$, where $\hbar$, m_e, n_e, k_B and T are the reduced Planck's constant, electron mass, electron number density, the Boltzmann constant and plasma temperature, respectively. In this situation, the electron thermal pressure may be negligible as compared to Fermi degeneracy pressure arising due to the implications of Pauli's principle. Such degenerate electrons may be non-relativistic, relativistic or ultra-relativistic depending upon the ratio of Fermi energy to the rest mass energy of electron. In compact astrophysical objects, the mass is imparted by the ions/nuclei and degeneracy pressure by the dense Fermi gas of electrons (e.g., the bulk electron number density in white dwarfs $\sim 10^{30}$ cm^{-3} or higher) which pre-

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