DRIFT AND STREAMING INSTABILITIES IN COLLISIONAL DUSTY PLASMAS

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ABSTRACT

Recent theoretical work on instabilities in collisional dusty plasmas is presented. The focus is on instabilities that may be relevant to weakly ionized dusty plasmas in the lower ionosphere or in laboratory dusty plasma experiments. First, the effects of charged dust on the gradient drift instability are discussed with application to dusty regions of the upper mesosphere. Next, low frequency dust-acoustic type instabilities driven by electron cross-field drifts are studied with application to dusty meteor trails. Finally, an ion-dust streaming instability with frequency less than the dust-neutral collision frequency is considered with application to laboratory dusty plasmas.

INTRODUCTION

Dust grains (micron to sub-micron sized solid particles) in plasma and/or radiative environments are generally electrically charged due to processes such as plasma current collection, photoemission, or secondary electron emission. The presence of a very heavy, charged dust species in a plasma can both modify the properties of known instabilities and lead to new very low frequency instabilities associated with the motion of the dust. Certain dusty plasmas in near-Earth space environments or in laboratory experiments are weakly ionized and thus collisional [1]. Examples include dusty plasmas in polar mesosphere summer echo (PMSE) regions (see reviews in e.g. [2, 3]), dusty meteor trails [4], and laboratory dust wave experiments (see review in e.g. [5]). In this paper, recent theoretical studies on several instabilities in collisional dusty plasmas are summarized. These instabilities include the gradient-drift instability in a dusty plasma, a low frequency dust acoustic instability driven by electron cross-field drifts, and and a resistive ion-dust streaming instability.

DRIFT INSTABILITIES

It has been shown [6, 7] that the presence of charged dust can affect the Farley-Buneman instability, which is an electrojet instability applicable to the low E-region of the Earth's ionosphere (see e.g. [8]). For example, the presence of negatively charged dust can lower the critical electron $\mathbf{E}\times\mathbf{B}$ drift for instability at altitudes $h < 95$ km, and increase the critical drift at $h > 95$ km [7]. Charged dust may also affect another electrojet instability known as the gradient-drift instability (see e.g. [8]). For example, localized regions of negatively charged dust in the low E-region, with small scale spatial variations in the dust charge density, may lead to the generation of small scale electron density gradients. The presence of such density gradients, with components perpendicular to the ambient magnetic field, could affect the properties of the gradient drift instability [9]. Preliminary results [9] show that, if there are perpendicular electron density gradients with scale size $\sim$ several tens of meters in the polar ionosphere at altitudes $\sim$ 90 km, waves with wavelengths $\sim$ a few meters may be driven unstable by electron drifts on the order of the ion thermal speed. This may have application to dusty plasmas in the Earth's lower ionosphere, such as PMSE regions.

A very low frequency analog of the Farley-Buneman instability or its shorter wavelength version referred to as a high-frequency Hall current instability [10], has recently been studied in [11, 12]. This low-frequency Hall current instability, which is driven by an electron $\mathbf{E}\times\mathbf{B}$ drift, is a dust-acoustic type instability with wavelengths shorter than the ion mean free path. For certain plasma and dust parameters (e.g., the presence of a sufficient density of dust grains with large positive charge), the critical electron $\mathbf{E}\times\mathbf{B}$ drift can be $\lesssim$ the ion thermal speed [11, 12]. This instability may have application to dusty meteor trails resulting from large meteors and containing substantial amounts of larger sized, positively charged dust. If applicable, the instability would have implications for radar scattering from such trails [11, 12]. Recently, the effect of plasma density gradients on this instability has been investigated with application to the edges of dusty meteor trails at altitudes $h > 95$ km [13]. Preliminary results [13] show that, under certain conditions, a dust-acoustic-drift type instability, with wavelengths longer than the ion mean free path, may be excited by an electron cross-field drift smaller than the ion thermal speed.

STREAMING INSTABILITY

Since charged dust in laboratory plasmas are generally levitated by electric fields, ions which acquire drifts due to these fields can stream through the dust, leading to various kinds of streaming instabilities. Recently, an ion-dust streaming instability with frequency less than the dust-neutral collision frequency was investigated [14]. Under certain conditions, this instability may excited by ions drifting with speed $\sim$ the ion thermal speed, even when the dust acoustic wave is heavily damped. The instability may have application to observations of waves in certain laboratory dc glow discharge dusty plasmas. Since dusty plasmas in the laboratory generally have finite spatial extent, boundary effects may alter the properties of such ion-dust streaming instabilities.

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