

# Chapter 1

## Introduction

Dusty plasmas are low-temperature multispecies ionized gases including electrons, ions, and negatively (or positively) charged dust grains typically micrometer or submicrometer size. In such circumstances, the dust particles can be charged due to the collection of electron and ion currents from the background plasma. Therefore, the dust charge becomes another dynamical variable that distinguishes a dusty plasma from an ideal electron-ion plasma. Dusty plasmas are found in various space environments as well as laboratory devices and industrial processes. In this investigation we primarily consider several applications to space environments. Effluents from large space platform and exhausts from rockets and the space shuttle can create dust clouds. Recently, radar returns have been observed from the space shuttle exhaust [*Bernhardt, 1995*]. Figure 1.1 shows a space shuttle orbiting in the ionosphere. Figure 1.2 shows a schematic diagram of a dusty plasma created by the exhaust plume. The expanding water vapor condenses into ice, which becomes negatively charged by pickup of ionosphere electrons. The resulting dusty plasma acts as an enhanced backscatter target. Also, naturally occurring charged ice crystals are associated with noctilucent clouds which are confined to a geometrically thin layer (typically 1 to 3 km). and are often cirruslike in appearance. Figure 1.3 shows noctilicent clouds that are indeed at about 80km and are visible only in twilight. Figure 1.4 shows common-volume dust density and radar measurements from an experiment in which a sounding rocket payload flew through the radar beam

during the passage of the dust layer [Havnes *et al.*, 2000]. There was a good correspondence between the dust charge density  $n_d Z_d$  and the radar backscatter efficiency. Figure 1.5 shows meteor shower which is thought to be present at altitudes of  $\sim 80 - 100$  km. Ice particles can form around meteoric dust particles which can possibly influence the charge balance of the region. The waves and turbulence in noctilucent clouds and space shuttle exhaust may produce scattering of the radar beam. There has been considerable interest in new wave modes, plasma instabilities, and turbulence in dusty plasmas recently and this is currently a rapidly growing area in dusty plasma physics [Shukla, 1998; Rosenberg, 1996; Verheest, 1996]. Numerous unique types of electrostatic and electromagnetic waves and instabilities exist in dusty plasmas because of the dust charging process.

Most of the previous works on dusty plasmas have not studied waves and turbulence extensively with numerical simulations and assume constant charge on the dust grains. This is the first simulation study which includes the dust grain charge response to the plasma fluctuations. In this study, we investigate several important wave processes in magnetized and unmagnetized dusty plasmas using a two-dimensional simulation model which includes the temporal evolution of the dust grain charge. A fluid model is chosen to describe the background plasma electrons and ions since many plasma phenomena can be explained by this simplified model. The fluid model neglects the identity of individual particles and only the motion of fluid elements as a whole is taken into account and an important advantage of this fluid model is less simulation time. A Particle-In-Cell PIC model [Birdsall *et al.*, 1991] is used for the dust since we want to ultimately investigate the effects of charge and mass dispersion of individual dust grains. Using this numerical model, we first consider the dust charge fluctuation mode and low frequency ion wave damping in magnetized plasmas because these are important features that show the unique effects of the dust charging in a dusty plasma. Next, we consider plasma instabilities associated with the expansion of a dust cloud into a background plasma across a magnetic field. Last, we consider a streaming instability

due to the dust charging in unmagnetized dusty plasmas.

The physical model, numerical methods, and the details of the simulation results will be discussed in the following chapters.



Figure 1.1: A space shuttle orbiting in the ionosphere [Courtesy of NASA].

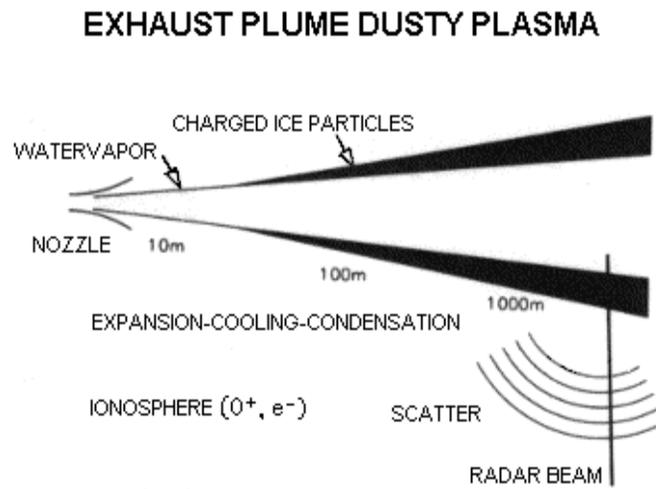


Figure 1.2: A schematic diagram of the exhaust plume [Bernhardt *et al.*, 1995].



Figure 1.3: Noctilucent clouds [Photographed by P. A. Dalin, Space Research Inst., Russia, 1999].

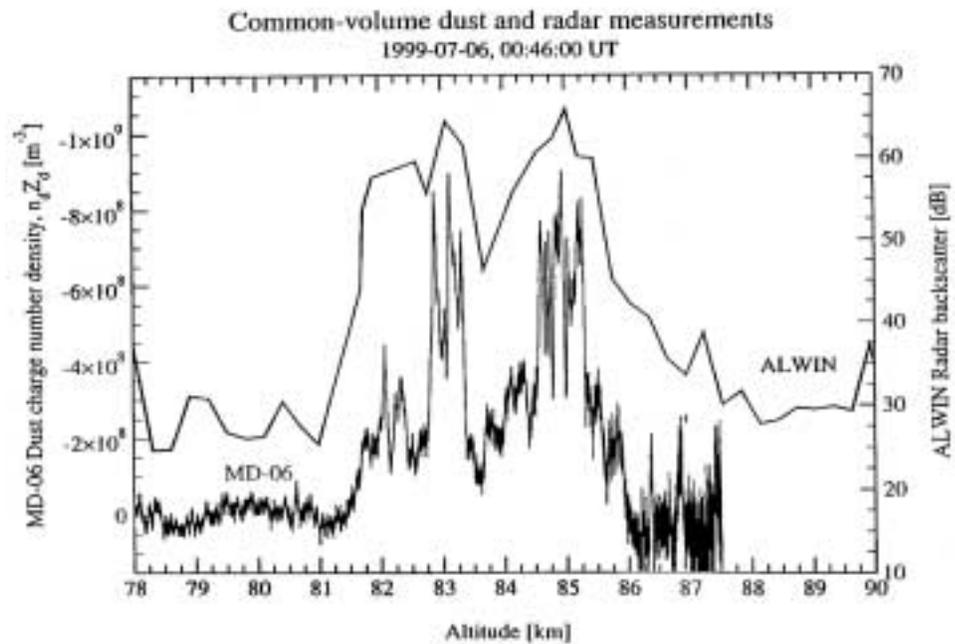


Figure 1.4: The Alwin 50MHz radar backscatter in dB and the dust charge density inside a noctilucent cloud [*Havnes et al.*, 2000].

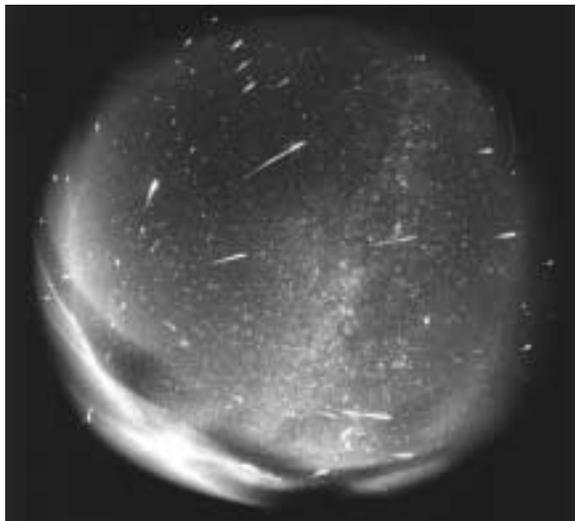


Figure 1.5: Meteor shower [Photographed by Juraj Toth, Modora Observatory, 1998].