SINGLE PARTICLE CHARGING MODELS COMPARISON: DISCRETE AND CONTINUOUS METHODS

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Abstract

When a dust particle is immersed in plasma, it will be gradually charged up by collecting electron and ion currents. In previous works [Chen and Scales, 2005], the dust charge is determined from the standard continuous charging model. In this work, discrete charging model will be introduced and compared with the continuous charging model. Besides, two new proposed charging models will be analyzed and compared with the traditional OML charging model to study about behavior for the single dust particle charging process. The purpose of this research is to find a more accurate charging model for the future lab and experimental research.

1. Introduction

Typically, there is only one electron charged on the dust particle in the earth's upper atmosphere. Therefore, for dusty plasma study in this region, the use of a continuous charging model may certainly be brought into question. In this work, we proposed a new discrete charging model. The results will be compared with the previous continuous model to verify the validation of the theories which is based on continuous model. Also, traditional OML charging model will be compared with another two new proposed sophisticated charging models.

A fundamental characteristic of the plasma is its ability to shield out electric potentials that are applied to it for the majority of the plasma. A measure of the plasma shielding is called the Debye length, which is a measure of the shielding distance. Here, the background plasma is called quasi-neutral gas which means that its neutral enough to assume $n_i = n_e = n$ where n is the plasma density. Assume the electron density $n_e = 10^{10}$ 1/m3 and electron temperature $Te = 150$ k, then the Debye length $\lambda_D = 1$ cm. Assume the dust radius equal to 10 nm, then, for 10% dust particles. Simple calculations that using the OML discrete charging model show that the Debye length is much smaller than both collision mean free path and charging mean free path. Also, for these parameters, typically, there is only one electron charged on a single 10 nm radii dust particle. Therefore, the use of a continuous charging model may certainly be brought into question.

2. Charging Models Comparison: Discrete and Continuous Approach

The probabilities of ion and electron attachments will be a key aspect of the collection of discrete plasma particles (ions and electrons) that are identified and incorporated into the model. The attachment of either ions or electrons will not be random. They obey probabilities that depend on the dust grain potential ϕ_d . The detailed discrete charging model is described in [Chen and Scales, 2007]. Figure 1 shows the simulation comparison of continuous and discrete charging model. In this simulation electron temperature were modified from time 25 seconds to time 125 seconds using a radio wave heater. As soon as the heater is on, the electron temperature will increase immediately. Different dust density cases were shown in the figure. The discrete charging model curves are change up and down along the smooth continuous charging model curves. The figure indicates very similar behavior between the two charging models. The charging model difference will also depends on other parameter such as dust radius, electron temperature etc. Simulation results show reasonable close behavior for these different parameter changes.

The difference between the discrete model and continuous model comes from the distribution of the dust charges. Figure 2 shows the evolution of the dust charge number distribution in the form of a histogram for three different times during the simulation of Figure 1 with 1% dust density. The envelop curve is also shown. The dashed lines represents the equilibrium dust charge number distribution in the equilibrium state before the heating (t = 23 seconds), primarily with each dust grain carrying one electron. Note some dust grains have 2 electrons. The dotted lines furthest to the right represent the charge distributions during the heating (t = 110 seconds). The electron temperature increases rapidly during this period of time, therefore, more electrons will attach on to the dust particles. The envelop curve is a

Gaussian-like shape distribution, and the mean is about 8 electrons. Then, after turning the heater off, the distributions recover back to the original state. The solid curves show this transition (t = 165 seconds). It is observed that when the dust charges number distributions are more close to Gaussian distribution, the smaller differences between the discrete model and the continuous model.

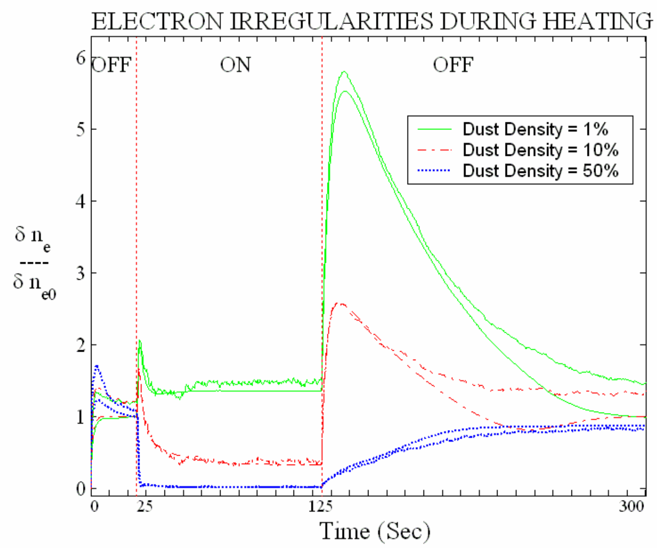

Figure 1. The time evolution of electron irregularities during radio wave heating with varying dust densities. Both discrete and continuous model results are shown.

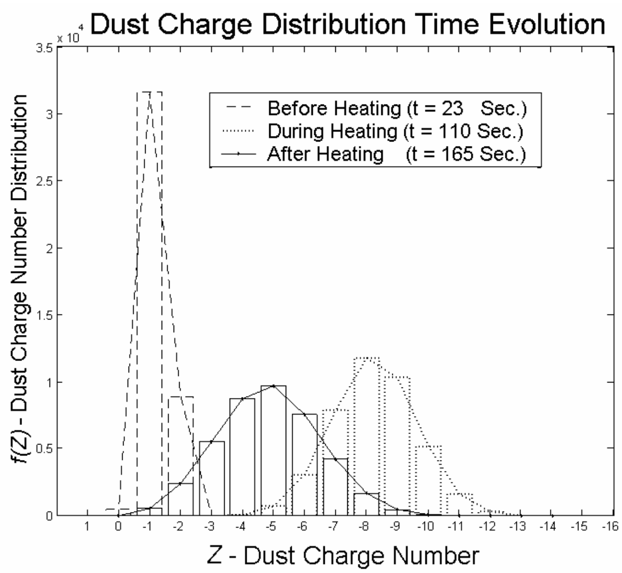

Figure 2. Time evolution of dust charge number distributions.

3. Charging Model Improvement and Comparison

The traditional OML charging model [*Bernstein and Rabinowitz,* 1959] is widely applied for dusty plasma study. However, it may not accurate enough for some cases. Here in this section, another two charging models will be compared with OML charging model. The two new proposed charging model are Drain and Shtin model [*Drain and Sutin,* 1987] and Natanson Model [*Natanson*, 1960] (see also[*Lie-Svendsen*, 2003]).

These three different charging models have their own advantages but also the limitations. Figure 3 shows the charging rate comparison of all three models. The charging rate is defined as: $f_c = (I_e+I_i)/e$, where I_e and I_i are electron and ion currents respetively.

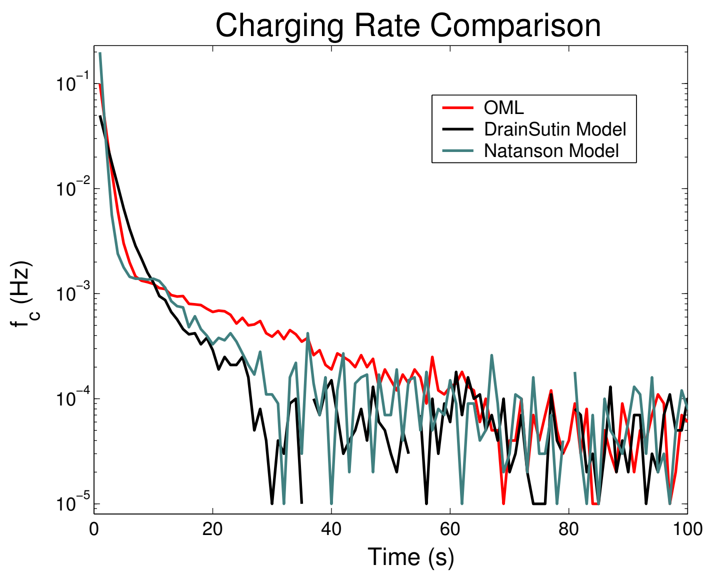

Figure 3. The charging rate comparison of three different charging models.

In this case, the dust density is 1% of the initial plasma density, i.e., $n_{d0}=n_0 = 0.01$ and the wavelength is $lambda$ = 4 m (f = 30 MHz), dust radius r_d = 10 nm. The simulation runs for 100 seconds to guarantee that the electron and ion densities reach equilibrium. It is noted that this charging rate is proportional to the charging current which is described in the previous sections. From the curves, the three models are reasonably close to each other. The OML model decreased slightly faster comparing with the other two models. All three models reach a close agreement at the equilibrium.

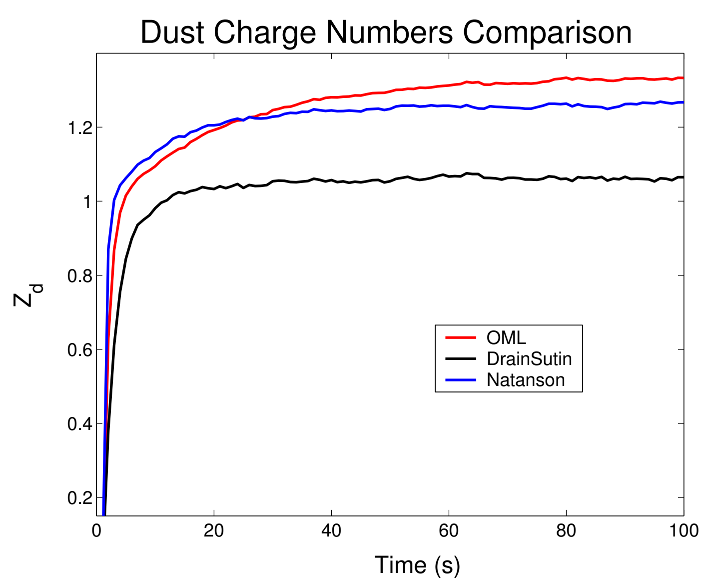

Figure 4. The comparison of average charge numbers on dust particles.

Figure 4 shows the average charge numbers on each dust particles using the same physical parameters in figure 3. The results are slightly different from each other. At equilibrium, OML charging model has averagely about 1.3 electrons on each dust particles; while 1.2 and 1 electrons for Natanson model and Drain&Sutin model respectively. Figure 5 shows the temporal evolution of the electron irregularity amplitude for each model. All three show relatively close profiles during the whole simulation. They all reached similar values at the equilibrium.

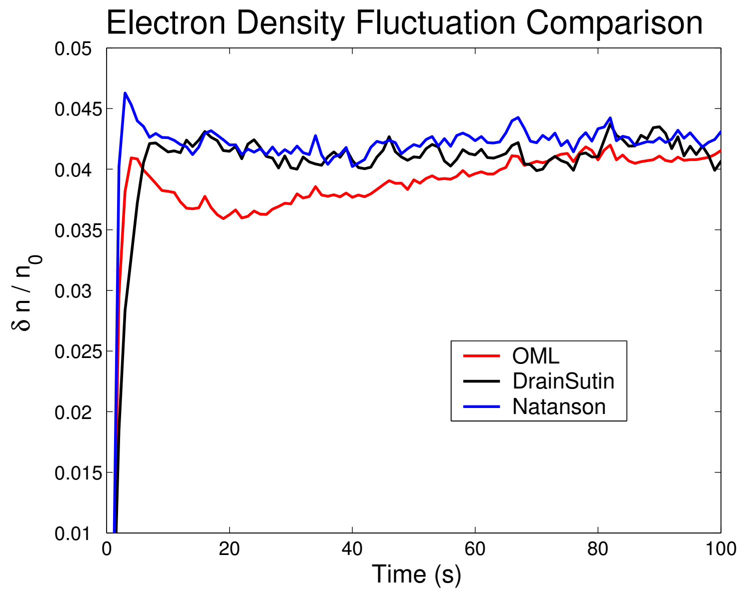

Figure 5. Time evolution of electron density irregularities with different charging models.

4. Conclusion

In this work, a new discrete charging model is introduced. The simulation results show similar behavior as the previous used continuous charging model. The more Gaussian like dust charge number distributions, the smaller differences between the discrete and continuous charging model. Also, 3 different charging models were introduced and compared. These three charging models show very similar behavior for the single dust particle charging process. They are supplementary to each other in different physical conditions. The purpose of this comparison is finding a more accurate charging model for the future research. Extensive experimental observation should be operated to provide sufficient results for further conclusion.

5. References

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