Effects of stochastic charging on micron sized grains in protoplanetary disks. K. S. Ashrafia, S. Esparza1, C. Xiang1, L. Matthews1, A. Carballido1, T. Hyde1 and B. Shotorban2, 1Center for Astrophysics, Space Physics and Engineering Research, One Bear Place #97310, Baylor University, Waco, TX, 76798-7310, USA, 2Department of Mechanical and Aerospace Engineering, The University of Alabama in Huntsville, Huntsville, AL 35899.

Introduction: Small dust grains are a major constituent of the material making up protoplanetary disks. In the earliest stages of planet formation, these grains agglomerate to form larger bodies, which are the precursors to planetesimals. In the last several years, numerical and semi-analytical models have shown that micron-sized dust grains play a significant role in the magnetohydrodynamic (MHD) evolution of protoplanetary disks (PPDs) [1,2,3]. The dust grains collect electrons and ions from the gas and provide a surface for electron recombination, affecting the ionization balance, which is crucial for the development of turbulence due to the magnetorotational instability [4].

Many of the sophisticated MHD disk models have assumed relatively simple recipes for dust charging, using, for example, analytical expressions for collision rates between charged particles and dust grains, as well as for electron sticking coefficients [5]. Likewise, these and other models mostly assume spherical grain shapes [1,3]. However, stochastic charging of grains can drive significant development of dust aggregate structure when the grains have a small charge [6]. This, in turn, would affect the available surface area for recombination on dust grains, and hence affect the overall ionization balance.

In this work, we use a model of discrete stochastic charging to calculate time-dependent electric charging of dust aggregates, with the aim of using the results for future MHD simulations of PPDs. We compare the electron and ion currents to micron and submicron grains which consist of aggregates of spherical monomers to those incident on spherical grains of equivalent mass. We calculate the average charge and charge distribution for (i) aggregates composed of monomers of 10 nm, 20 nm and 50 nm radius with an effective aggregate radius of 0.1 μm, and (ii) aggregates consisting of up to 50 monomers with monomer radius of 0.1 μm. Figure 1, 2, and 3 show the aggregates of equivalent radius 0.1 μm made of monomers of 10 nm, 20 nm and 50 nm radius respectively.

Method: An aggregate charging code that relies on Orbital Motion Limited theory with a Line Of Sight approximation (OML_LOS) is employed [7]. The surface of each spherical monomer within an aggregate is divided up into many small patches. The electron and ion current to each patch is calculated by determining whether the line of sight from the patch center along a given direction is open or blocked by other monomers within the aggregate. Only electrons or ions impinging from an open line of sight contribute to the charging currents.

The random charge fluctuations on the aggregates due to the electron and ion currents can be described by a master equation [8,9]

\[
\frac{dP(Z, t)}{dt} = \sum_{p=1}^{n} i_{p}(Z-e_{p})P(Z-e_{p}, t) + i_{p}(Z+e_{p})P(Z+e_{p}, t) - [i_{p}(Z) + i_{p}(Z)]P(Z, t) 
\]

where \( N \) is the total number of patches on the aggregate, \( Z = \{Z_1, Z_2, \ldots, Z_N\} \in R^N \) is the vector of the elementary charges collected on patches, \( P(Z, t) \) is the probability density function of a state at which the patch \( p \) has \( Z \) charges, \( I_{p} \) and \( I_{e,p} \) are the rates of attachment for ions and electrons to the patch \( p \), respectively, and \( e_{j} \in R^{N} \) is the unit vector, e.g. \( e_{3} = \{0,0,1,0, \ldots, 0\} \). In accordance with the master equation, the discrete stochastic method (DSM) is based on the following algorithm

1. Initialize the system with \( Z = Z_0 \) at \( t = t_0 \)

2. Evaluate \( I_{p}(Z) \) and \( I_{e,p}(Z) \) of all patches and calculate

\[
\lambda(Z) = \sum_{p=1}^{M} I_{p}(Z) + I_{e,p}(Z).
\]

3. Generate the time interval \( \tau \) between the attachment of the plasma particles to the aggregate according to \( \tau = \frac{1}{\lambda(Z)} \ln r_1 \), where \( r_1 \) is a random number.

4. Generate \( p \), the patch which experiences the attachment, according to \( p = \) the smallest integer satisfying \( \sum_{p=1}^{M} I_{p}(Z) + I_{e,p}(Z) > r_2 \lambda(Z) \) where \( r_2 \) is another random number.

5. Use a third random number \( r_3 \) to specify the kind of attaching plasma particle according to: if \( \frac{I_{p}}{I_{p} + I_{e,p}(Z)} > r_3 \), then \( Z = Z + e_{p} \), otherwise, \( Z = Z - e_{p} \) electron.
6. Change $t$ to $t + \tau$, and iterate

This algorithm is a customized version of the stochastic simulation algorithm developed for chemical kinetics [10].

Results: Figure 4, 5, and 6 show the charge distribution function $f(Z)$ for grains in plasma with $T_e = T_i = 280 \, K$, $n_e = 0.1 \, n_i$ and aggregate equivalent radius of 0.1 $\mu$m for different monomer radius.

Figure 4: Charge distribution function $f(Z)$ for 0.1 $\mu$m sized aggregates made of 10 nm sized monomers.

Figure 5: Charge distribution function $f(Z)$ for 0.1 $\mu$m sized aggregates made of 20 nm sized monomers.

Figure 6: Charge distribution function $f(Z)$ for 0.1 $\mu$m sized aggregates made of 50 nm sized monomers.