EXTENDED GRAIN LATTICE FORMATION WITHIN A DUSTY PLASMA; T.W. Hyde and W.M. Richter, Department of Physics, Baylor University, Waco, TX 76798-7316.

There are still open questions in theories concerning the origin of planetary systems. Many of these questions are centered around the problem of planetesimal formation by dust grain coagulation processes. Most current theories simply start with the planetesimals already in existence as an initial condition. There are also unanswered questions concerning the existence of the tenuous rings in our own solar system which are linked to grain coagulation. One promising mechanism suggested in the literature (1) which allows for grain coagulation while avoiding the problems of sticking coefficients, grain fragmentation, settling by gravitational instability, etc. examines a dusty plasma as a coupled system. It has been suggested (2) that the Uranian ring system (and perhaps the protoplanetary disk) might be examples of coupled systems. If the dusty plasma comprising a thin ring could be described in such a manner it might provide for the formation of a "Coulomb lattice" with the dust grains ordered along a solid-state lattice style structure or collapsed to a "solid" in the center of an extended mass-loaded plasma.

The coupling between the dust grains and the plasma is strongly dependent upon both the charge on the grains in the ensemble as well as the plasma Debye length. Both of these are also dependent upon the interaction between the dust grain ensemble and the plasma. As a result, the manner in which an extended grain ensemble charges within a plasma must be examined. The plasma particle depletion which occurs when a large dust grain ensemble is embedded in a plasma (especially a tenuous or limited plasma) or any sort of dust grain production mechanism produced by the plasma moving over the larger ring particles such as that suggested by Sheridan and Goree (3) should enhance many of the well known collective effects which occur due to the interaction of the plasma with the grain ensemble. In addition, a dust source or plasma particle sink will alter the plasma particle distribution function in a non-linear manner affecting grain charging as well as the plasma Debye length.

The standard method for calculating the charge on a dust grain ensemble is to attempt a solution of the Poisson equation under appropriate conditions. This is customarily accomplished by a linearization of the Poisson equation (usually by assuming a Maxwell-Boltzmann distribution of the plasma) and then solving by means of a Green's function approach. Although the Green's function approach can still be used, the approximation which allows a linearization of the Poisson equation is not applicable to the problem at hand since the plasma distribution function will be strongly non-linear due to the interaction of the plasma with the dust grain ensemble. In this case, the problem of determining the plasma distribution in the vicinity of the grain ensemble (which in turn allows for a calculation of the charge on the grains and determines the local plasma Debye length) demands the simultaneous solution of the Boltzmann-Vlasov transport equation and the Poisson equation. This can be accomplished numerically as shown by Hyde and Richter (4) using a modified 2-D particle-particle algorithm. This approach provides a method for studying the charging of a grain lattice immersed in a plasma while including the collective effects caused by the interaction of the lattice with the plasma and the interparticle effects (both of the grains within the lattice and the particles which comprise the plasma). Figure 1 shows the equilibrium charge (in electrons) on individual grains positioned in a two-dimensional (9 by 9) square dust grain lattice immersed in a plasma. The grains have a 5μ radius and are immersed in a 10 eV plasma with an initially random distribution of plasma particles (with a Maxwellian velocity distribution) and an initial plasma density around 100 electrons per cubic centimeter. The outermost grains in the lattice charge to the highest values while the grains farther into the lattice charge to lower values. Grains at the very center of the lattice obtain a charge slightly higher than their nearest neighbors. Figure 2 shows the radial electron distribution where the origin represents the center of the grain lattice. Their is an electron "pile-up" at the outer edge of the grain lattice and then a sharp drop past the lattice boundary. The electron distribution begins to climb before dropping again past the next lattice layer. The electron distribution falls to a minimum near the center of the grain lattice. Figure 3 shows individual grain potential as a function of time (again for grains arranged along a 9 by 9 square dust grain lattice).

It is seen from the above that an extended mass-loaded plasma will cause a decrease in the charge on inner lattice grains and also decrease their coupling parameters. However, the decrease in the radial electron distribution will at the same time change the plasma Debye length and may allow coupling of the grain lattice as a whole (especially for extended lattices) to remain fairly large. If a mechanism for continual mass-loading of the plasma is included (for example, the one suggested by Sheridan and Goree mentioned above) the interaction of the charged lattice grains with the plasma becomes more pronounced. Dense grain packing causes the charge on the inner grains of the lattice to become much smaller than that on the outer lattice grains. In addition, the interaction of the grain lattice with the plasma creates a significant decrease in the radial electron distribution which in turn increases the Debye shielding length to the point that the grains are no longer shielded from each other by the plasma (even for relatively dense plasmas). This allows for long-range Coulomb interactions in the grain lattice since lattice grains on the outer boundary of the lattice will no longer be shielded (necessarily) from the grains on the opposite side of the lattice (perhaps even for lattices which are tens of meters wide). Also, toward the center of the lattice, the grains will be at a lower charge which may enable them to collapse to a quasi-solid while the outer grains (being at a larger charge and intergrain displacement) remain in equilibrium. This would create an extended grain lattice in which the outer layers of the lattice remain in a quasi-stable equilibrium while the inner layers collapse to a densely packed, low charge configuration. This densely packed collection of grains should have a relatively high probability for coagulation. An attempt to quantify the necessary stability conditions as well as determine coagulation rates at the center of this grain configuration is presently underway.

References: (1) Michel, F.C., Geophys. Res. Lett.,Vol. 13, pp. 442, 1986. (2) Goertz, C.K., Reviews of Geophysics, 27, 2 pp. 271-292, 1989. (3) Sheridan, T.E. and J. Goree, Journal of Geophysical Research, Vol. 97, No. A3, pp. 2935-2942, 1992. (4) Hyde, T.W. and W.M. Richter, Adv. Space Res. 13, No. 10, 1993.

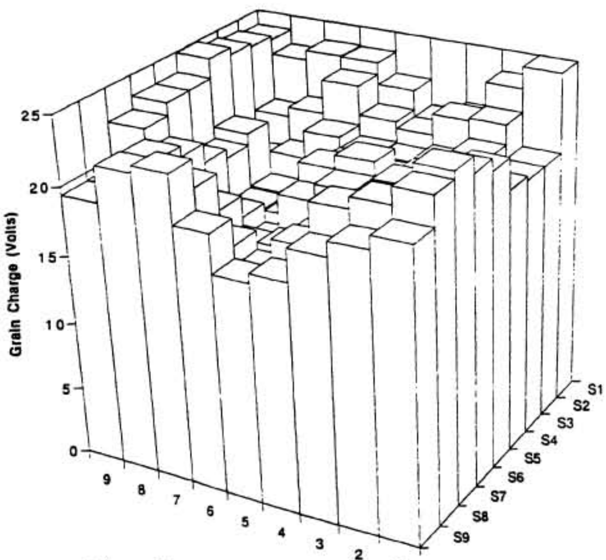

Fig. 1

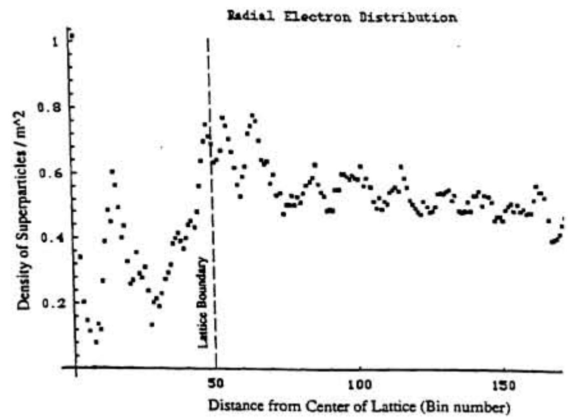

Fig. 2

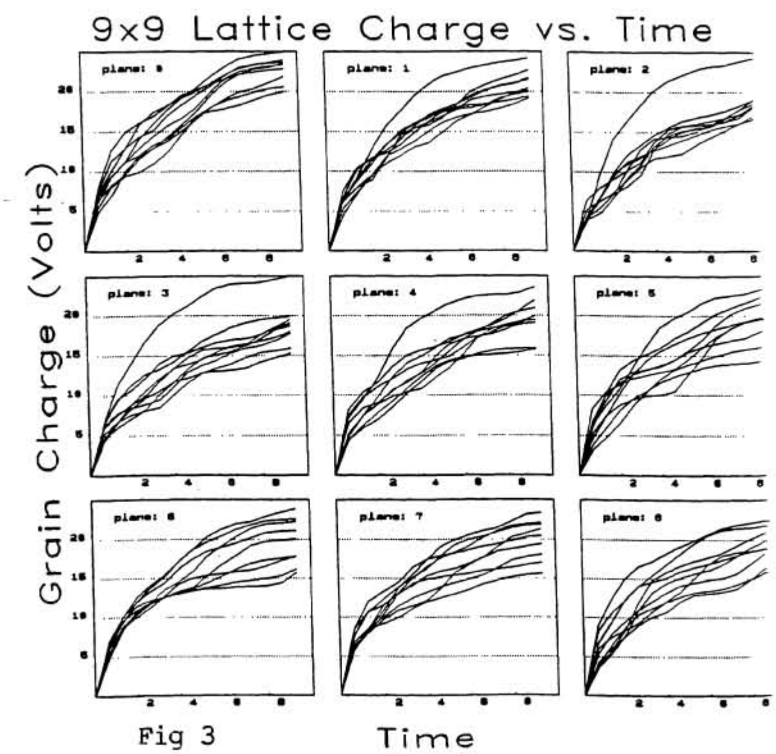

Fig 3