Charging Behavior of Dust Aggregates in a Cosmic Plasma Environment. S. A. Frazier[1], L. S. Matthews[2], and T. W. Hyde[2], [1]Rice University, Houston, Texas, 77005, USA [2] CASPER, Baylor University, Waco, Texas 76798, USA.

Introduction: The behavior of a charged dust aggregate in a plasma is essential to understand the formation and growth of dust aggregates in protoplanetary disks, the dust in cometary tails, and the dynamics of extrasolar grains entering the solar system. Numerous studies have shown that the growth and dynamics of charged dust aggregates are significantly different from those of their neutral counterparts [1, 2].

Dust grains in complex plasmas become charged by multiple phenomena: negatively charged by the impact of electrons, and positively charged through impacts of positive ions. Because the lower-mass electrons move with a greater velocity, they impact the dust grains more frequently than ions. In an isolated environment, dust grains generally reach a negative equilibrium charge.

UV radiation constitutes another positive charging current. Incident UV rays can excite electrons in a dust grain which are then emitted from the grain's surface. The polarity of the grain's charge depends on the integrated flux of the UV radiation.

Due to the porosity of an aggregate's structure, an electron that is ejected due to UV excitation will not always leave the aggregate. If an electron is ejected from a constitutent monomer along a path that collides with another monomer, the electron can be "recaptured" by the other monomer within the aggregate. Thus, the overall charge of the aggregate does not change with the emission of this electron.

In some cases, dust aggregates charged in a plasma environment that includes UV radiation can exhibit a mixed charging history. These aggregates which exhibit a "flip-flop" are positive at the beginning of their charging history, but negative for the latter part. This effect is similar to the "flip-flop" discussed by Meyer-Vernet for charging of an isolated spherical dust grain by secondary electron emission [3]. It is interesting to note that isolated spherical grains charged with UV radiation do not exhibit the "flip-flop" behavior, but aggregate grains consisting of spherical monomers do.

This study employs a numerical model to charge aggregates in a cosmic plasma environment including UV photoemissions. It explores the range of parameter space, including integrated UV flux, compactness factor of the aggregates, and number of monomers in the aggregates to determine the conditions under which the flip-flop charging behavior occurs.

Methods: Several hundred unique aggregates were charged under the conditions found in a hydrogen plasma at 1 AU, with plasma density of 6×10^{6} m^{-3} and temperature of 2×10^{5} K [8]. The aggregate library used was made up of silicate polydisperse spherical monomers with radii $0.5 – 5.0 \times 10^{-6}$ m. The integrated UV flux ranges from $0.5\text{-}1.5 \times 10^{13}$ m^{-1}s^{-1}. The aggregates consisted of $2 \leq N \leq 20$ monomers, which corresponds to a range of compactness factors from 0.457-0.988. The compactness factor describes the "fluffiness" or "openness" of a dust aggregate and is defined as the ratio of a total volume of the constituent spherical monomers to the volume of a sphere with a radius determined by the averate projected area [7]. As aggregates grow to larger size (higher N), they become less compact, or more fluffy and porous.

The numerical model used to charge the aggregates is based on Orbital Motion Limited (OML) theory with a Line of Sight (LOS) approximation [7]. OML theory calculates the equilibrium grain potential assuming conservation of energy and angular momentum of the incoming plasma species. However, the calculation becomes more complicated for non-spherical species, namely, dust aggregates. For this reason, the incorporation of the LOS factor is necessary to determine which portions of an aggregate's surface are exposed to impinging plasma particles or radiation.

The current density J from plasma species s to any point on the surface of a grain due to the collection of a given species of plasma particles is given by

$$J_s = n_s q_s \int_{v_{min}}^{\infty} v_s^3 f(v_s) dv_s s \iint \cos\alpha \, d\Omega.$$

The integral is split into two parts: one integral over

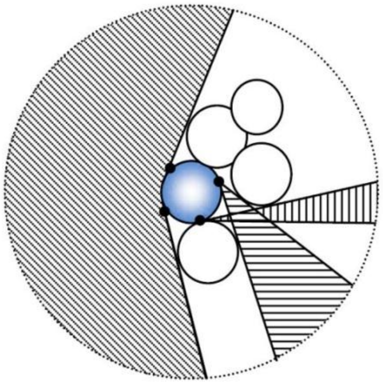

Fig. 1. The LOS factor is calculated by finding the paths to the monomer's surface which are unblocked. For the four test points on the blue-shaded monomer depicted in the 2-D cross-section, an ion or electron would have to be ejected along one of the gray-shaded paths in order to leave the dust aggregate.

the plasma particle velocity v with distribution $f(v)$ (assumed Maxwellian in this case), and $v_{\min}$ being determined by the relative charge of the dust grain and the plasma species, and another integral over the open solid angle $d\Omega$, where α is the angle between the incoming plasma particle and the surface normal. This second integral must be evaluated numerically for an aggregate to determine the open lines of sight, and is termed the *LOS factor*.

The current density due to photoelectric emission can similarly be split into two integrals,

$$J_{ph} = q_e \int_W^\infty Q_{\text{abs}}(h\nu)F(h\nu)Y(h\nu)d(h\nu) \iint \cos\alpha \, d\Omega, \quad q_e\varphi_s < 0$$

$$= q_e \exp\left(\frac{-q_e\varphi_s}{kT_{ph}}\right) \int_W^\infty Q_{\text{abs}}(h\nu)F(h\nu)Y(h\nu)d(h\nu) \iint \cos\alpha \, d\Omega, \quad q_e\varphi_s \geq 0$$

where the first is the integrated photon flux which includes the absorption efficiency Q_{abs}, the photon flux, F, and the photoelectric yield Y, as a function of the photon energy $h\nu$, and the second integral is the LOS factor [9]. Ejected electrons may only leave the aggregate upon open lines of sight, otherwise they are re-collected on the aggregates surface (Fig. 1).

Results and Discussion: Many aggregates begin their charging history with a positive charge, but eventually became negative (Fig. 2). This effect is similar to the "flip-flop" discussed by Meyer-Vernet [3]. The charging history of the aggregate depends mostly on the compactness factor of the aggregate and the integrated photon flux of the environment. Fig. 3 shows all of the aggregates included in the study plotted according to compactness factor and size. The aggregates that exhibited the flip-flop tend to be larger and less compact. The charging results for all aggregates are presented in Fig. 4 grouped by the integrated UV flux. The"flip-flop" effect is much more common for lower values of the integrated UV photon flux. For a given UV flux, the more open aggregates tend to be positively charged, while the compact aggregates tend to be negatively charged.

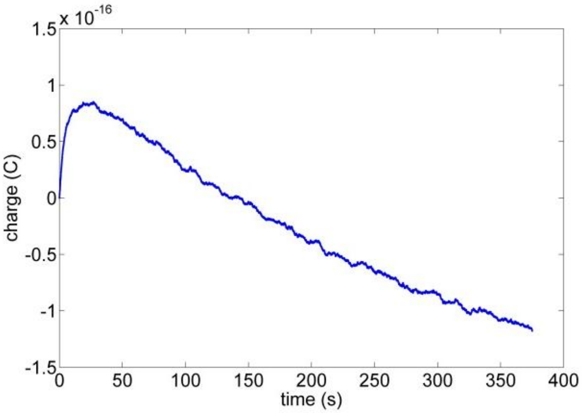

Fig. 2. Charging history for an aggregate, N = 15 and compactness factor 0.582, which exhibits the flip-flop effect. Integrated photon current is 5×10^{12} $\text{m}^{-2}\text{s}^{-1}$.

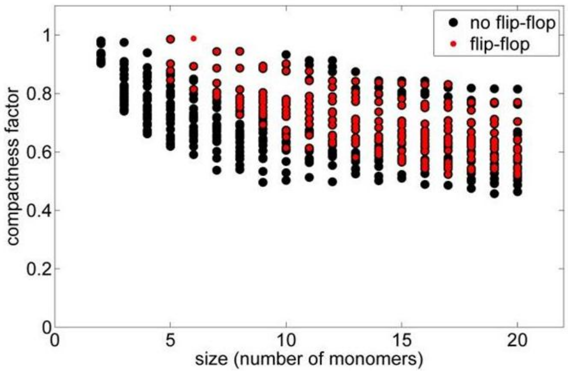

Fig. 3. Aggregates that exhibit the flip-flop effect tend to be of larger size and have a lower compactness factor, corresponding to a less compact aggregate.

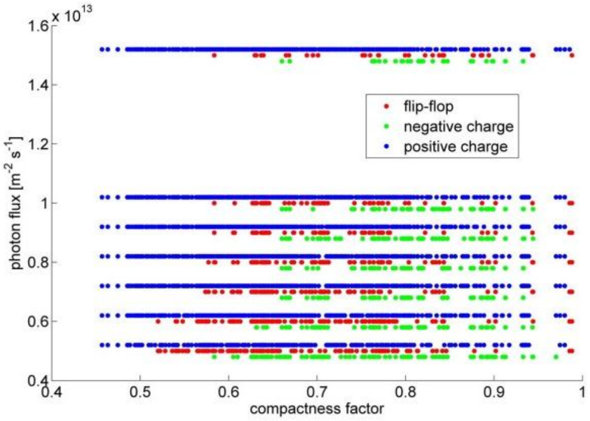

Fig. 4. Charging of aggregates according to charging history and organized into a density plot according to the integrated photon flux of the UV radiation.

Future Work: Previous research has shown that the charge on a dust grain is important in its growth and coagulation. The charge and growth rate effect the dynamics of the grain. It would be interesting to study the effects of a mixed charging history on the coagulation and growth rates of dust in a plasma and to conduct a similar study on aggregates that consist of monodisperse monomer sizes.

References: [1] L.S. Matthews et al. (2011) *Ap. J., 744(8).* [2] Okuzumi, S. (2009) *Ap. J., 698,* 1122-1135. [3] N. Meyer-Vernet (1981) *A&A, 105,* 98-106. [4] J.D. Perry et al. (2012) *A&A, 539,* 1-7. [5] R. Schwenn (1990) *Physics of Inner Heliosphere I: Large-Scale Phenomena*. Springer-Verlag, New York. [6] D. Paszun and jC. Dominik (2009) *A&A.* [7] L.S. Matthews and T.W. Hyde (2008) *IEEE Trans. on Plasma Sci., 36,* 310-314. [8] Tobiska, W.K. (1991) *Atmosph. Terrestr. Phys., 53,* 1005-1018. [9] Ma, Q. et al. (2013) *Ap. J., 763.*