Charging Behavior of Dust Aggregates in a Cosmic Plasma Environment

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The electric charge on an aggregate is a major component in understanding an aggregate's coagulation and growth behaviors [1]. Aggregates found in protoplanetary disks are the building blocks of protoplanets and the charge on these dust grains may affect how these aggregates contribute to early planet formation [2,3].

Under isolated conditions, a dust grain in a plasma will charge negatively, because electrons have higher mobility than positive ions in the plasma. However, UV radiation from a nearby star can excite electrons in the grain and cause them to be emitted. This positive current complicates the charging process [1].

Some aggregates charged under conditions that include both plasma and UV radiation exhibit a mixed charging history. For these aggregates, the beginning of the charging history is positive, followed by a "flip-flop," after which the charge is negative. This is similar to the charging pattern found for a spherical dust grain charged by secondary electron emission, as found by Meyer-Vernet [4].

One application of this study is the charging of dust particles in comet tails, as the aggregate sizes studied and charging conditions fall within the range found for cometary dust [5,6]. Understanding the charging behavior of dust in a cometary tail would lead to greater understanding of the dynamics and evolution of dust released near a star.

OML_LOS Model

OML Theory

The current density to a dust grain from plasma species α is

$$J = n_{\alpha\infty} q_\alpha \int f v^3 dv \int \cos(\theta) d\omega$$

where $n_{\alpha\infty}$ is the number density of the species, q_α is the charge on the species, f is the distribution function, assumed to be Maxwellian [7], and θ is the angle between the path of the plasma species and the surface of the dust grain.

LOS Adjustment

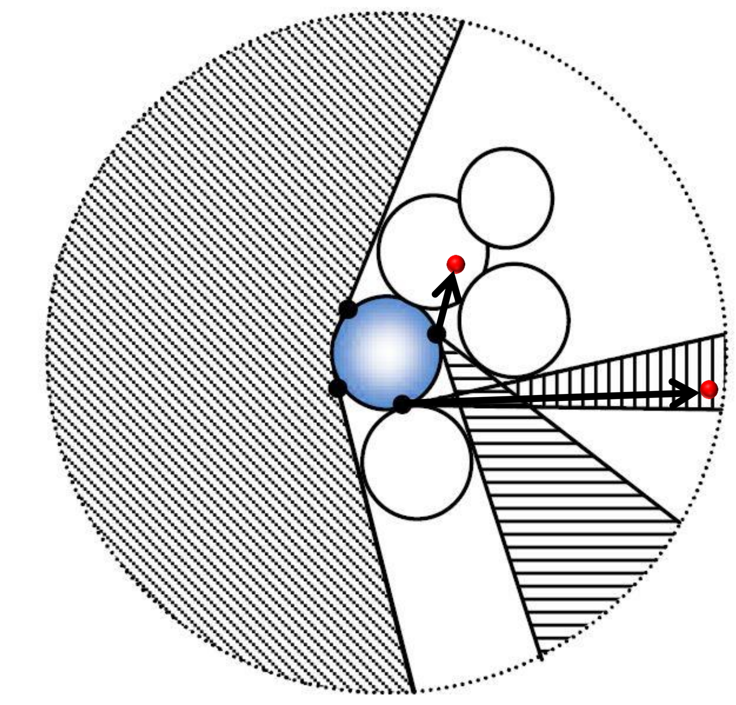
The Line of Sight (LOS) factor is used to determine which orbital paths are unobstructed to points on the surface of an aggregate.

$$J = n_{\alpha\infty} q_\alpha \int f v^3 dv \boxed{\int \cos(\theta) d\omega}$$

The LOS factor replaces the boxed integral in the current density equation.

The LOS factor is determined numerically for points on the surface of the aggregate by finding the open lines of sight that make up the limits of the solid angle [7].

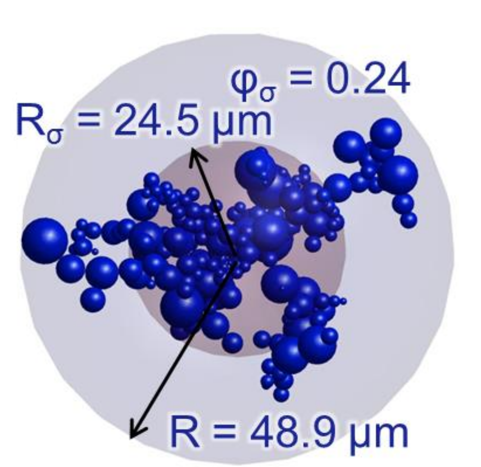
No electron can be emitted from a specific monomer along blocked lines of sight without being recaptured by another monomer within the aggregate, while those emitted along open lines of sight escape from the aggregate.



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 electron would have to be ejected along one of the gray-shaded paths in order to leave the dust aggregate.

Compactness Factor

An effective way to describe the "fluffiness" or "openness" of a dust aggregate is the compactness factor, φ_σ. To calculate this parameter, the projected cross sectional area of the aggregate is found for many orientations, and the average radius of these projections, R_σ, is taken. The compactness factor is calculated using the ratio of the actual volume of the dust aggregate versus the volume of a sphere with radius R_σ [7].



$$\varphi_\sigma = \frac{\sum r_i^3}{R_\sigma^3}$$

Compactness factor, where r_i is the radius of the ith monomer and R_σ is the radius of the average projected cross section.

Variation of Parameters

Over 500 aggregates were studied under the conditions for a hydrogen plasma at 1 AU with density $n_{e,i} = 6 \times 10^6$ m^{-3} and temperature $T_{e,i} = 2 \times 10^5$ K [8].

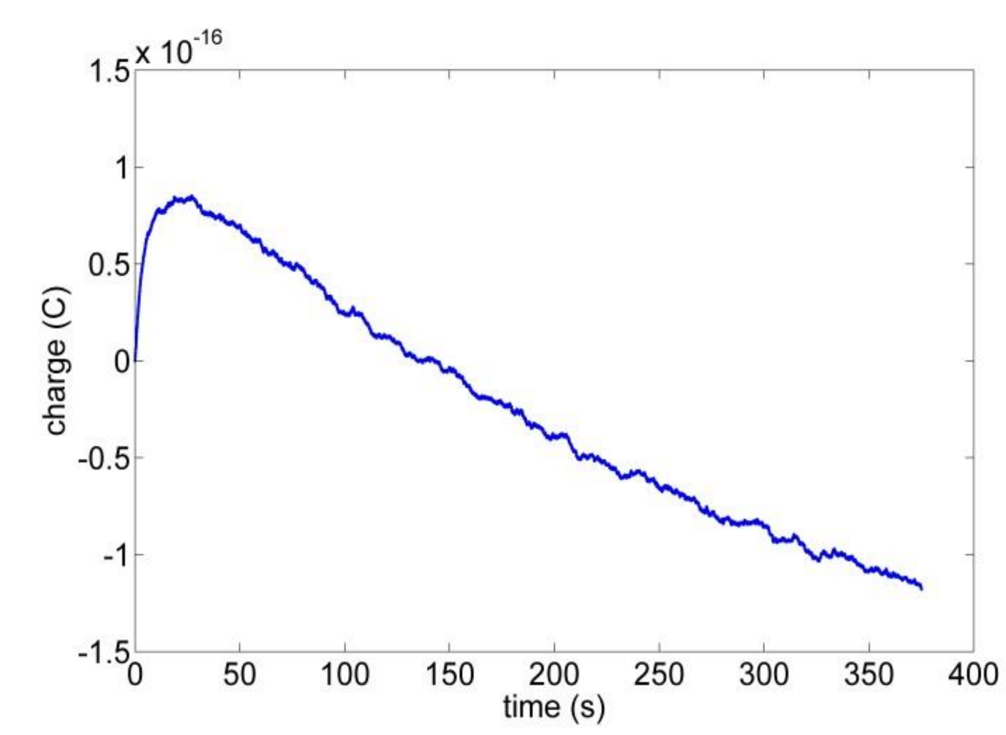
- Aggregate sizes range from 2-20 spherical monomers
- Compactness factors range from $0.457 \le \varphi_\sigma \le 0.988$
- Silicate monomer radii range from 0.5 – 5.0 × 10^{-6} m

The following values were used for the integrated photon current.

5×10^{12} m^{-2}s^{-1}
6×10^{12} m^{-2}s^{-1}
7×10^{12} m^{-2}s^{-1}
8×10^{12} m^{-2}s^{-1}
9×10^{12} m^{-2}s^{-1}
1×10^{13} m^{-2}s^{-1}
1.5×10^{13} m^{-2}s^{-1}

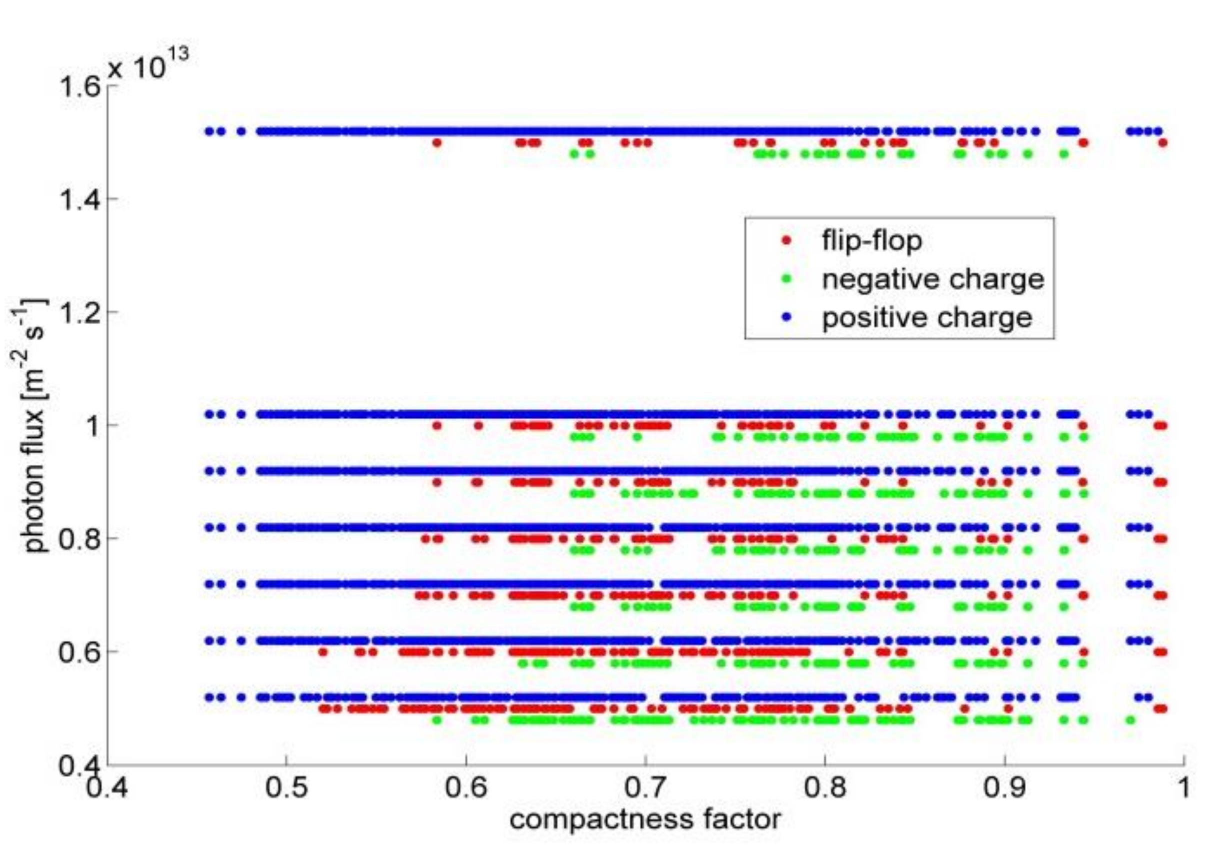
The Flip-Flop

The charging history for this aggregate of size 15 monomers and compactness factor φ_σ = 0.582 exhibits the flip-flop effect. The integrated photon current of the UV radiation is 5 x 10^{12} m^{-2}s^{-1}.

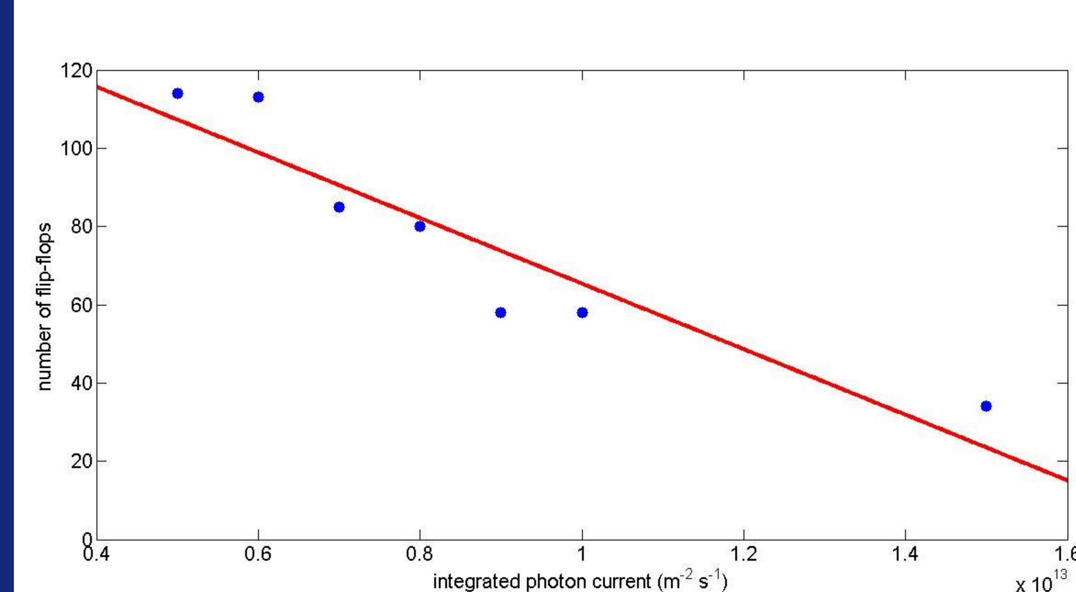


Results by Charging History

The aggregates charged are separated by charging history, offset in the y-direction. The integrated photon current of the UV radiation is plotted against the compactness factor of the individual aggregate.



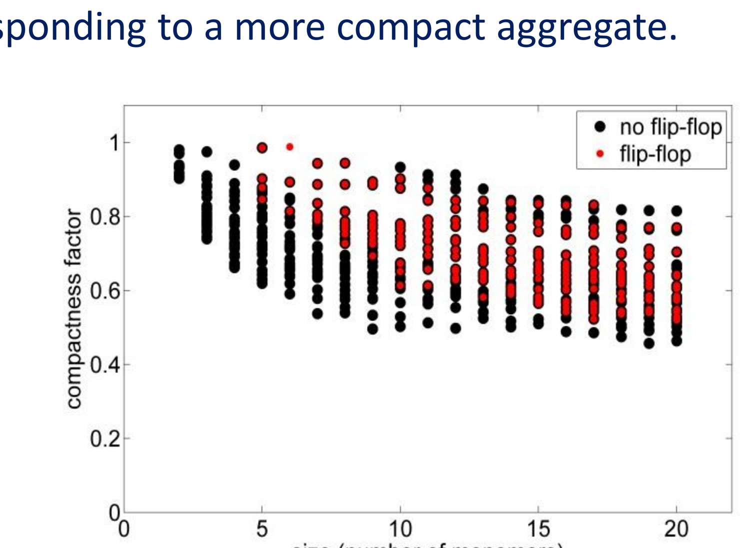
Flip-Flop Depends on Photon Current



For the given plasma parameters, the frequency of the occurrence of the flip-flop effect demonstrates a negative relationship with the integrated photon current of the UV radiation.

Flip-Flop and Compactness

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



Conclusions and Future Work

The flip-flop generally occurs for a lower photon current density. At the lower photon current densities, the flip-flop to occurred for a wide range of compactness factors.

Previous research has shown that the charge on a dust grain affects its coagulation and growth [2-3,7], so the effects of a mixed charging history on the growth of a dust grain should be examined.

Additionally, it would be worthwhile to conduct a similar study for aggregates made up of a mixture of spherical and ellipsoidal monomers, which may be more physically accurate than aggregates of entirely spherical monomers.

References

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