Investigation of dusty plasma effects on radio frequency emissions generated by hypervelocity impacts on spacecraft

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Spacecraft are routinely impacted by macroscopic particles such as meteoroids and space debris, which can be travelling tens of km/s. These impacts are referred to as hypervelocity because the impactor travels faster than speed of sound in the target material, causing a shock wave and pressure stresses greater than the material strength. On impact, these particles and part of the target material vaporize and ionize, forming a dense plasma plume that expands into the vacuum. As the plasma expands, differing species mobilities lead to charge separation, resulting in oscillations. This generates both high-frequency emissions at the electron plasma frequency and broad spectrum emissions in the radio frequency (RF) range. The RF component in particular may include a strong electromagnetic pulse (EMP) that can harm spacecraft electronics, potentially resulting in anomalies or failure.

The post-impact state and degree of ionization strongly depends on the impactor and target materials, and the size and velocity of the impactor. Depending on the impact conditions, the ejected material does not fully ionize and consists of a mixture of plasma, neutral vapor, and condensed phase ejecta. This condensed phase component may acquire a surface charge, leading to dusty plasma effects. Surface charging of ejecta been suggested as a source of macroscopic charge separation and field production. Understanding how attachment affects the plasma expansion process is of particular importance in interpreting the results of light gas gun hypervelocity impact experiments.

To model these complex plasma effects, we first extend an analytical expansion model to account for electron depletion due to ejecta charging. We then describe a dust charging model based on orbital motion limited (OML) theory to model charging, heating, and ablation of ejecta due to interactions with the impact plasma. Finally, we develop a kinetic plasma expansion model that incorporates the effects of charge attachment and interactions with the neutral background, and apply this model to study electromagnetic field production under conditions representative of the post-impact environment.