Theory and experiments characterizing hypervelocity impact plasmas: Toward weatherproof spacecraft systems

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Space weather, including solar activity and background plasma, sets up spacecraft conditions that can magnify the threat from hypervelocity impacts. Hypervelocity impactors include both meteoroids, traveling between 11 and 72 km/s, and orbital debris, with typical impact speeds of 10 km/s. When an impactor encounters a spacecraft, its kinetic energy is converted over a very short timescale into energy of vaporization and ionization, resulting in a small, dense plasma. This plasma can produce radio frequency (RF) emission, causing electrical anomalies within the spacecraft.

In order to study this phenomenon, we conducted ground-based experiments to study hypervelocity impact plasmas using a Van de Graaff dust accelerator. Iron projectiles ranging from 10^{-16} g to 10^{-11} g were fired at speeds of up to 70 km/s into a variety of target materials under a range of surface charging conditions representative of space weather effects. Impact plasmas associated with bare metal targets as well as spacecraft materials were studied. Plasma expansion models were developed to determine the composition and temperature of the impact plasma, shedding light on the plasma dynamics that can lead to spacecraft electrical anomalies. The dependence of these plasma properties on target material, impact speed, and surface charge was analyzed.

Our work includes three major results. First, the initial temperature of the impact plasma is at least an order of magnitude lower than previously reported, providing conditions more favorable for sustained RF emission. Second, the composition of impact plasmas from glass targets, unlike that of impact plasmas from tungsten, has low dependence on impact speed, indicating a charge production mechanism that is significant down to orbital debris speeds. Finally, negative ion formation has a strong dependence on target material. These new results can inform the design and operation of spacecraft in order to mitigate future impact-related space weather anomalies and failures.