Hypervelocity Impact Plasma Measurements and Simulations

S. Close (1), N. Lee (1), A. Fletcher (2), A. Goel (3), A. Nuttall (1), M. Hew (1), P. Tarantino (1), I. Linscott (1)
(1) Stanford University (2) Massachusetts Institute of Technology (3) California Institute of Technology

Hypervelocity micro particles, including meteoroids and space debris with masses < 1 ng, routinely impact spacecraft. Upon impact, a hypervelocity particle, defined as a particle with a speed greater than the speed of sound in the material (~5–10 km/s), produces plasma with a density that is approximately that of the solid material (>10^{27} m^{-3}). The temperature is relatively cool and thus the plasma is considered non-ideal. Because of the strong pressure gradient relative to the background vacuum, the plasma expands at approximately the isothermal sound speed. During this process the density drops and the plasma transition from non-ideal to ideal and collisional to collisionless. This plasma, with a charge separation commensurate with different species mobilities, can produce a strong electromagnetic pulse (EMP) with a broad frequency spectrum. Subsequent plasma oscillations resulting from instabilities can also emit significant power and may be responsible for many reported satellite anomalies.

We present theory and recent results from ground-based impact tests aimed at characterizing hypervelocity impact plasma. We also show results from particle-in-cell (PIC) and computational fluid dynamics (CFD) simulations that allow us to extrapolate to regimes not currently possible with ground-based technology in order to predict the effect of meteoroid impacts on spacecraft. We show that significant impact-produced radio frequency (RF) emissions occurred in frequencies ranging from VHF through L-band and that these emissions were highly correlated with fast (>20 km/s) impacts that produced a fully ionized plasma.

Figure 1 shows representative radio frequency data at 315 MHz and 916 MHz collected using patch antennas at the Max Planck Van de Graaff accelerator in 2011. These data demonstrate a dependence on the emission strength and characteristics as a function of impact velocity. In particular, impactors with high velocity (>20 km/s) demonstrate a strong emission at 916 MHz that is not detected for lower velocity impacts. This velocity threshold is also where the plasma transitions from partly to fully ionized.

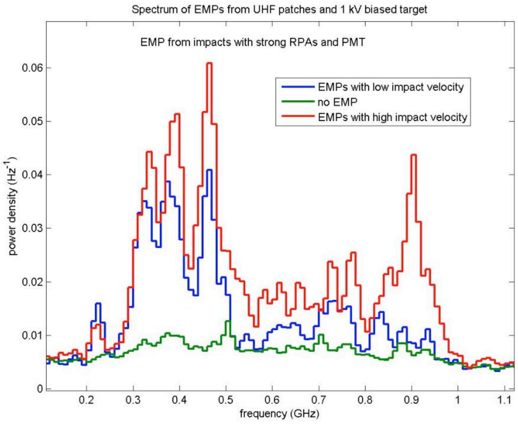

Figure 1. Radio frequency emission for high and low velocity meteoroid impacts on a biased impact target. This plot shows accumulated/normalized RF power density for [X] total impact events (in red), and partitioned into the power density contributed by impacts above and below 20 km/s (in blue and red, respectively)