URSI GASS 2023, Sapporo, Japan, 19 – 26 August 2023

Analysis of Electromagnetic Waves Generated From Simulated Hypervelocity Impact Plasmas for Spacecraft Threat Assessment

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In the space environment, spacecraft are impacted by a higher flux of less massive particles, such as micrometeoroids and debris, compared to larger impactors [1]. These smaller impactors have velocities typically greater than 11 km/s. Due to their high kinetic energy, these hypervelocity impacts can ablate the impactor and spacecraft surface, leading to vaporization and ionization of the material, forming a plasma. Under certain conditions, radio frequency (RF) waves are generated from the hypervelocity impact [1, 2]. This emission is suggested to be a possible cause of electrical damage and spacecraft failure.

This work investigates the behavior of electromagnetic pulses (EMPs) generated by hypervelocity impact plasmas with a 2D discontinuous Galerkin particle-in-cell (DG-PIC) model. This differs from previous models by including perfectly matched layers at the boundary, allowing for longer simulations without expanding the computational domain. Figure 1 shows that EMP can be spontaneously generated after plasma production from hypervelocity impacts. This EMP is nearly (but not perfectly) circular, radiating from the point of the plasma with the highest density. Furthermore, we have concluded that the EMP has characteristics similar to waves emitted by antennas; waves closer to the plasma source will decay similarly to waves in the Fresnel region of an antenna, while waves farther away decay similarly to far-field region waves, *i.e.* proportional to the inverse of the distance. However, antenna theory cannot be applied to these plasmas, as the theoretical boundaries for the near-field, Fresnel, and far-field regions differ from what is observed in simulations. Furthermore, comparisons with experiments reveal discrepancies with simulations and theory which we attribute to the effects of charged impact surfaces. This motivates future work to improve simulation capabilities by including charged spacecraft surfaces, which can introduce background electric fields. With a combination of simulation and theory, we are able to investigate the behavior of the EMP and provides a cause of possible electrical damage on spacecraft.

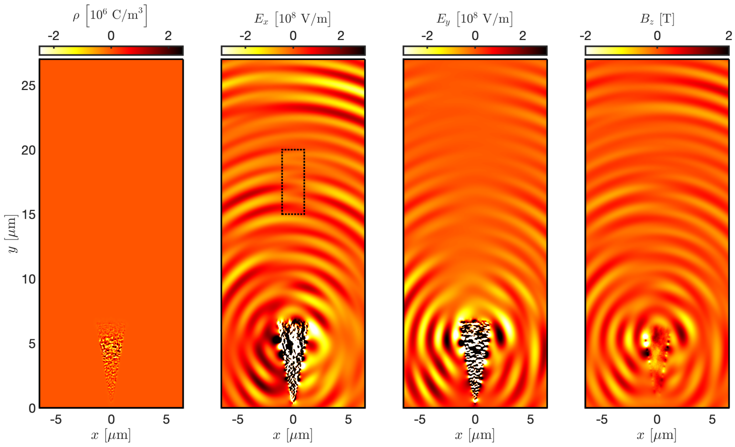

Figure 1. Charge density ρ, electric fields E_x and E_y, and magnetic field B_z at time $t = 0.1$ ps. The dotted black box highlights a region where the EMP is not perfectly circular.

References

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