Modeling Hypervelocity Impact RF Emission
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Introduction

The space environment can be a more hazardous site for spacecraft than previously thought. Dust particles, traveling at upwards of 70 km/s, strike satellites and space vehicles. Upon impact, both projectile and spacecraft materials ionize, resulting in an expanding plasma that emits a radio frequency (RF) wave. This propagating RF wave may interfere with onboard sensors and equipment and is potentially the source of unexplained electronic anomalies, several of which prevent spacecraft from further operations.

Hypervelocity Impact Experiment

To verify and understand this phenomenon, hypervelocity impact experiments were conducted at the Max Planck Institute in Heidelberg, Germany. Using their Van de Graaff generator and vacuum chamber, iron dust particles were accelerated at spacecraft targets while 315 MHz and 916 MHz patch antennas measured the RF emission. These are the first experiments to measure RF from a plasma due to an impacting particle.

Modeling the Emission Process

A model of an oscillating plasma RF emission process was created to replicate the experimental impacts. An important variable in the modeling process is the initial plasma scale length which is thought to lie within three regimes: crater depth (10^{-5}-10^{-6}), local thermodynamic equilibrium (10^{-4}-10^{-3}), and Debye length (10^{-12}-10^{-10}). These are separated by several orders of magnitude and dictate plasma density, plasma frequency, charge displacements, and electric field calculations. To model the emission process, the expanding plasma is assumed to expand conically with a uniform charge distribution on its surface. Also, the ions are assumed to be moving much slower than the electrons. This allows us to estimate the emission process at each patch antenna as a radiating dipole moving each time step.

Results

The model was computed over the range of possible scale lengths. In order to estimate the correct plasma scale length, the experimental electric field at each patch antenna was compared to the model electric field; the scale length corresponding to the smallest RMS error between the model and data provides the appropriate value. This process was repeated for several experimental data sets of varying mass and velocity. By simultaneously plotting the experimental and modeled results, we see the model matches the 916 MHz patch antenna data well while above the noise and the 315 less so.

Signal Structure

Short-time Fourier Transforms (STFT) as well as Fast Fourier Transforms (FFT) of the data were also being used to parameterize RF emission properties. The STFT can help to provide insight into the time evolution of signal frequencies. On the other hand, the FFT yields a more general frequency reconstruction.

Conclusion

As we varied the initial plasma scale length, comparisons of the data and model suggest the initial plasma scale length corresponds to the upper range of local thermodynamic equilibrium and lower range of crater depth. The initial plasma scale length being much larger than the Debye length suggests the early plasma is quasineutral.

Analyses of the signal structure record definitive peaks near 315 MHz that quickly decay in each of 315MHz patch antennas. However, the 916 MHz patch antennas show a smeared of the signal that persists over time. The FFT’s of each of these signals verify these results since there are distinct amplitude peaks for 315 MHz and a broad range of frequencies with a large relative amplitude for 916 MHz. The source of the wide frequency spectrum is under investigation.

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Bibliography


Further Information

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