High Altitude Re-entry Plasma Emulation Experiment (HARPEE)

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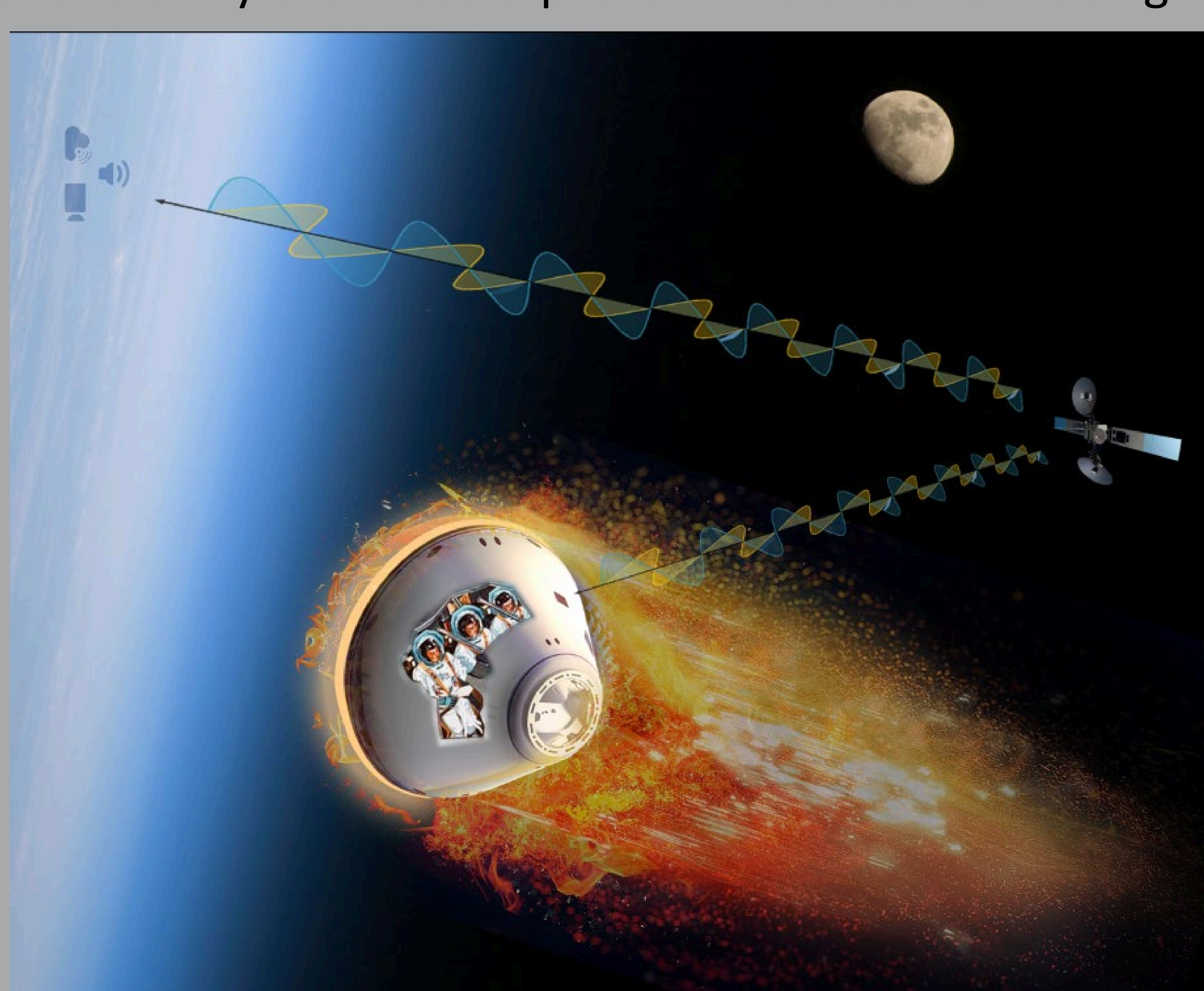
Introduction

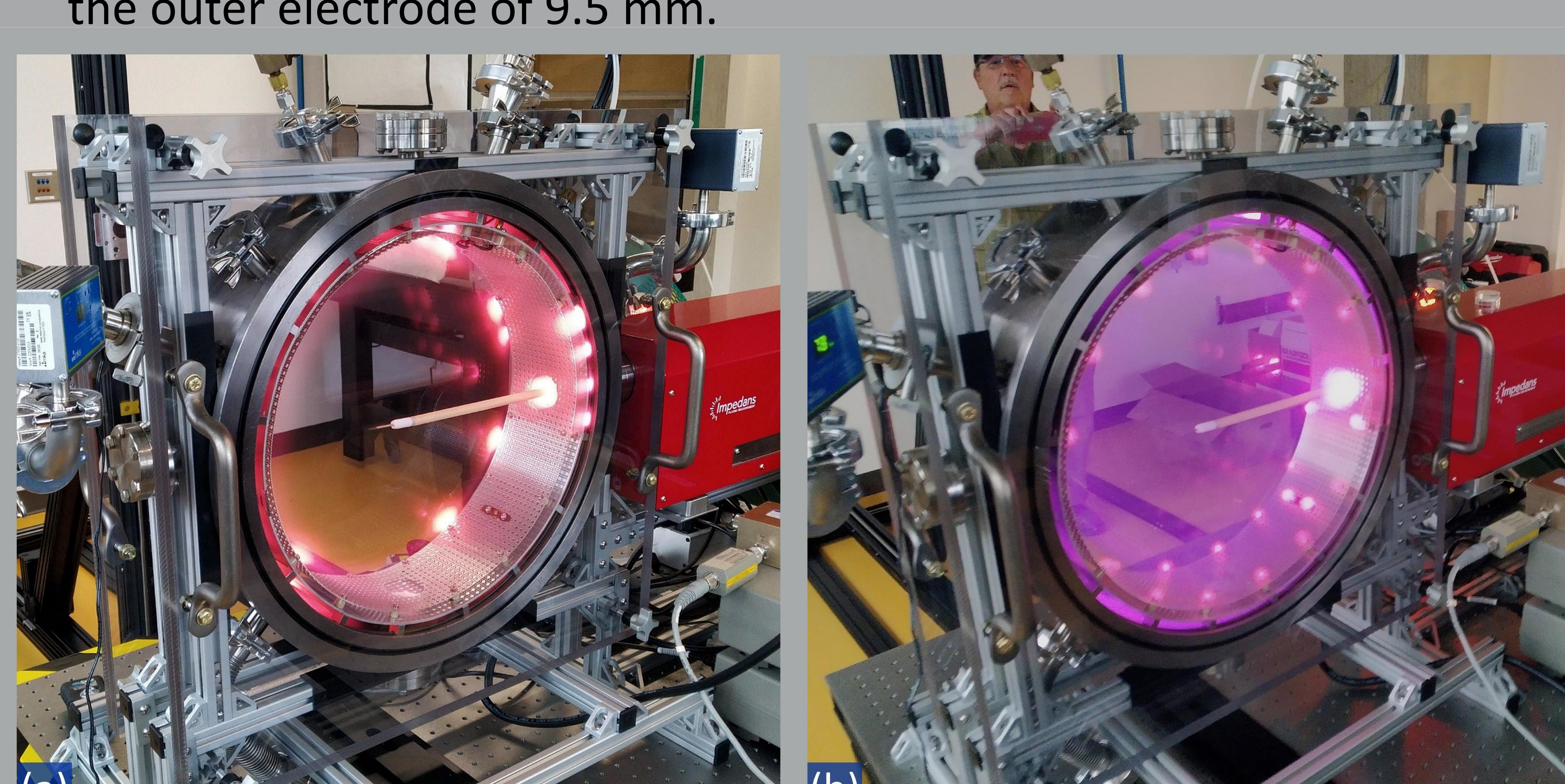
- Radio frequency (RF) *blackout* is the inability to communicate through the layer of kinetically ionized gas (or plasma) that engulfs a vehicle as it descends through an atmosphere at hypersonic speeds.
- Since the 1950s, NASA has tolerated the RF blackout problem for bluntly shaped landing capsules.
- The aerodynamic, delta shape of the Space Shuttle allowed for RF communication with the Tracking and Data Relay Satellite System (TDRSS) through a hole in the plasma layer located near its tail.
- Space shuttle blackout data rates did not typically exceed 192 kbps [1] – only adequate for voice communication.
- Data rates of at least 2 Mbps are required to send system health telemetry to Mission Control [2].
- Having telemetry information immediately prior to a catastrophic atmospheric entry event could prevent mistakes from being repeated.



Depiction of RF communication through a re-entry blackout plasma [artist: T. K. Condrich].

Procedure

- A table-top apparatus has recently been constructed for investigating RF propagation through laboratory plasmas as well as potential mitigation solutions for addressing the RF *blackout* problem.
- A chamber was designed to emulate Earth-based atmospheric re-entry plasmas (occurring at an altitude of ~61 km) with electron densities in the range of 10^{16} m^{-3} to 10^{19} m^{-3} [3]. The design has similarity to that of prior work [4-5].
- Our system makes use of a corrosion-resistant aluminum, coaxial electrode pair with a 0.8-mm thick, inner electrode having a diameter of 386.0 mm of, a length of 100.4 mm, and a distance of separation to the outer electrode of 9.5 mm.

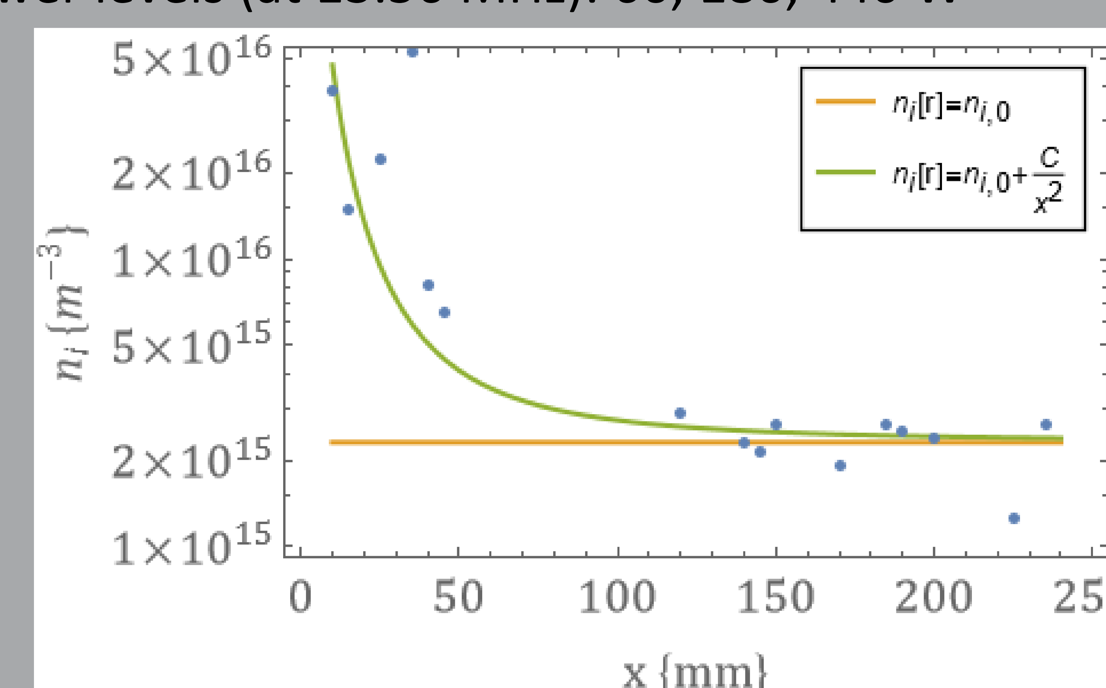


Photographs of HARPEE's first plasmas ignited with power levels of (a) 440 W from a 13.56-MHz generator and (b) 50 W from a 40-kHz generator. In both cases, the base pressure was ~100 mTorr and the input impedance of the electrode pair was not matched to the generator impedance.

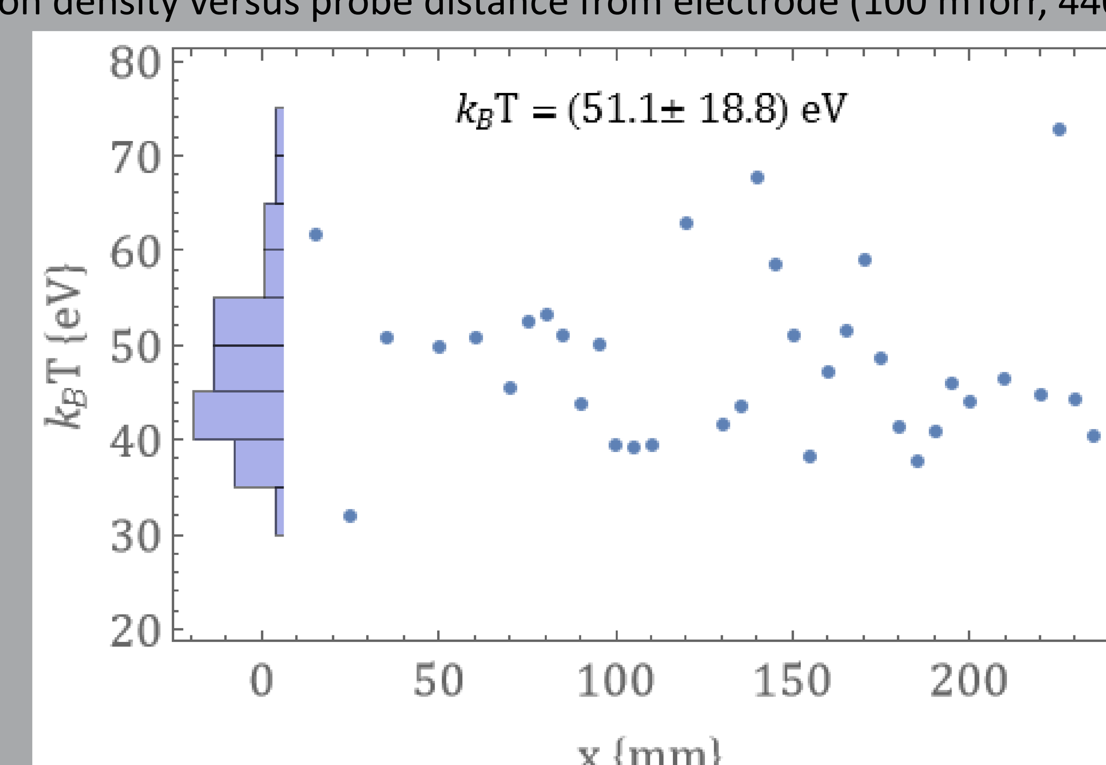
Results

Ion density and temperature were extracted from current versus voltages traces from an Impedans Ltd. *Langmuir Probe System* with a double probe mounted to a linear drive.

- Chamber base pressures (99.9999% N_2): 100, 300, 1000 mTorr
- RF power levels (at 13.56 MHz): 60, 180, 440 W



Ion density versus probe distance from electrode (100 mTorr, 440 W).



Thermal energy of the tail of the electron energy distribution function (EEDF) versus probe distance from electrode (100 mTorr, 440 W).

Conclusion

- Initial, Langmuir double-probe characterizations have been obtained using a 13.56-MHz RF generator as the plasma power source.
- The plasma was concentrated in the vicinity of the electrodes. Drastic improvement in plasma uniformity has been visually observed when using a 40-kHz RF power generator.
- Future experiments will involve investigations of RF propagation through plasmas with improved uniformity.

References

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[3] R. M. Manning, "Analysis of Electromagnetic Wave Propagation in a Magnetized Re-Entry Plasma Sheath Via the Kinetic Equation," NASA/TM–2009-216096 (December 2009).

[4] Y. Min, L. Xiaoping, X. Kai, L. Yanming, and L. Donglin, "A large volume uniform plasma generator for the experiments of electromagnetic wave propagation in plasma." *Phys. Plasmas* **20(1)**, 012101 (2013).

[5] Y. Liang, C. Yuan, R. Gao, J. Jia, G. Kirsanov, V. Bekasov, A. Marin, A. Kudryavtsev, S. Eliseev, and Z. Zhou, "Investigation of Low-Pressure Glow Discharge in a Coaxial Gridded Hollow Cathode," *IEEE Trans. Plasma Sci.*, **44(12)**, 2965-2972 (2016).

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