Crossover of space exploration and fusion research: spacecraft heat shields and meteoroids in the DIII-D tokamak.

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The development of materials that can withstand extreme heat flux environments is crucial for both the realization of fusion energy and the exploration of the solar system. Testing heat shield materials is challenging due to the lack of adequate ground testing facilities. Here, we present a study of carbon ablation in high heat plasma relevant to hypervelocity spacecraft entries that was conducted in the DIII-D tokamak. We showed that conditions in the DIII-D L-mode edge plasma can reproduce the flow velocity and high heat flux experienced during the Galileo probe's entry into the atmosphere of Jupiter.

In this study, three types of experiments were conducted using stationary graphite rods, porous carbon spherical pellets, and glassy carbon spherical pellets [1]. In each case, the mass loss rates as a function of heat flux was determined from an extensive array of spectroscopic measurements and compared against several semi-empirical ablation models obtained from spacecraft flight data [2,3]. Additionally, the experimental results for the pellet trajectories and mass loss rates of the porous and glassy carbon pellets were confirmed using the UEDGE-DUSTT [4] simulations. The coefficients learned from experiment and the semi-empirical models were used in simulations to investigate the ablation of different carbonaceous objects as they enter Jupiter's atmosphere. The results of this study demonstrate that scaling between DIII-D experiments, available flight data, and numerical models can be used to optimize heat shields for future planetary missions.

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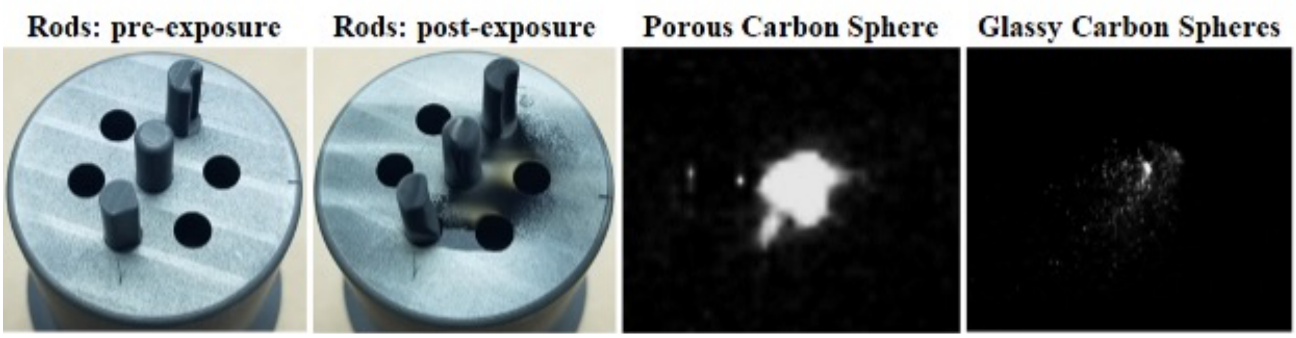

Figure 1. Graphite rods with different geometries before and after exposing them to the hot plasma from the floor of the tokamak (left). Formation of the mushroom-shaped ablation cloud around a porous carbon spherical pellet and uncontrolled spallation of glassy carbon pellets (right).