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Strategies for Rapid Implementation of Interstellar Missions: Precursors and Beyond (4)

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EFFECT OF ISM IMPACTS ON RELATIVISTIC SPACECRAFT

Abstract

As part of the NASA Starlight program collaboration we look at the implications of directed energy driven spacecraft capable of achieving relativistic flight and the issues of such missions impacting the Interstellar Medium (ISM) along their journey. The impact of the spacecraft with the ISM results in a range of material degradation concerns that we have analyzed both analytically and numerically.

Relativistic spacecraft will experience the interstellar medium as a wide, MeV-range beam of composed primarily of hydrogen and helium at constant velocity. A straightforward calculation of the sputtering yield for impacts at these energies shows that it is negligible. However, sputtering is not the only damaging process caused by particle irradiation. Bubble formation, blistering, and exfoliation are meso-scale processes driven by implanted insoluble gas atoms in solids, resulting in macroscopic changes to material properties and, in the case of blistering and exfoliation, material erosion. These processes have been studied extensively in plasma-facing materials research for nuclear fusion devices. In fusion devices, plasma-facing components (PFCs) will accumulate hydrogen and helium directly beneath the plasma-facing surface due to the low incident energy (keV-range) of plasma ions. These near-surface gas atoms interact with material defects and each other and can drive bubble formation, blistering, exfoliation, and nanostructure formation, resulting in decreased material properties and an erosion yield significantly greater than the expected sputtering yield. In a relativistic spacecraft, implanted gas atoms will stop deep beneath the ISM-facing surface, but due to the spacecraft-spanning nature of the exposure, a thin band of spacecraft surface perpendicular to the direction of exposure around the stopping peak will accumulate near-surface gas atoms. Relativistic Hydrogen and Helium at constant velocity will stop in the material at a similar depth, as predicted by Bethe-Bloch stopping and subsequent simulations of the implantation distribution with the binary collision approximation Code F-TRIDYN, leading to a hydrogen-helium-material system similar to that observed in fusion PFCs. However, the fundamental difference in the location of near-surface gas atoms with respect to the direction of exposure means that previously developed models of blistering cannot be used to predict bubble formation or blistering onset. In this work, we will present a model of the bubble formation threshold for materials exposed to the ISM at relativistic speeds. Expected effects on the spacecraft and mitigation strategies will be discussed.