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Mercury's Refractory Exosphere Becomes Sputter-Dominated during Strong Interplanetary Coronal Mass Ejections

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Solar wind ions that reach the surface of Mercury cause surface erosion via sputtering. Among several other processes, sputtering can then contribute to the planet's exosphere [1]. For the refractory elements Ca and Mg, NASA's MESSENGER spacecraft provided extensive observations of their occurrence [2, 3]. However, the dawn-centered characteristics and yearly periodicity of the exospheric emission have been attributed to micrometeoroid impact vaporization (MIV) with no significant contribution from sputtering under regular SW conditions [4-6].

Here we present a simulation study that predicts a significant change in dominant sources of Ca and Mg emission during strong interplanetary coronal mass ejections (ICMEs). We use the AMITIS hybrid plasma code to calculate surface precipitation of solar wind H^+ and He^{++} ions during such strong solar storms [7]. We specifically focus on disappearing dayside magnetosphere (DDM) events [8], where the planet's magnetic field cannot stand off the solar wind pressure and exposure of Mercury's surface increases significantly. Based on the ion impact results from Amitis, we calculate the sputter emission using regolith sputter yields simulated with SDTrimSP-3D and model the formation of the sputtered Ca and Mg exosphere in the Harrah's direct simulation Monte Carlo code (DSMC) [9,10].

Considering the ranges of ICME intensities that have been observed by MESSENGER at Mercury [11], our simulations clearly show that strong ICMEs allow full access of the solar wind to Mercury's surface and increase both the surface precipitation and the sputtering by more than two orders of magnitude. Above a dynamic pressure of around 100 nPa, our calculated sputter rates exceed the surface emission that was reported from MESSENGER and attributed to MIV.

Our DSMC simulations further show that the increased surface erosion rates are also expected to significantly affect the distribution of refractories in the exosphere. Contrary to the dawn-centered MIV emission, the sputtering adds an additional noon-centered emission feature that overwhelms the otherwise preferential dawn emission. The Ca and Mg exospheres show differences in their detailed response to the ICME impact due to the highly efficient photoionization of Ca, which limits the transport of the atoms across the exosphere.

ICME-induced exosphere enhancements as modeled here are expected to be temporary and to last a few hours, due to the highest solar wind pressures typically occurring in the short shock phases of an ICME and the exospheric lifetime of Ca and Mg of similar duration. Such features have not been reported so far, but should be observable similar to exospheric enhancements following meteoroid impacts reported by MESSENGER [12]. Future measurements of such events with BepiColombo and further analysis of the MESSENGER exosphere observations will help understand the response of Mercury's system to ICME impacts and the role of solar wind sputtering in the exosphere formation.

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