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Self-consistent 3D modeling of Mercury's solar wind-surface-exosphere interaction

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Abstract

It can be speculated that the composition of Mercury's exosphere is related to the composition of Mercury's crustal materials. If this relationship is true, then inferences regarding the bulk chemistry of the planet might be made from a thorough exospheric study. The most vexing of all unsolved problems is the uncertainty in the source of each component which depends highly on the solar activity. Mercury's surface, especially its age, origin, evolution and composition are not well known at present, due to the lack of sufficient remote and in situ measurements and observations. Efforts have been carried out to estimate the planet's surface composition by using spectral reflectance measurements in comparison with lab-based spectra of analogue materials. During the past decades optical and near-infrared spectra have been obtained [1]. The infrared spectra of Mercury, combined with laboratory studies of analogue materials, indicate that the rock composition is dominated by feldspars and low iron pyroxene [2].

Around the year 2000 disk resolved measurements also became available [e.g. 3, 4, 5], but the spatial resolution is limited to 200 – 300 km because of atmospheric disturbance [4, 5]. Thus, the results from the ground-based observations have to be interpreted as global averages or at least as averages over a large area on the surface involving several geological units. Where spatially resolved measurements are available (ground- and space-based) they indicate compositional heterogeneity of the surface on the investigated scales [4, 6, 7]. Thus, our mineralogical model of Mercury's surface, which is used in this study, can only be seen as a global average.

We start out with a set of minerals and their abundances. From this we calculate the elemental abundance of the surface and the sputter yields for all elements for the chosen mineral abundances. The sputter yields and the elemental abundances are inputs to the calculation of the exospheric densities [8]. This model serves as a tool to estimate densities of species in the exosphere depending on the release mechanism and the associated physical parameters quantitatively describing the particle release from the surface.

The precipitation of the solar wind protons on the surface of Mercury is studied by 3D global hybrid model [9]. In the three-dimensional self-consistent hybrid model (ions are particles, electrons are handled a fluid) model ions can hit the surface of the planet. The response of the precipitation to ordinary solar wind conditions and a typical CME-Mercury collision to surface sputtering of various elements and the refilling of the planets exosphere is studied. The participating plasma fluxes are used to produce a surface composition related sputtering map as a function of latitude and longitude. The released elements produce various velocity distributions which are used as input for a 3-D exosphere model. We show the effects of expected exosphere refilling by various surface elements such as O, Na, Mg, Al, Si, P, S, K, Ca, Ti, Fe, Zn. Finally we compare our 3-D exosphere with previous 1D model results. Our results show that Mercury's exosphere should be efficiently refilled by sputter-induced surface elements after a solar CME collides with the planet. In such a case the magnetosphere cannot protect the planet's surface which results in large areas where CME particles can act as sputter agents and an efficient exosphere refilling by various surface elements.

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