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Ion weathering of the surface of the Martian moon Phobos as inferred from MAVEN ion observations

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Phobos is the closest of the two moons of Mars and its surface is not only exposed to ions coming from the solar wind (mainly protons H^+ and alpha particles He^{++}), but is also bombarded by ions coming from Mars itself (mainly atomic and molecular oxygen ions O^+ and O_2^+). Space weathering at Phobos would be intimately linked to the planetary atmospheric escape if Martian ions significantly alter the properties of the moon's surface.

In this presentation, the long-term averaged ion environment seen by the surface of Phobos (omnidirectional and directional fluxes, and composition) is constructed from 4 years of ion measurements gathered in-situ by the NASA MAVEN mission. The MAVEN spacecraft repeatedly crossed the orbit of Phobos from January 2015 to February 2019 and was uniquely suited to unprecedentedly observe ions there with its three ion instruments: SWIA, STATIC, and SEP. These three experiments together constrain the entire range of ion kinetic energies that impact Phobos, from cold ions of a few eV to solar energetic ions of several MeV. In addition, the STATIC instrument (1 eV to 30 keV) is able to discriminate the mass of the observed ions by measuring their time-of-flight. This capability is important to understand the weathering of the surface of Phobos, as for instance the effect on the surface of a precipitating heavy molecular oxygen ion is significantly different from the one of a proton.

The relative importance of Martian and solar wind ions is in turn assessed from the observed ion omnidirectional fluxes for two space weathering effects: (1) surface sputtering, which is computed by using ion specie and energy-dependent sputtering yields available in the literature and (2) the production of vacancies inside the regolith grains, which is estimated with the SRIM software. (1) We find that Martian ions dominate solar wind ions in sputtering the surface of Phobos when the moon crosses the Martian magnetotail. We also reveal that molecular oxygen O_2^+ ions sputter as much as or more from the surface of Phobos than atomic O^+ ions. (2) Martian heavy ions significantly contribute to the production of vacancies in the uppermost nanometer of Phobos regolith grains. Finally, MAVEN directional flux measurements are used to study the anisotropy of the bombarding ion fluxes at Phobos, which we find implies an asymmetric weathering of the surface: the near side (always facing Mars) is primarily weathered by Martian ions, whereas the far side is primarily altered by solar wind ions.