Asymmetric ion bombardment and weathering of the Martian moon Phobos

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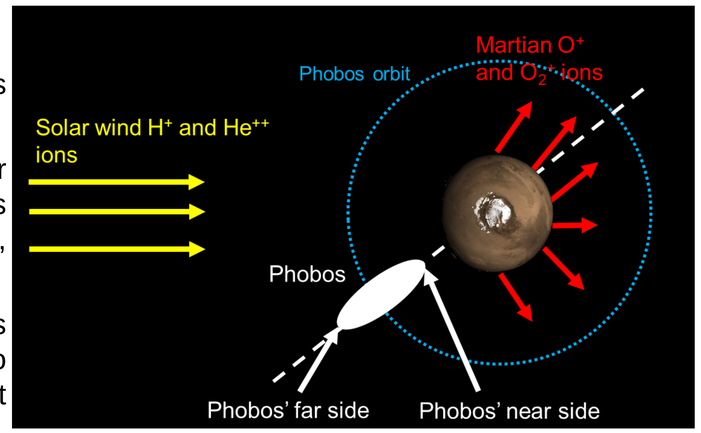
Key points

- Ion bombardment and weathering of Phobos' surface are highly asymmetric between the moon's near side (pointing towards Mars) and far side
- O^+ and O_2^+ ions escaping the atmosphere of Mars are implanted mainly on the near side, where they accelerate ion weathering by a factor of 2

1. Context: Ions impacting the surface of Phobos and the MAVEN STATIC instrument

- Phobos is tidally locked: it always points its near side towards Mars.
- Phobos is impacted by not only solar wind ions (H^+, He^{++}), but also by ions escaping the atmosphere of Mars (O^+, O_2^+).
- The NASA MAVEN mission apoapsis was right at Phobos' altitude from 2015 to 2019. All longitudes along the moon's orbit were explored by MAVEN.



- Onboard MAVEN, the SupraThermal and Thermal Ion Composition instrument (STATIC) observes <30 keV/q ions. STATIC measures ion time of flight, and can therefore separate solar wind ions from Martian ions.

2. Motivations

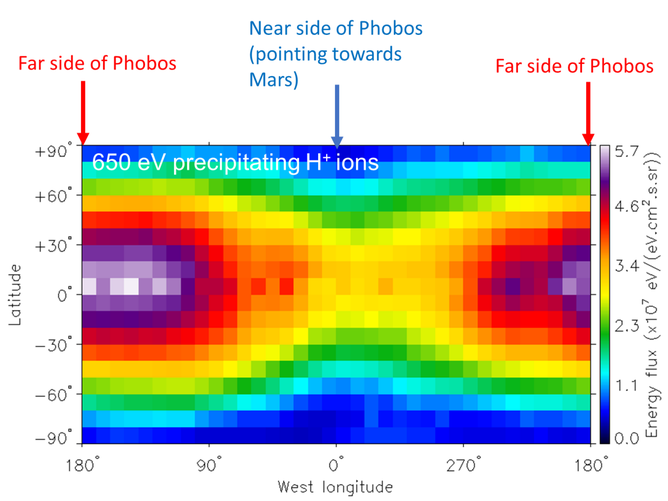
- A previous study [Nénon et al., JGR 2019] analyzed the long-term averaged omnidirectional flux of ions impacting Phobos, and found that Martian ions significantly sputter the moon's surface compared to solar wind ions. The moon's surface was treated as a whole.
- Are ion precipitating fluxes inhomogenous on the surface of Phobos? What are the implications for ion weathering and future sample return missions?

3. Asymmetric ion bombardment of Phobos' surface

We aggregate all direction resolved ion flux measurements obtained by MAVEN STATIC near the orbit of Phobos, and determine this way the long-term averaged energy spectrum and anisotropy of precipitating ions.

Each point on Phobos' surface is assumed to be impacted by the above 2π sr ion flux.

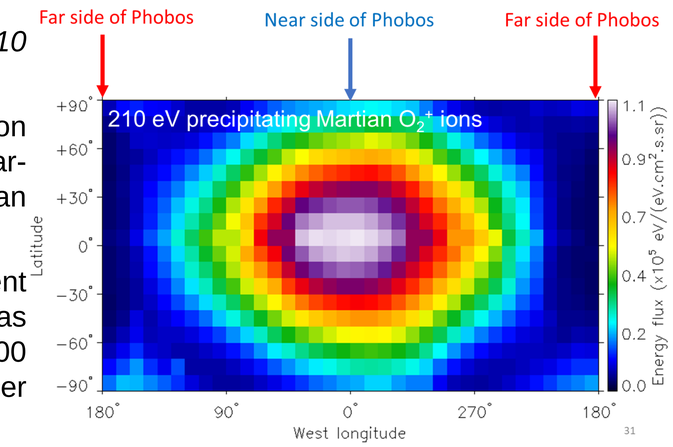
***Figure 1**: The long-term averaged flux of precipitating 650 eV protons, as a function of west longitude and latitude on Phobos' surface.*



3. Asymmetric ion bombardment of Phobos' surface

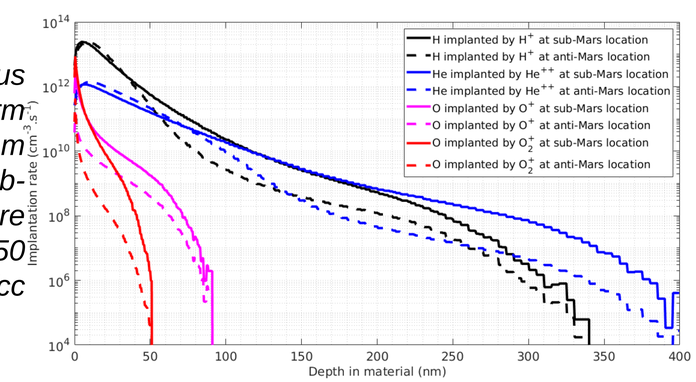
***Figure 2**: The long-term averaged flux of 210 eV O_2^+ ions impacting Phobos' surface.*

- Solar wind ions primarily impact Phobos on its far side (*Figure 1*). However, the near-side/far-side asymmetry is small, with an ion flux ratio of ~3.
- A strong asymmetry in the bombardment by Martian O^+ and O_2^+ ions is revealed, as fluxes on the near side are 20 to 100 (depends on the ion energy) times higher than on the far side (*Figure 2*).



4. Contamination of Phobos' near side by atmospheric ions

***Figure 3**: Implantation rate of exogenous atoms within Phobos' regolith. Long-term averaged ion fluxes determined from MAVEN-STATIC observations at the sub-Mars and anti-Mars locations were convolved with SRIM simulations. Fo50 olivine ($MgFeSiO_4$) with a density of 3.8 g/cc is used.*



- **Exogenous atoms coming from the atmosphere of Mars are implanted inside the near-side regolith grains of Phobos.** Transport of ions in matter simulations show that they penetrate down to a depth of a few 10s of nanometers (*Figure 3*).
- **It can therefore be anticipated that the oxygen, carbon and noble gas isotopic composition of future Phobos near-side samples is altered by atmospheric ions,** as seen in lunar samples contaminated by terrestrial ions (Ozima et al, Nature 2005; Terada et al., Nature Astronomy 2017).
- Phobos' near side regolith contains **a unique archive of the current and past atmosphere of Mars**.

5. Asymmetric ion weathering

Ion sputtering alters the surface composition and sources the putative Phobos neutral torus. Using energy and specie dependent sputtering yields computed with SRIM, we find that:

- The flux of neutrals ejected from the near side is 1.4 times higher than on the far side.
- **Martian ions accelerate the sputtering of Phobos' near side by a factor of 2.**

Atomic displacements and material amorphization:

- Martian ions significantly contribute to atomic displacements within Phobos' near side grains, so that **they accelerate the creation of 10s nanometer thick amorphous rims by a factor of 2.**