In Situ Characterization of Elemental Compositions for Small Bodies Throughout the Solar System

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Introduction: Asteroids and moons are too small to maintain a significant atmosphere, and therefore they are directly exposed to ionizing radiation from both the central star and, in some cases, magnetospheric plasma. Impacts of 0.1-10 keV ions, typical for the dominant low-Z component of the solar wind and magnetospheric ions, eject positive and negative secondary ions from regolith minerals, in addition to sputtered neutrals. Mass, charge, and energy analysis of the sputtered secondary ions is highly diagnostic of the irradiated surface. A robust and sensitive technique for obtaining elemental composition of surfaces in high vacuum environments is the collection and analysis of secondary ions ejected due to solar wind and magnetosphere ion sputtering and meteorite impacts. First proposed for space based compositional analysis over 30 years ago [Managadze and Sagdeev, 1988; Johnson and Baragiola, 1991], this technique is commonly known in the laboratory as SIMS and can achieve excellent signal to noise ratios due to low ion backgrounds and high detection sensitivities achievable. Additionally, SIMS measurements at small bodies can help resolve whether these bodies harbor any potentially valuable resources for future exploration missions and how the composition of rocky asteroids varies throughout the Solar System.

This work combines laboratory measurements of sputtered secondary ions with Monte Carlo estimates of the total (ion + neutral) sputtering yields and a computational model of ion transport to calculate the density and distribution of sputtered species in the exospheres of small (~1-100 km) bodies. The results will are benchmarked against previous sputtering calculations and ion mass spectrometer measurements from planetary bodies with measured ionospheres, such as the Moon. This study provides the best available estimates of the sputtered secondary-ion fluxes and density distribution around small bodies in the Solar System.

Background: Laboratory work using lunar soils and analog materials has clearly shown that the composition of surfaces can be determined using a compact SIMS instrument to detect sputtered secondary ions [Elphic et al., 1991; Dukes and Baragiola, 2015]. These studies showed that secondary ions are not sputtered in direct relation to the elemental concentration at the surface but depend on the elemental ionization potentials of the various species. Using relative secondary ion yields measured in sputtering experiments with known surface composition - such as a returned sample from the Martian moons - the observed secondary ion fluxes can be converted into relative abundances of the elements in the target material [Schaible et al., 2017]. Additional measurements have shown that SIMS can detect the trace presence of OH in lunar samples. Using sputtered flux estimates obtained from experiments and Monte Carlo modeling of solar wind sputtering [Elphic et al., 1991; Schaible et al., 2017], it has been demonstrated that the solar wind creates sufficient secondary ions for SIMS to provide successful composition measurements at airless bodies such as Phobos and Deimos

Results: A combined computational and experimental approach has been used in order to better constrain the solar wind sputtering rates of small, rocky bodies. First, a series of SIMS measurements in the laboratory were carried out to determine the relative ion sputtering ratios from several lunar samples of known composition. Then, using Monte Carlo simulations of sputtering due to both solar wind and magnetosphere ions under measured ion energy distributions to determine the total sputtering yields, the total abundance and relative composition of sputtered ions can be determined for an arbitrary small body. Figure 1.1 shows secondary ion sputtering composition ratios for several compositional analogs to solar system bodies. Finally, we will utilize analytical codes to produce ion flux and energy spectrum at any position above the bodies for assumed configurations of the solar wind velocity, IMF, and initial surface fluxes.

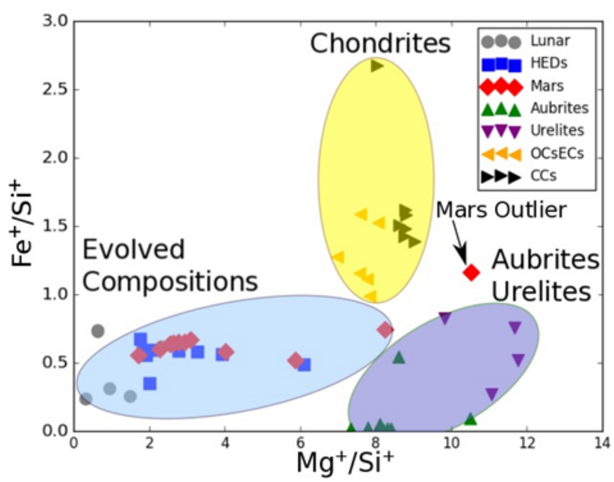

Figure 1: Sputtered secondary ion ratios for a representative suite of meteorite compositions. The ratios show a clear separation between evolved bodies such as the Moon, Mars, and the Howardite, Eucrite, Diogenite (HEDs) meteorite class and the primitive bodies such as ordinary and enstatite chondrites (OCsECs) and carbonaceous chondrites (CCs).

References: Managadze, G.G. and R.Z. Sagdeev (1988), *Icarus*, 73, 294-302. Johnson, R.E., and R.A. Baragiola (1991), *GRL*, 18(11), 2169–2172. Elphic, R.C. et al. (1991), *GRL*, 18, 216-218. Dukes, C.A. and R.A. Baragiola (2015), *Icarus*, 255, 51-57. Schaible, M.J., et al. (2017), *JGR – Planets*.