Laboratory Simulation of Solar Wind Ions Irradiation on the Surface of Mercury

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Background

Na and He are the two dominant confirmed neutral species in the Hermean exosphere. The solar wind is the source of the He, while the Na source is predicted to be plagioclase feldspars on Mercury's surface [1,2]. Observations from the ground [3,4] and from the MESSENGER mission [5,6] find variable enhanced high latitude Na abundance in Mercury's exosphere, suggesting that the Na is due to sputtering by solar wind ions precipitating to the surface through the planet's magnetic cusps.

Studies of the Na exosphere provide clues to the surface mineralogy and are an important constraint for formation models of Mercury. However, current exosphere models [7,8] make questionable assumptions about the ion sputter yield, due to the lack of experimental data for regolith-like loose powders.

Spectrophotometry is a combined analysis of the spectral and photometric properties of a surface [9], enabling understanding composition and regolith structure. MESSENGER's MACSC and MDIS instruments provided spectral and photometric observations. However, to better interpret these observations, we need to understand how solar wind ions affect the spectrophotometry of Na-bearing minerals such as plagioclase feldspars.

Research Objective

Our goal is to improve the interpretation of *in-situ* and remote-sensing data of Mercury through benchmark laboratory studies. We will perform ion-irradiation studies of loose powder analogs of the Hermean regolith and provide quantitative data for the corresponding sputtering yields and spectral changes in the visible to near infrared (0.35 – 2.5 μm). The results will provide needed inputs for Mercury's exosphere and spectrophotometric models.

Science Questions

1. What role do solar wind ions play in the formation of Mercury's sodium exosphere?
2. What fraction of the sputtered Na returns to the surface and what fraction escapes to space?
3. How do solar wind ions affect the spectrophotometric properties of Hermean minerals?
4. How do the measured ion-generated spectrophotometric changes compare to the observed distribution of Mercury's spectrophotometric properties?

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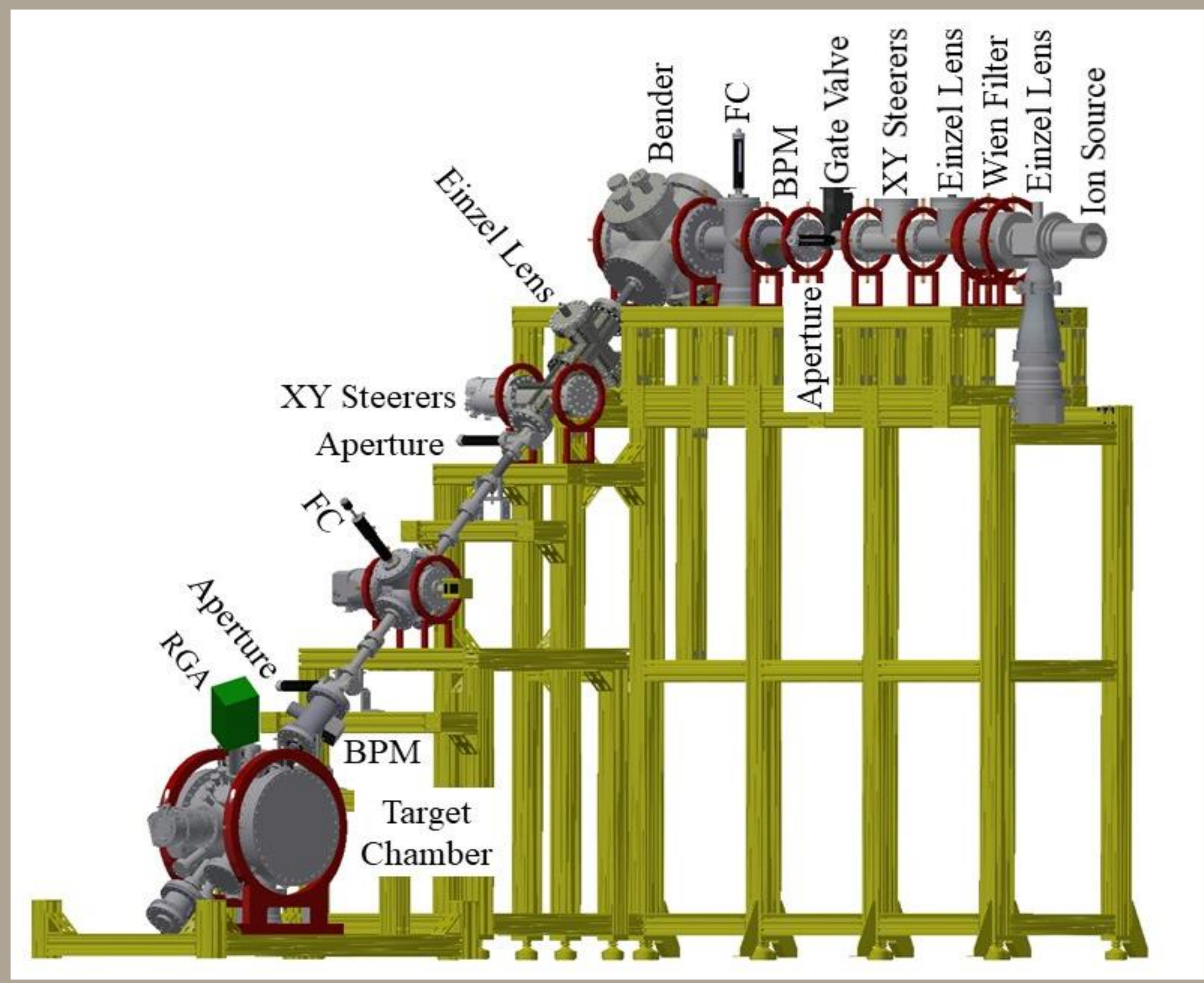
Relevant Publications:

[1] T. J. McCloy et al. (2018), in *The View after MESSENGER*, 176–190. [2] W. E. McClintock et al. (2018), in *The View after MESSENGER*, 371–406. [3] A. E. Potter et al. (1999) *Space Sci.* 47, 1441–1448. [4] A. E. Potter et al. (2002) *Planet. Sci.* 37, 1165–1172. [5] R. J. Vervack et al. (2010) *Science* 329, 672–675. [6] V. Mangano et al. (2015) *Planet. Space Sci.* 115, 102–109. [7] R. M. Killen et al. (2018), in *The View after MESSENGER*, 407–429. [8] D. Gamborino et al. (2019) *Ann. Geophys.* 37, 455–470. [9] B. Hapke (2012) *Theory of Reflectance and Emittance Spectroscopy.*

Experimental Details



A Novel Ion-Beam Apparatus to Simulate Solar Wind Ion Irradiation

- 1 – 20 keV ions: charge-to-mass selection; neutrals/photons exclusion.
- Ultra-high vacuum: beam line ≈ 2×10^{-6} Torr; target chamber ≈ 5×10^{-10} Torr.
- Loose powder samples: horizontally monted.
- Catcher foils surrounding the sample to collect the sputtered particles
- *In-vacuo* and *In-situ* bidirectional reflectance measurements
- Low-energy electron flood gun for charge compensation

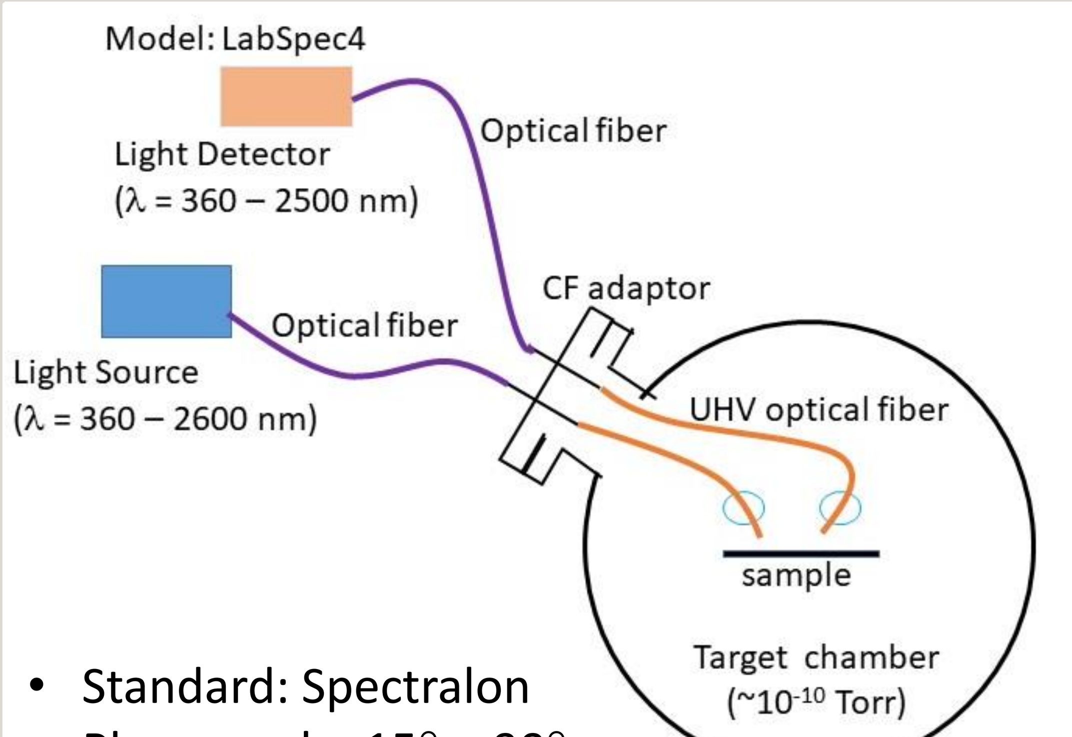
Samples: powders of plagioclase feldspar to simulate Mercury's regolith

Irradiation ion:1 keV H^+ and 4 keV He^+

Irradiation flux: 6×10^{11} H^+ cm^{-2} s^{-1}, and 3×10^{13} He^+ cm^{-2} s^{-1}

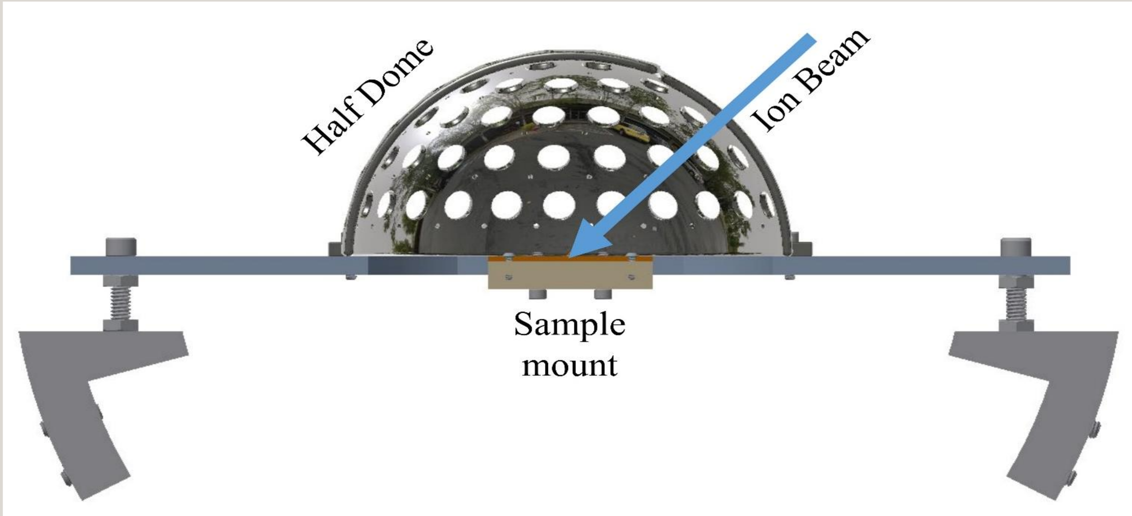
Irradiation fluence: ~10^{17} – 10^{18} ions cm^{-2}

Bidirectional Reflectance Measurements



- Standard: Spectralon
- Phase angle: 15° – 90°
- Polar angle: 15° (no specular reflectance)

Sputter Yield Measurement



Sample mount and half dome holding the catcher foils. The foils are located at the openings in the half dome, not all of which are visible here.

Sputtering Yield: defined as ejected atoms/incidence ions

Total yield and the angular distribution: mass-gain measurements on each of the foils before and after each ion-irradiation, using a high precision, trace metal clean, automated quartz crystal microbalance weighting system.

Elemental sputter yields and the energy distribution: depth profiles of the relative elemental abundances on each foils after irradiation, using synchrotron based X-ray photoelectron spectroscopy .

Conclusions

- We are commissioning a novel ion-irradiation apparatus that allows us to simulate solar wind ion irradiation using regolith-like loose powders.
- We have designed a system to collect the ion-induced sputtered particles using catcher foils.
- The absolute total yields and their angular distributions will be derived by the mass gains of the catcher foils measured with a quartz crystal microbalance weighting system.
- The elemental sputter yields and the energy distribution will be derived based on the stoichiometry of the sputtered atoms on the foils analyzed with synchrotron-based X-ray photoelectron spectroscopy.
- *In-vacuo* and *in-situ* bidirectional reflectance spectra will be performed as a function of ion fluence.
- The measured sputter yields and spectral changes will be incorporated into current exosphere and spectrophotometric models for a better understanding of Mercury's exosphere and surface compositions.