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A detailed look on the interaction of solar wind helium with Mercury's surface in the laboratory

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Motivation

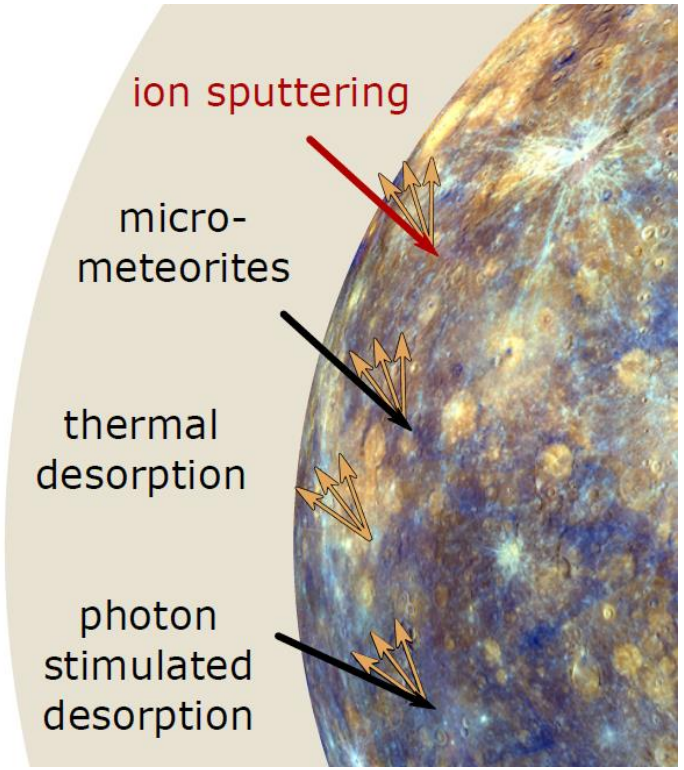


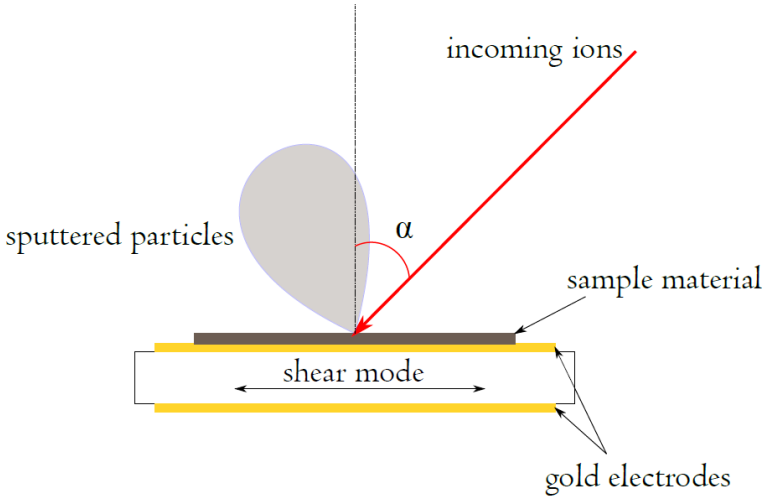
Image of Mercury: NASA

- Several effects alter the surface of airless bodies, called space weathering [1, 2]
- Thin collision-less exospheres are formed
- Solar wind ions are sputtering but can be implanted and stay in the surface
- Implantation and release of these particles can affect both surface structure and exosphere formation [3, 4]

[1] Hapke B.: J. Geophys. Res. Planet., 106, 10039, 2001.
[2] Noble S.K., et al.: Sol. Syst. Res. 37, 31, 2003.
[3] Sasaki S., et al.: Adv. Space Res., 33, 2152, 2004.
[4] Hartle R., et al.: J. Geophys. Res., 80, 3689, 1975.

Experimental techniques

a) Quartz Crystal Microbalance (QCM) irradiations with solar wind He



- Sample irradiated with 4keV $^4He^+$ under normal incidence and at room temperature
- Resonance frequency dependent on mass:

$$\frac{\Delta m}{m_0} = -\frac{\Delta f}{f_0}$$

b) Thermal Desorption Spectroscopy subsequent to the irradiations

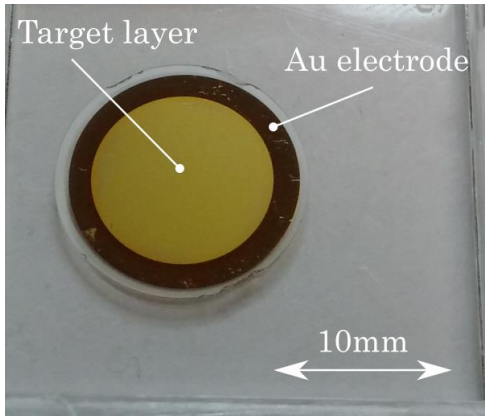
- Sample can be heated up to 700K
- Constant heating ramps used
- Released ^4He detected via Quadrupole Mass Spectrometer (QMA)
- Mass before and after heating can be determined with the QCM
- Experiments performed under Ultra-high vacuum

Sample preparation

Magnesium rich Pyroxene

Pulsed Laser Deposition (PLD)

Target layer on QCM

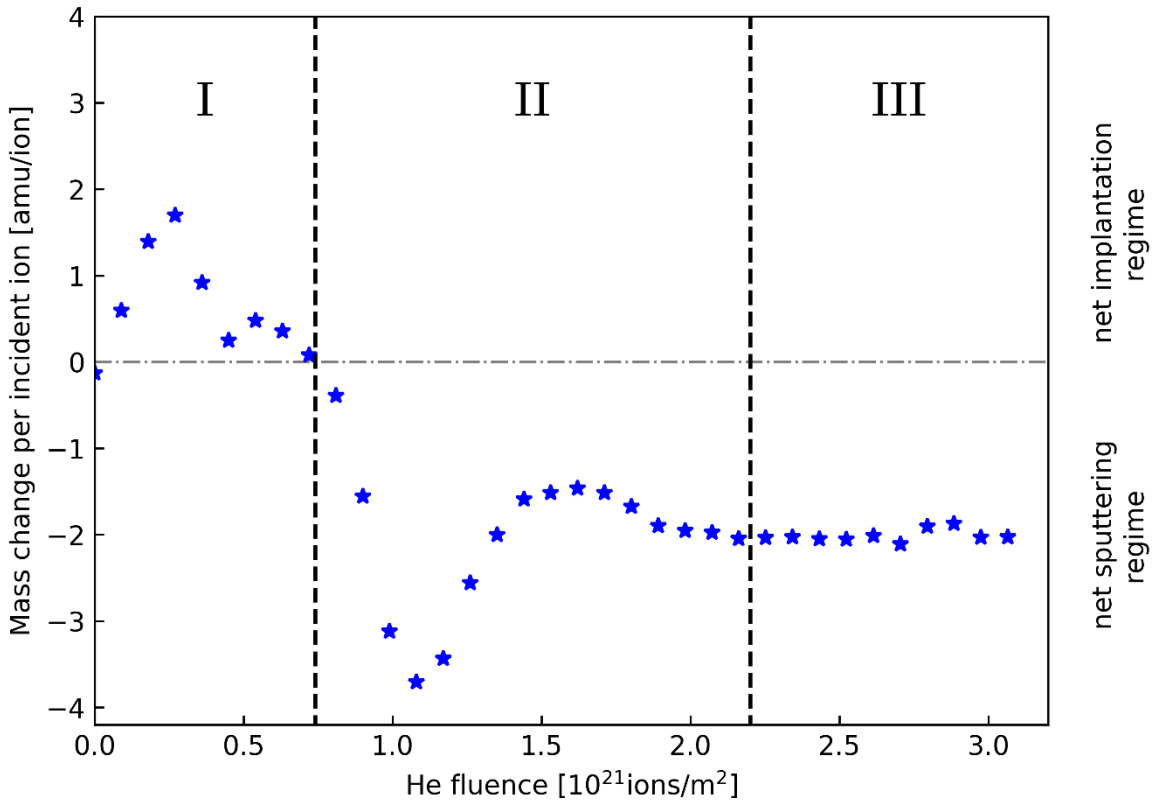


- Elemental composition and thickness of target deducted from combined Rutherford Backscattering Spectrometry (RBS) and coincidence Time-of-flight/Energy Elastic Recoil Detection Analysis (ToF-E ERDA)
- Flat surfaces are observed via Atomic Force Microscope

	H	C	O	Mg	Si	Ca	Fe
[at. %]	1.4	1.1	60.3	8.9	20.5	1.8	6.0

Tab.:Elemental composition from ERDA

Mass change during irradiation



- Net implantation in the beginning (I)
- Region with oscillation in mass change and enhanced release (II)
- Equilibrium reached after 2.2*10^{21} ions/m^2 (III) - some 100 years of solar wind on Mercury [1]
- Assuming constant sputtering, the implanted mass can be calculated

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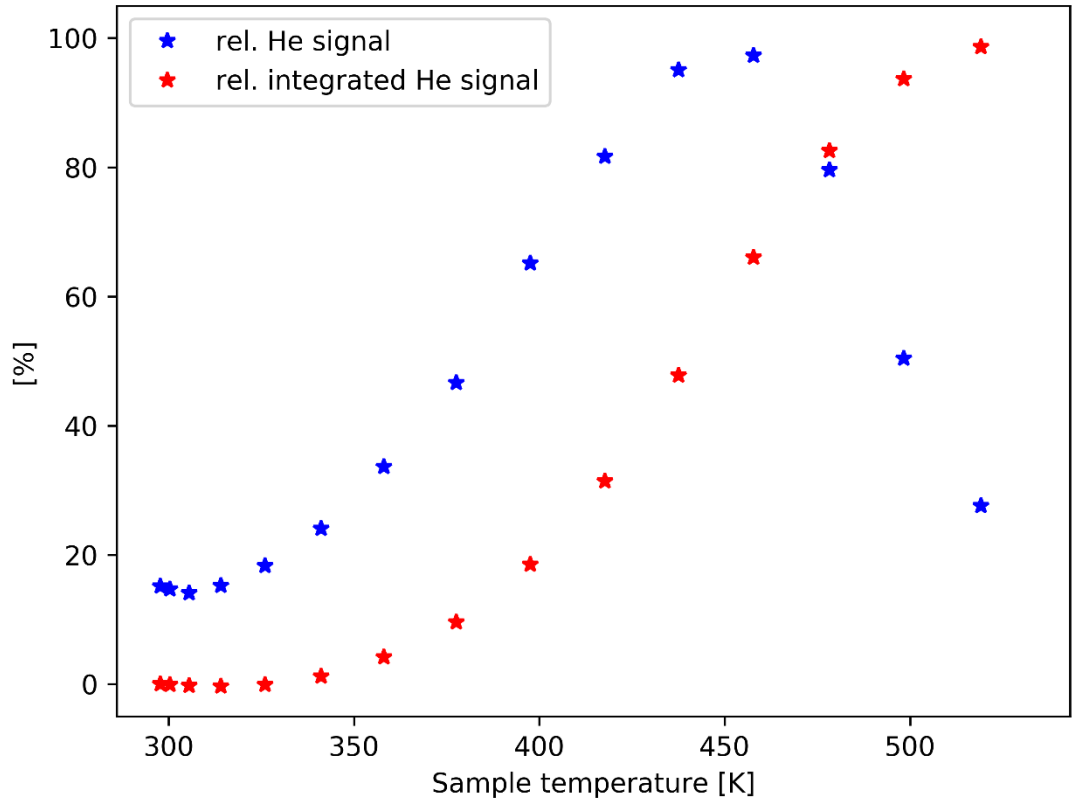
https://owncloud.tuwien.ac.at/index.php/s/xJ2oyQsyNfy8LeY

[1] Wurz P., et al.: Planet. Space Sci., 58, 1599, 2010.

Subsequent Thermal Desorption Spectroscopy



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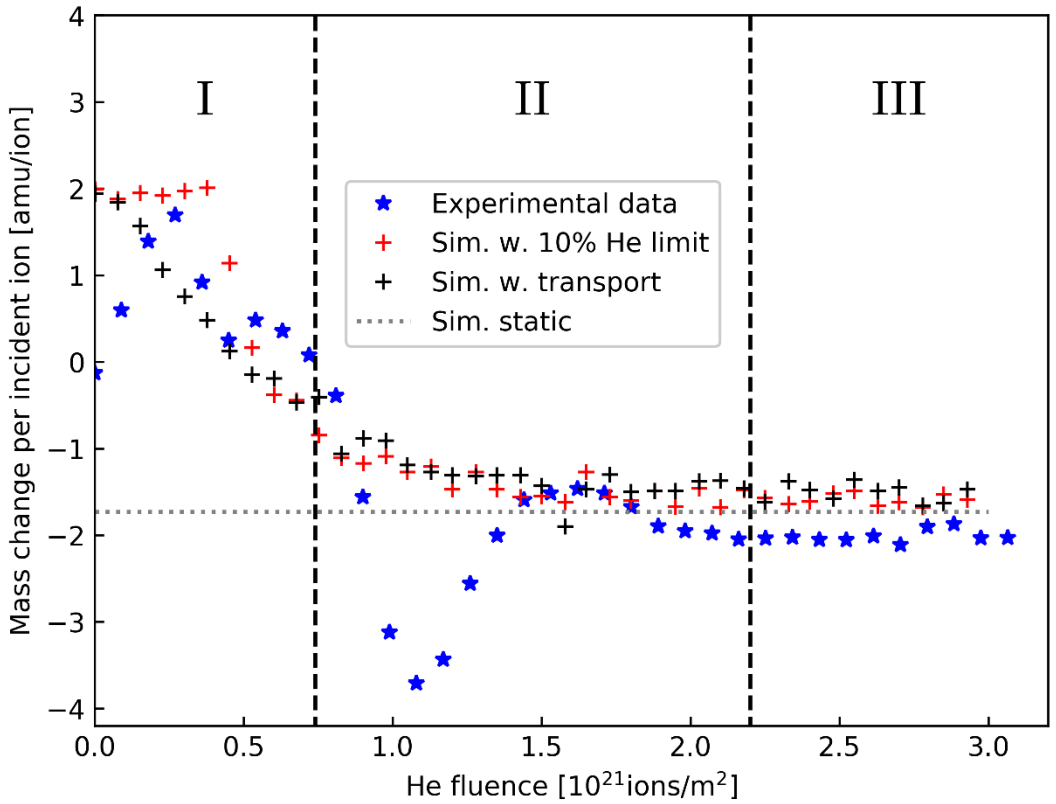
- Peak in release at about 450K
- Mass loss due to heating agrees with previously implanted He mass
- He completely removed below 500K
- Mercury surface temperature is 100-700K, depending on illumination

[1] Wurz P., et al.: Planet. Space Sci., 58, 1599, 2010.

Comparison with SDTrimSP simulations



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- Comparing with SDTrimSP [1]
- Limiting to 10 at.% He reproduces the general trend
- Enabling ion induced transport does so too
- Oscillations can not be explained with this methods

[1] Mutzke A., et al.: IPP Report, 2019.

Summary

- Saturation with Helium is reached after about $2.2*10^{21}$ ions/m^2
  equal to some hundreds of years of solar wind on Mercury
- When heating the sample, all He gets removed below 500K
- Mercury surface temperatures range from about 100K (dark) to 700K (illuminated), so possibly fluctuations in He implantation occur
- Oscillation in implantation with enhanced release of implants are observed
- SDTrimSP can reproduce general trend of implantation, but not the oscillations

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