Planetary Science Group

Dr. Daniel Wolf Savin  Dr. Kyle Bowen  Dr. Ruitian Zhang  Becks Carmack

Additional thanks to Amy, Georgia, and John
Outline

• Why study Mercury?
• Overall project
• My research
• Conclusions
Mercury differs from the other terrestrial planets:

- **Mercury**
  - Rocky
  - Fe core
  - Fe poor surface

- **Venus**
  - Rocky
  - Fe core
  - Fe rich surface

- **Earth**

- **Mars**
  - 50%
We don’t know why Mercury’s surface lacks Fe

There have been no landers or sample return missions

But we have data from 2 flyby missions

Mariner 10 (1973-1975)
Three flybys

Three flybys then 4 years in orbit
Indirect measurements constrain Mercury’s surface composition

→ **Surface reflectance spectra**
  - Minerals include: plagioclase feldspar, pyroxene, and olivine
  - Abundance of volatiles: S, K, Na

→ **Exosphere composition**
  - Composed of: Na, Ca, Al, K, Fe, He, & H
  - H and He from Solar Wind ions (95% H & 5% He)
  - Ca from vaporization of impactors
  - Are the other elements from Mercury’s surface?

→ **Mercury’s crustal composition can constrain its formation**
Ground based observations show Na in exosphere

(Killen, private communication)

2006 solar transit
Dunn solar telescope
How Na is released into Mercury’s exosphere

Micrometeorite Impact Vaporization
• Source of Ca in exosphere

(Gamborino et al., Ann. Geophys. [2018])
How Na is released into Mercury’s exosphere

(Gamborino et al., Ann. Geophys. [2018])
How Na is released into Mercury’s exosphere

(Gamborino et al., Ann. Geophys. [2018])
How Na is released into Mercury’s exosphere

(Gamborino et al., Ann. Geophys. [2018])
We lack understanding of how sputtering contributes ions to the exosphere.
Slabs versus regolith

- Extensive studies have been done for sputtering on slabs
- Models for slabs have been made based on measurements
- We don’t know how to scale these models to regolith

- General information on sputtering from regolith exists
- Studies show 90% of sputtered atoms stay beneath surface

In Regolith:
- Ions can be sputtered underneath the surface and trapped
- Momentum transfer causes most sputtered ions to go deeper
Outline

• Why study Mercury?
• **Overall project**
• My research
• Conclusions

⇒ Construct a novel apparatus
⇒ Measure sputtering yields
Solar Wind Ions Sputtering Facility at Nevis Labs
Which is currently being built...
Electrostatic Ion Beam Line

Deflector

Ion Source

Electrostatic & Magnetostatic Ion Optics

UHV (Ultra-High Vacuum) Beam Line

Target Chamber

45°
Experimental Setup

Sputtered Particle Detector

Sputtered Particles

Ion Beam: 20 keV Ar+

Target: Feldspar Regolith

Vary porosity and grain size
Outline

• Why study Mercury?
• Overall project
• My research
• Conclusions

⇒ Model sputtered particle angular distribution
SRIM: Stopping and Range of Ions in Matter

TRIM: TRansport of Ions in Matter

- Monte Carlo code
- Calculates interactions of ions with a target
- Made for slabs
- Sputtering
- Implantation
Determine if SRIM shows a polar dependence on ion beam angle of incidence (AOI)

Ion Beam: 20 keV Ar+
Varied AOI = 0°, 15°, 30°, 45°, 60°, 75°, 85°

Target: Labradorite Feldspar
(\text{Na}_{0.5}\text{Ca}_{0.5})\text{Al}_{1.5}\text{Si}_{2.5}\text{O}_{8}
Polar distribution with varying AOI

SRIM does not vary polar distributions with AOI
Previous studies show polar angle dependence on AOI

(Bay et al. 1980, Appl. Phys., 21, 327)
Applicability of SRIM

- Solar wind ~1 keV / u
- At lower energies (keV) nuclear sputtering is dominant
- Experiments show polar dependence on AOI
- SRIM does NOT show polar dependence on AOI
- SRIM is not appropriate for solar wind sputtering
Outline

• Why study Mercury?
• Overall project
• **My research**
• Conclusions

⇨ Model sputtered particle angular distribution
⇦ **Investigate SRIM energy distributions**
Sputtered energy distributions for slabs

\[ f(E_e) = \frac{6E_b}{3-8\sqrt{E_b/E_c}} \frac{E_e}{(E_e+E_b)^3} \left\{ 1 - \sqrt{\frac{E_e+E_b}{E_c}} \right\} \]

(Wurz et al. 2010)

- \( E_e \) = energy of sputtered particle
- \( E_b \) = surface binding energy
- \( E_c \) = cut-off energy
  - = max energy imparted to a sputtered particle
Theorized sputtering $f(E)$ v SRIM

Ion Beam: 20 keV Ar$^+$
AOI 45°
Target: Labradorite
$(Na_{0.5}Ca_{0.5})Al_{1.5}Si_{2.5}O_8$

SRIM predicts higher energies
Model $f(E)$ for varying polar angles ($\phi$) and elements

Beam: 20 keV Ar$^+$ AOI 45°
Target: Labradorite Feldspar
\((Na_{0.5}Ca_{0.5})Al_{1.5}Si_{2.5}O_8\)

Elements: Na, Ca, and Al

$\phi$: 0°, 15°, 45°, & 75°
Sputtered ion kinetic energy increases with $\phi$

Threshold energy increases with Surface Binding Energy ($E_b$)

<table>
<thead>
<tr>
<th></th>
<th>$Z$</th>
<th>Weight (amu)</th>
<th>$E_b$ SRIM (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td>11</td>
<td>22.99</td>
<td>1.12</td>
</tr>
<tr>
<td>Ca</td>
<td>20</td>
<td>40.08</td>
<td>1.83</td>
</tr>
<tr>
<td>Al</td>
<td>13</td>
<td>26.98</td>
<td>3.36</td>
</tr>
</tbody>
</table>
Outline

• Why study Mercury?
• Overall project
• **My research**
• Conclusions

- Model sputtered particle angular distribution
- Investigate SRIM energy distributions
- Plot implantation depths of sputtered particles into collection wafers
Collection wafers are placed inside target chamber on a half dome around target.
Method for determining implantation depth

1. 100,000 Ar+ ions at AOI 45° hit (Na$_{0.5}$Ca$_{0.5}$)Al$_{1.5}$Si$_{2.5}$O$_8$

2. Sputtered atoms collected by “wafers” at $\varphi$ and $\theta$
Normalized SRIM implantation depth distributions

- Fewer particles with increasing $\phi$
- Implantation depth increases with:
  - Polar angle
  - Sputter energy
  - Sputter SBE
Normalized SRIM implantation depth distributions

Forward Sputtering
Right Sputtering
Backward Sputtering
Left Sputtering

- Sum of Na, Ca and Al sputtered particles
- No azimuthal dependence
- Sputtered particles stay on surface of collection wafers
Outline

• Why study Mercury?
• Overall project
• My research

• Conclusions

⇒ SRIM is not appropriate for determining polar sputter yield distributions

⇒ Increasing $E_b$ results in increasing sputtered kinetic energy (KE) threshold & deeper implantation

⇒ Particles sputtered at higher $\phi$ have more KE and implant deeper

⇒ SRIM shows no azimuthal $\theta$ dependence on sputtering yields and implantation depths