MESSENGER Observations of the Composition of Mercury’s Ionized Exosphere and Plasma Environment

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Fast Imaging Plasma Spectrometer

- Measures E/q, Time-of-flight (TOF) and incident angle for plasma ions
- E/q range: 0.5 – 13 keV/e
- m/q range: 1-60+ amu/e
- Time resolution down to 8s
- Nearly hemispherical instantaneous field of view (1.4 π steradian)
- Designed and built at University of Michigan
- Primary role: Heavy ion composition

Mass: 1.41 kg  Power: 1.9(ave)/2.1(max) W
• Measure: $E/q$, MCP position, Time-of-Flight
• Derive: 3D vector velocity, $M/q$
• FIPS looks out to the side of MESSENGER, tilted down and toward front.

• FIPS FOV is blocked within 12 degrees of radial direction.
• Identified through long-duration heliospheric measurements.
• Dominated by dark counts, a structured signal at ~0.14 counts per second.
• Characterized signatures through flight tests and modeling.
• Developed a probabilistic removal method based on signal map.
\[ E_{tot} = q_i \left( \left( \frac{E}{q} \right)_{ESA} - V_{PA} \right) - E_{loss} \]

\[ \nu = 438 \sqrt{\frac{E_{tot}}{m}} \]

\[ TOF = \frac{d}{\nu} - \tau_e - \tau_{MCP} \]
Energy Loss in Carbon Foil

• Energy loss in carbon foil depends on incident energy and mass (not charge)
• Hard to measure over full range in lab
• Model foil loss with software, TRansport of Ions in Matter (TRIM).
  – Lots of runs (many ions for each mass and energy)
  – Find peak loss
  – Fit to polynomial
  – Verify consistency with calibration data.
• Test for heliospheric particles for which composition is known
Forward Model Results

Solar wind observed during cruise in 2009.

* These are protons which exit the foil charged.
Interstellar Helium

**MESSENGER Trajectory**

**MESSENGER/FIPS Available Measurements**

**Enhanced He⁺ Counts**

**$V_{\text{SUN}}$ through Interstellar medium**

He gravitational focusing cone

1AU
Previously Published Results
Zurbuchen, et al., 2008

<table>
<thead>
<tr>
<th>Mass/charge (amu/e)</th>
<th>Representative ion or molecular ion species</th>
<th>Abundance ratio*</th>
</tr>
</thead>
<tbody>
<tr>
<td>23–24</td>
<td>Na⁺, Mg⁺</td>
<td>1.00</td>
</tr>
<tr>
<td>32–35</td>
<td>S⁺, O₂⁺, H₂S⁺</td>
<td>0.67 ± 0.06</td>
</tr>
<tr>
<td>28</td>
<td>Si⁺, Fe⁺⁺</td>
<td>0.53 ± 0.06</td>
</tr>
<tr>
<td>39–40</td>
<td>K⁺, Ca⁺</td>
<td>0.44 ± 0.05</td>
</tr>
<tr>
<td>17–19</td>
<td>H₂O⁺, H₃O⁺, OH⁻</td>
<td>0.20 ± 0.03</td>
</tr>
<tr>
<td>4.67–11</td>
<td>Multiply charged ions</td>
<td>0.20 ± 0.03</td>
</tr>
<tr>
<td>16</td>
<td>O⁺</td>
<td>0.20 ± 0.03</td>
</tr>
<tr>
<td>14</td>
<td>N⁺, Si⁺⁺</td>
<td>0.09 ± 0.02</td>
</tr>
<tr>
<td>11–12</td>
<td>C⁺, Na⁺⁺, Mg⁺⁺</td>
<td>0.08 ± 0.02</td>
</tr>
<tr>
<td>4</td>
<td>He⁺</td>
<td>0.03 ± 0.01</td>
</tr>
</tbody>
</table>
M1 Magnetosphere Analysis

![Graph showing energy vs. time of flight for various ions]

- **H+**
- **He2+**
- **He+**
- **O6+**
- **C5+**
- **O2+**
- **C2+**
- **Na+**
- **Mg+**
- **O+**
- **H2O+**
- **S+**
- **Ca+**

**Axes:**
- **Y-axis:** Energy (amu/e)
- **X-axis:** Time of Flight (ns)
M2 – M1 Magnetosphere Comparison

M2 flyby

M1 flyby

E/Q (amu/e)

TOF (ns)

E/Q (amu/e)

TOF (ns)
• Found a new operational mode that reduces dark-counts by 90% for Group 1 and 50% for Group 2.
• New data product added which will allow for measurement of detailed proton velocity distributions not available during M1 and M2.
• Orbital measurements will greatly improve counting rates and m/q resolution.
### Results Summary

<table>
<thead>
<tr>
<th>Ion</th>
<th>M1 Counts</th>
<th>Abundance ratio*</th>
<th>M2 Counts</th>
<th>Abundance ratio*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar wind heavies</td>
<td>119</td>
<td>0.72</td>
<td>87</td>
<td>0.68</td>
</tr>
<tr>
<td>He⁺</td>
<td>62</td>
<td>0.38</td>
<td>37</td>
<td>0.48</td>
</tr>
<tr>
<td>Doubly charged ions</td>
<td>32</td>
<td>0.20</td>
<td>24</td>
<td>0.18</td>
</tr>
<tr>
<td>O⁺ + H₂O⁺</td>
<td>43</td>
<td>0.26</td>
<td>47</td>
<td>0.29</td>
</tr>
<tr>
<td>Na⁺ + Mg⁺</td>
<td>164</td>
<td>1.00</td>
<td>128</td>
<td>1.00</td>
</tr>
<tr>
<td>S⁺</td>
<td>98</td>
<td>0.60</td>
<td>99</td>
<td>0.77</td>
</tr>
<tr>
<td>Ca⁺ + K⁺</td>
<td>27</td>
<td>0.16</td>
<td>21</td>
<td>0.16</td>
</tr>
</tbody>
</table>

* Abundances are listed relative to Na⁺ + Mg⁺

- Systematic errors estimated at ~20%
- Statistical errors based on count rates (Poisson statistics)
- Example: Na⁺ + Mg⁺, 0.21 ; Ca⁺, 0.30
## Comparison

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<tr>
<th>Ion</th>
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<th>M2 Abundance ratio*</th>
<th>Zurbuchen et al. 2008 Abundance ratio*</th>
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<tr>
<td>Solar wind heavies</td>
<td>0.72</td>
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<td>0.40</td>
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*Abundances are listed relative to \(Na^+ + Mg^+\)

- \(Na^+ + Mg^+\) are dominant species
- More solar wind ions found in magnetosphere
- Doubly charged ions still present
- Reduction of \(Ca^+\) abundance
Conclusions

• New analysis methods have been developed which include removal of background and physical behavior of ions within the instrument.
• Application of these methods to M1 flyby data yields overall comparable results to those already published, but some important corrections apply (Zurbuchen 2008; Raines 2010, in preparation).
• Substantial abundance of solar wind heavies detected.
• Doubly charged ions still consistent with measurements.