Distribution of $\text{H}_2$ in the Lunar Exosphere from LAMP Observations

Conservation of solar wind $H^+$

Measured $H^+$: (Kaguya, ARTEMIS);
$H$: (IBEX, Chandrayaan-1)

LAMP: THIS WORK

LADEE

LADEE, Interesting for ISRU
LAMP Atmosphere Observations

- Lyman Alpha Mapping Project (LAMP)
  - FUV imaging spectrograph
  - 0.3° x 6° field of view
  - 570-1960 Å
  - Onboard LRO

- Nadir pointed
  - Illuminated atmosphere over dark surface
  - Limited to near-terminator “Twilight”
  - Polar regions for low β orbits
  - Entire nightside for β ~ 90°
• **Stern et al., Icarus, 2013**
  
  • Average “Twilight” Observation
    - High latitude, nightside
    - Residual: red, Fluorescence model: blue
    - Density 1200 cm\(^{-3}\) consistent w/ Apollo 17 UVS upper limit: <9000 cm\(^{-3}\)
Dawn/Dusk Spectra

- Coadd data
  - Latitude 35°-75°
  - Post-dusk (LT=18:22-19:18)
  - Or pre-dawn (LT=4:42-5:34)
Dawn/Dusk H₂ Spectra

- H₂ spectrum obtained by subtracting
  - Background
  - H (Lyman series)
  - He (multiple orders)
  - Ar, Ne
  - Known instrumental effects
Dawn/Dusk H$_2$ Spectra

- Fit model of H$_2$ fluorescence
  - Lyman and Werner bands
- Dusk 410±130 cm$^{-3}$
- Dawn 690±170 cm$^{-3}$
- Enhanced H$_2$ is detected at dawn compared to dusk
Immediate diffusion of incident p⁺ as H₂ does not reproduce a dawn/dusk asymmetry.
H$_2$ Model, Many Processes

Dayside thermal release

Dayside sputtering release

Morning thermal release

Morning impact vaporization

Global thermal release

Global impact vaporization

H$_2$ density (cm$^{-3}$)

Local Time (hr)
H$_2$ Model—Micrometeoroid Release

- Global isotropic background
- Enhancement for morning hemisphere representing motion of Earth-Moon system sweeping into particles
- Source centered on the dawn terminator reproduces the dawn/dusk asymmetry.
- Density consistent with 12% of solar wind (assuming $T=1000 \text{ K}$)
## Inventories of H₂

<table>
<thead>
<tr>
<th></th>
<th>Flux (g cm⁻² s⁻¹)</th>
<th>Mass rate (g s⁻¹)</th>
<th>Efficiency that would produce 22 g s⁻¹</th>
<th>Efficiency that would produce 3 g s⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micrometeoroid delivery</td>
<td>6.67 x 10⁻¹⁶</td>
<td>250</td>
<td>8.8%</td>
<td>1.5%</td>
</tr>
<tr>
<td>Micrometeoroid release</td>
<td>1.77 x 10⁻¹⁵</td>
<td>670</td>
<td>3.3%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Solar wind delivery</td>
<td>3.34 x 10⁻¹⁶</td>
<td>32</td>
<td>70%</td>
<td>12%</td>
</tr>
</tbody>
</table>
H₂ in the LCROSS Impact Vapor

**Table:**

<table>
<thead>
<tr>
<th>Species</th>
<th>Observed (kg)</th>
<th>Mass released (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂</td>
<td>1.33</td>
<td>117±16</td>
</tr>
<tr>
<td>CO</td>
<td>0.70</td>
<td>41±3</td>
</tr>
<tr>
<td>Ca</td>
<td>0.16</td>
<td>16±1</td>
</tr>
<tr>
<td>Mg</td>
<td>0.04</td>
<td>3.8±0.3</td>
</tr>
<tr>
<td>Hg</td>
<td>0.12</td>
<td>12.4±0.8</td>
</tr>
</tbody>
</table>

Gladstone et al., Science, 2010; Hurley et al., JGR, 2012
LAMP observes a dawn/dusk asymmetry in the distribution of H$_2$ in the lunar exosphere.

Modeling shows:
- An asymmetric source is required to reproduce a dawn-dusk asymmetry
- Higher energy release mechanisms produce lower density for a given source rate
- For T=1000 K, 3 g s$^{-1}$ source rate needed to reproduce density

Modeling of micrometeoroid vaporization of implanted hydrogen reproduces LAMP observations.
- Steady state achieved with a source rate of a few 10s% conversion of solar wind (through subsequent impact vaporization).
- Perhaps the H$_2$ observed in the LCROSS plume was analogously released.