CONTRIBUTIONS OF SOLAR WIND AND MICROMETEOROIDS TO THE INVENTORY OF H_2 IN THE MOON'S EXOSPHERE.

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Introduction: There are multiple pathways by which hydrogen brought to the Moon by the solar wind and micrometeoroids can exit. In steady state, the influx must equal the outflux. The influx is well understood; but the outflux is not as well observerd. We use data from the Lyman Alpha Mapping Project (LAMP) onboard the Lunar Reconnaissance Orbiter (LRO) to constrain the amount of H from micrometeoroids and solar wind that is converted into molecular hydrogen and released into the Moon's atmosphere.

LAMP Data: The LAMP instrument is a Far Ultraviolet (FUV) mapping spectrograph [1]. Its wavelength range of 570 Å – 1960 Å includes the Lyman and Werner bands of the H_2 molecule. We compile LAMP data as a function of local time to produce spectra for the pre-dawn region and the post-dusk region. The dawn and dusk spectra are each fitted to spectral lines, background, and other known or potential features of the spectra, including Ar, He, H, Ne, H_2, a glint artifact, a ghost of Lyman α, and background [2]. Figure 1 shows the residual spectrum after subtracting out all of the fitted features except H_2. The fits indicate a pre-dawn density of H_2 of 690 ± 170 cm^{-3} and a post-dusk density of 410 ± 130 cm^{-3}. This represents a dawn-dusk asymmetry with a dawn/dusk ratio of 1.67.

Monte Carlo Model: We use a Monte Carlo technique [3] to simulate the spatial distribution of H_2 in the lunar exosphere for a range of assumptions of the initial release mechanism. Parameters varied include the spatial distribution of the source and the velocity distribution of the release mechanisms. The model follows test particles along their ballistic trajectories through the collisionless exosphere using the equation of motion under gravity. It simulates their interaction with the regolith and re-emission into the exosphere. It accounts for loss due to escape and photodissociation and photoionization [4].

Results: The model reproduces the spatial distribution observed by LAMP only when a source that is asymmetric with respect to dawn and dusk is used. An isotropic source or a dayside only source cannot reproduce the observed asymmetry.

The magnitude of the density is highly modulated by the energy of the initial release mechanism because H_2 is light enough to escape lunar gravity for some of the possible release mechanisms. Thermal source mechanisms at the Moon's surface temperature reproduce the observed density with a source rate of ~ 1 g s^{-1}. For higher temperature of 1000 K, a source rate of ~4 g s^{-1} reproduces the observed density. An impact source at T=3000 K reproduces the observed density with a source rate of ~20 g s^{-1}. Sputtering reproduces the observed density with a source rate of 1500 g s^{-1}.

Discussion: Potential sources for H_2 in the lunar exosphere are the solar wind, endogenic hydrogen, and meteoritic infall [5]. Of these, only meteoritic infall matches the spatial distribution needed to reproduce the observations.

The infall rate of meteoroids is 250 g s^{-1} [6]. The abundance of hydrogen in meteoroids is on the order of 1000 ppm in the form of water and hydrated minerals. Thus the source rate of H from meteoritic infall is 0.25 g s^{-1}, although it is expected to be mostly in the form of water or hydrated minerals [7]. Thus meteoritic infall is insufficient as a source to supply the observed density. However, meteoroids also vaporize local lunar material on impact at a rate of 670 g s^{-1}. The amount of H in the lunar regolith is ~100 ppm [8]. For stoichiometric release of H as H_2, meteoroids release 0.067 g s^{-1}. This is also too small to account for the observed density of H_2 even when added to the H from meteoric infall. However, there is reason to support the release of H_2 would exceed stoichiometry. H_2 is liberated at temperatures well below 3000 K as observed in temperature-programmed desorption experiments [9] and in the LCROSS impact [10]. The mass of regolith that reaches T=1000 K is far larger than the mass of regolith that is nominally considered as vaporized by the impactor.

The solar wind supplies an influx of hydrogen of ~32 g s^{-1} to the Moon. Kaguya has observed that 1% of the solar wind is immediately reflected as protons [11]. Two spaceraft (IBEX and Chandrayaan-1) have observed 10-20% of the solar wind protons being reflected as energetic neutral atoms (ENAs) [12-13]. In steady state, the remaining 80% of the solar wind must be transient on some timescale. It is possible that some of the remaining inventory participates in the formation of water [14]. Another possibility is that the protons are converted to atomic hydrogen at energies below the range detectable by the ENA instruments [15]. We conclude that the protons could be implanted into the regolith and later released as H_2 by micrometeoroid impacts. For the T=1000 K model, 12% of the solar wind inventory converted to H_2 through micrometeoroid liberation would produce the LAMP observed spatial distribution and density.

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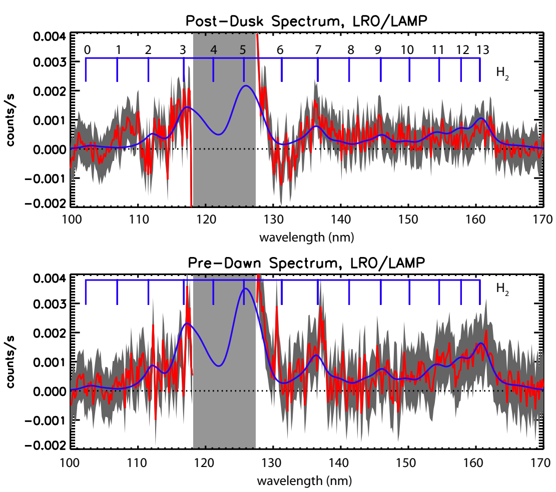

Figure 1. LAMP post-dusk (top) and pre-dawn (bottom) spectrum attributed to H_2. The inferred H_2 densities pre-dawn are 1.67 times greater than post-dusk.

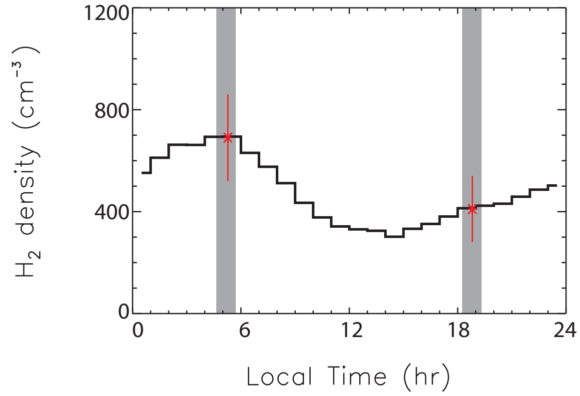

Figure 2. Model of H_2 exosphere from a dawn-centered source released with T=1000 K thermal velocity distribution. The LAMP observations are shown by the asterisks. They are reproduced with a source rate of 3.8 g s^{-1}.

Table 1. Possible sources of H_2 in the lunar exosphere

	Flux ($g\ cm^{-2}\ s^{-1}$)	Mass rate ($g\ s^{-1}$)	Efficiency that would produce 3.8 g s^{-1}
Micrometeoroid delivery	6.67 x 10^{-16}	250	1.5%
Solar wind delivery	3.34 x 10^{-16}	31.5	12%
Micrometeoroid liberation	1.767 x 10^{-15}	670	0.57%