# The Effects of Solar Cycle Variability on D and H in the Upper Atmosphere of Mars

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**Abstract**

The upper atmosphere of Mars is directly affected by solar activity and the resulting solar irradiance impinging upon it. Variations in solar forcing can affect the rate at which atmospheric species escape from the planetary system. Remotely sensed observations of the upper atmosphere of Mars have been made during solar activity extrema of Solar Cycles 22 and 24. These observations were made of D and H Lyman-a emissions using the Mars Atmosphere and Volatile Evolution (MAVEN) mission and the Hubble Space Telescope (HST) high resolution spectrographs. Data obtained from the two missions are analyzed and used to derive densities and escape rates of D and H from the martian upper atmosphere. The results show that the properties of these two water-spawned atoms vary with solar cycle, and display significant inter-annual variability, mainly due to variations in atmospheric temperature. The findings suggest that cooler atmospheric temperatures due to reduced solar EUV flux may enhance the abundance of H atoms in the upper atmosphere of Mars, yet this does not increase their escape rates.

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## Abstract:

The solar cycle directly influences the solar irradiance that impinges upon planetary atmospheres (Fig 1). These variations can affect the rate at which atmospheric species escape from planets. Observations by two spacecraft have been used to constrain the properties of the atomic species D and H at Mars.

These observations span solar activity extrema and are used to constrain the abundances and escape rates of these water-spawned atoms to investigate their variability with solar cycle. Results show large inter-annual variability in the properties of these species, and that the escape rates of both D and H atoms decrease markedly at times of lower solar activity, mainly due to a decrease in atmospheric temperature. The findings suggest that while reduced solar irradiance conditions may enhance the abundance of H atoms in the upper atmosphere of Mars, this does not increase their escape rates due to cooler atmospheric temperatures resulting from decreased solar EUV flux.

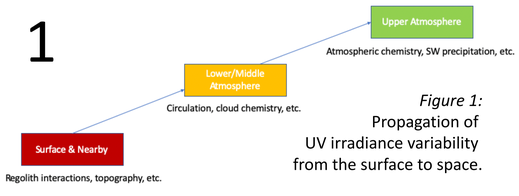


*Figure 1:* Propagation of UV irradiance variability from the surface to space.

## Observations:

D and H atoms resonantly scatter photons in Lyman-$\alpha$ at 1215.34 Å and 1215.67 Å, respectively. The Hubble Space Telescope (HST)'s Goddard High-Resolution Spectrograph (GHRS) and the Mars Atmosphere and Volatile Evolution (MAVEN) mission's Imaging Ultraviolet Spectrograph (IUVS) each have made observations of Mars with the required high-spectral resolution required to resolve the two emissions.

IUVS observations of Mars, used here, span Sept. 2014, during the maximum of solar cycle 24 and continued through 2020, during the solar minimum of cycle 24. This time range covers perihelion of Mars Year (MY) 32, to near perihelion in MY35. GHRS observations were made on Jan 1991, during the maximum of solar cycle 22, and Mars Year 20.

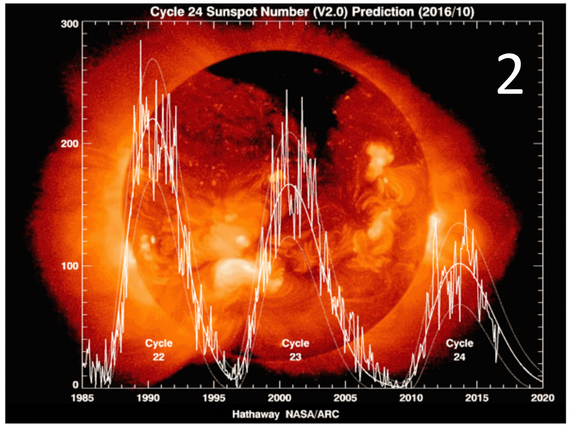


*Figure 2:* Solar cycles spanned in this work, as denoted by sunspot number. From David Hathaway, NASA, Marshall Space Flight Center: http://solarscience.msfc.nasa.gov/predict.shtml

## Results:

- Densities of upper atmospheric D and H atoms showed repeatable patterns year-to-year, and correlated with both seasonal and dust variability. These variations, among others, are accounted for by examining the data at seasonal times that are least affected by dust and seasonal variations (Ls < 200°).
- The D and H escape rates decrease with decreasing solar activity and subsequent cooler global temperatures. The D escape rate decreases by a factor of ~3.5 from MY33 to MY34. The H escape rates decrease by a factor of ~2.5 from MY33 to 35. In considering a broader timeline, the H escape rate derived for Solar Cycle 24 minimum is a factor of ~5 less than that derived for Solar Cycle 22 maximum, at Ls 65° (Fig 3).
- For MY20 65° Ls (Cycle 22 MAX), $D_{esc}$ ~$9x10^3$, $H_{esc}$ ~$2x10^8$ $cm^{-2}s^{-1}$.

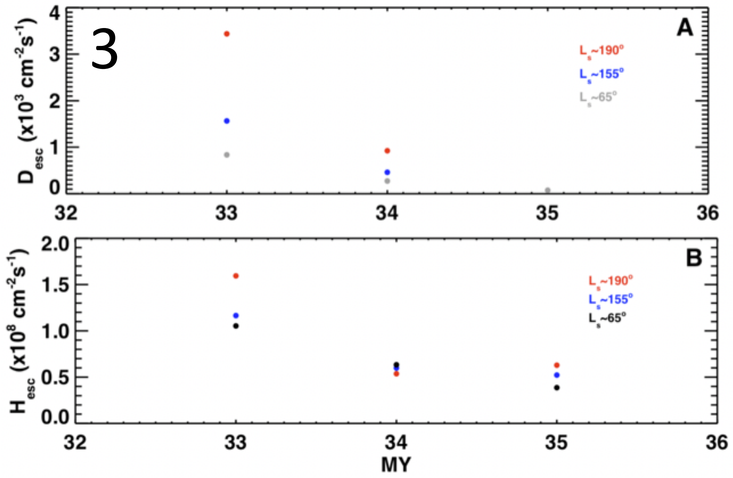


*Figure 3*: Escape rates derived for D (Panel A) and H (Panel B) in the seasonal ranges of 185°-200° Ls (red circles) and 150°-160° Ls (blue circles). The escape rates derived for aphelion at 65° Ls are shown for reference (grey circles) for D, as upper limits, and in black circles for H, denoting empirical result.

## Conclusions:

We examined martian high resolution UV spectra of the upper atmosphere of Mars during Solar Cycle 22 Maximum activity and Solar Cycle 24 Moderate through Minimum activity epochs. The upper atmosphere of Mars, specifically, the properties of water-originating species, D & H, were found to vary with Solar Cycle.

Between Solar Extrema (Cycle 22 Max and Cycle 24 Min):

- Aphelion H densities increased by 80%.
- Aphelion H escape rate decreased by ~80%.

During the declining activity of the last Solar Cycle (Cycle 24 Mode to Min):

- Aphelion D density appeared to increase.
- Aphelion D escape rate appeared to decrease.
- The upper limit of the aphelion D/H ratio appeared to increase.

## References:

[1] Mayyasi et al., under review with Icarus.