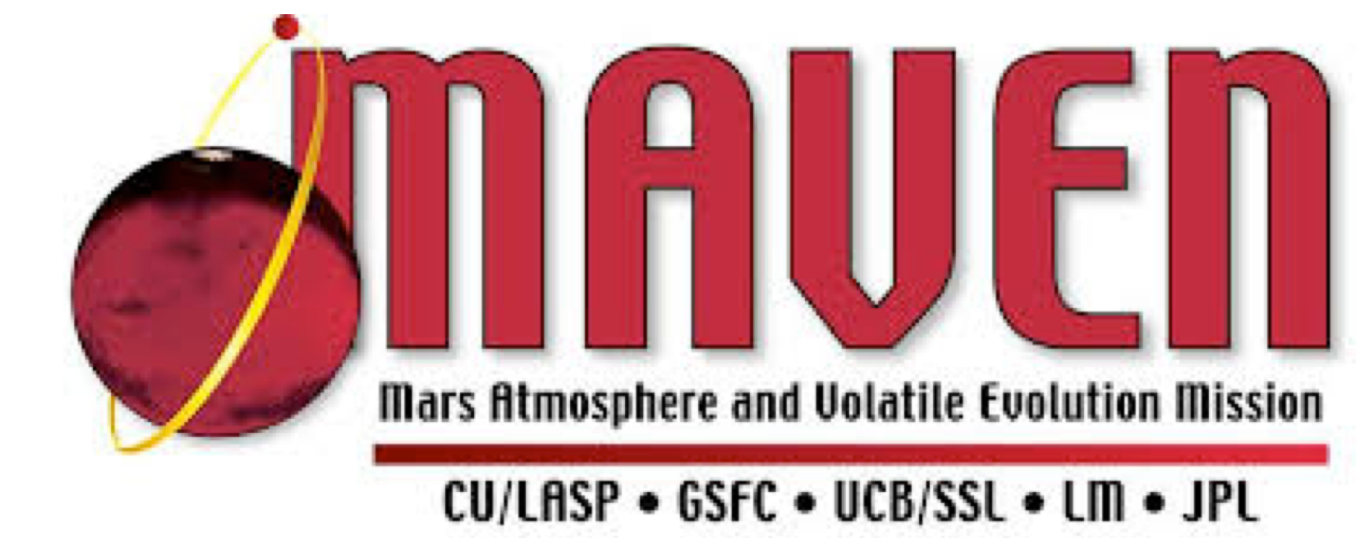
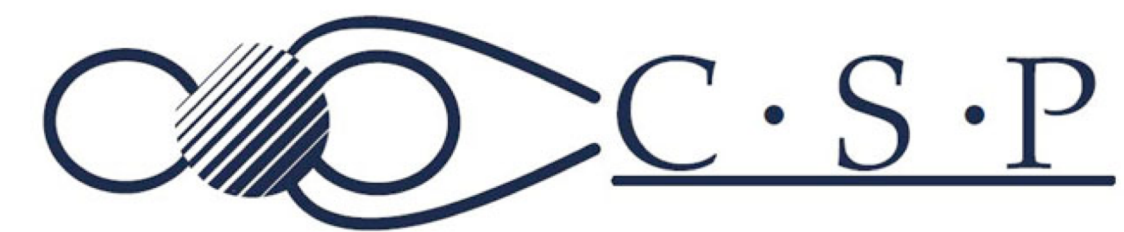




The Effects of Solar Cycle Variability on D and H in the Upper Atmosphere of Mars



Majd Mayyasi¹ (majdm@bu.edu), J. Clarke¹, J-Y. Chaufray², S. Bougher³, D. Kass⁴, G. Villanueva⁵, F. Montmessin², J. Deighan⁶, S. Jain⁶, N. Schneider⁶, B. Jakosky⁶. ¹Boston University, ²LATMOS, ³University of Michigan, ⁴NASA JPL, ⁵NASA Goddard Space Flight Center, ⁶Laboratory for Atmospheric and Space Physics.

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.

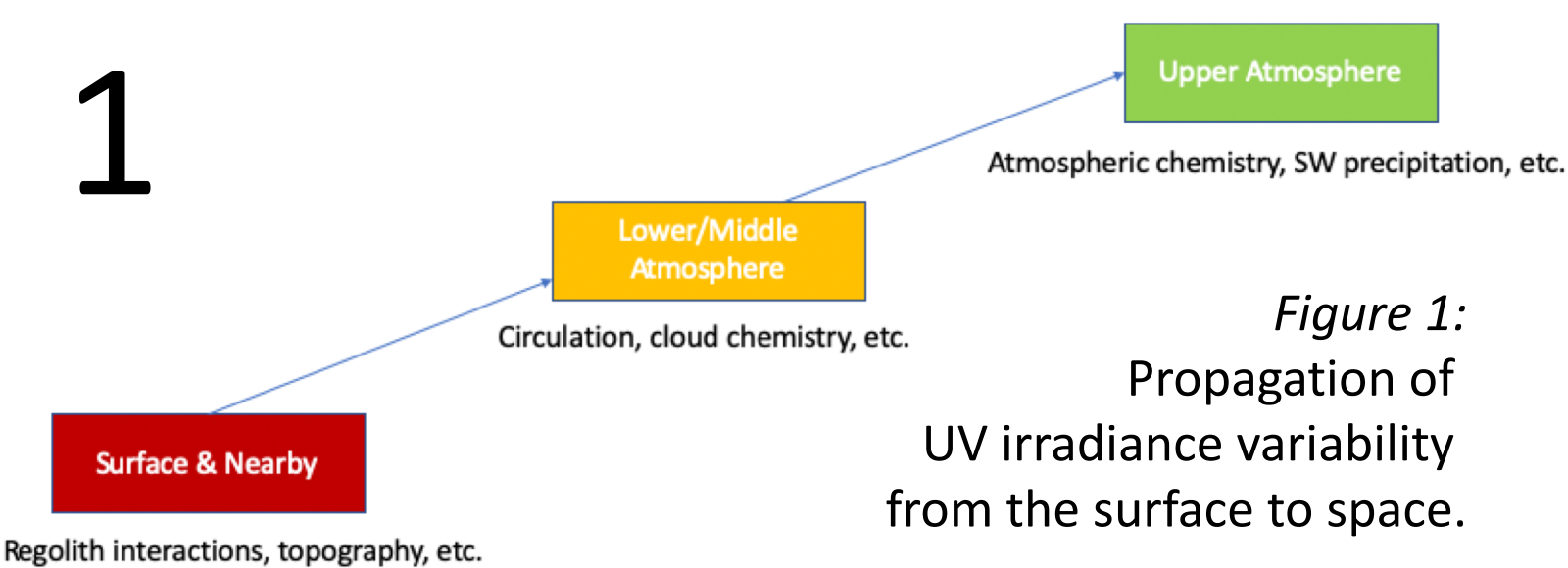


Figure 1:
Propagation of
UV irradiance variability
from the surface to space.

Observations:

D and H atoms resonantly scatter photons in Lyman- α 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.

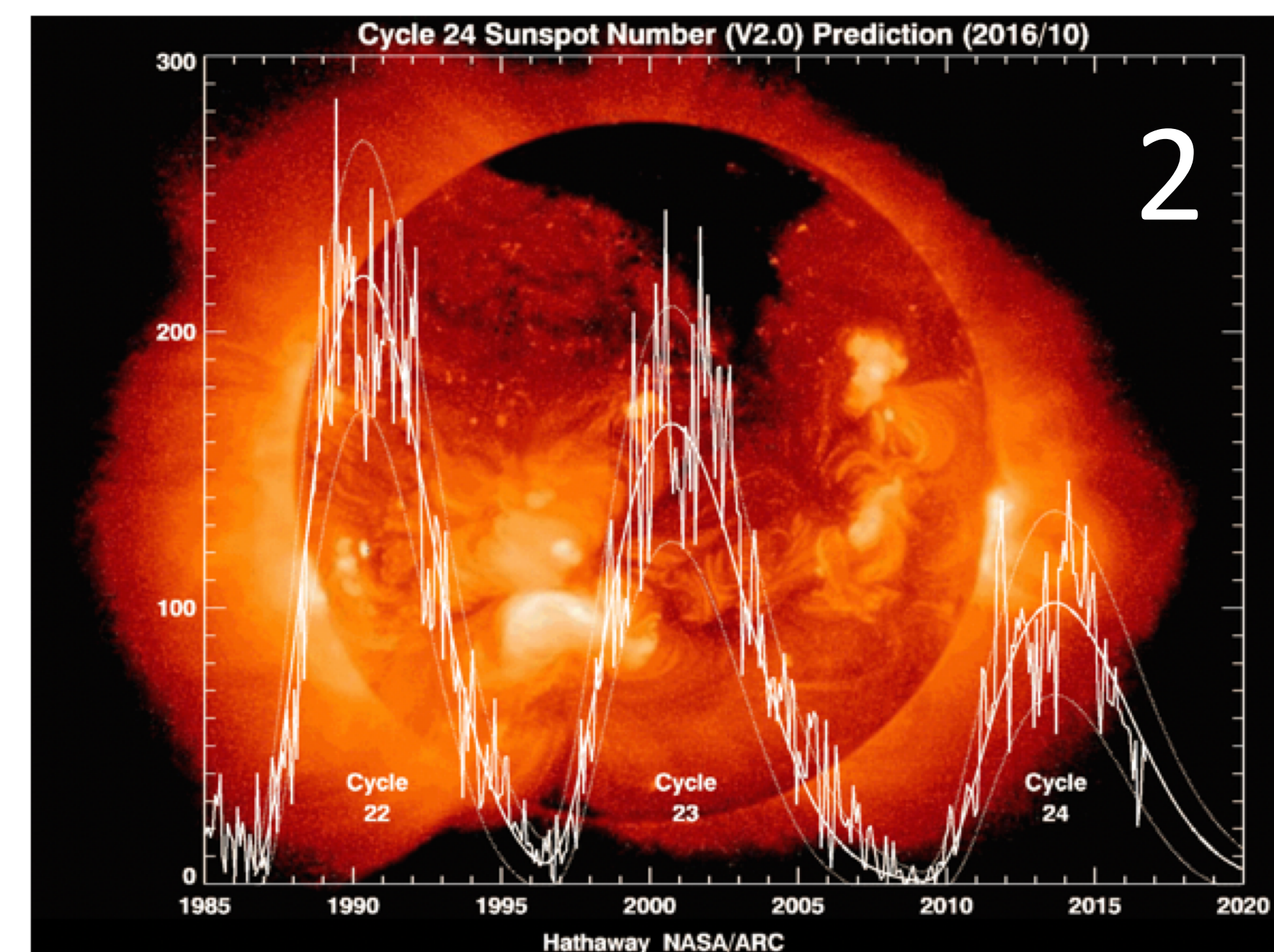


Figure 2: Solar cycles spanned in this work, as denoted by sunspot number. From David Hathaway, NASA, Marshall Space Flight Center: <http://solarscience.msfc.nasa.gov/predict.shtml>

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 ($L_s < 200^\circ$).
- 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 $L_s 65^\circ$ (Fig 3).
- For MY20 $65^\circ L_s$ (Cycle 22 MAX), $D_{\text{esc}} \sim 9 \times 10^3$, $H_{\text{esc}} \sim 2 \times 10^8 \text{ cm}^{-2} \text{ s}^{-1}$.

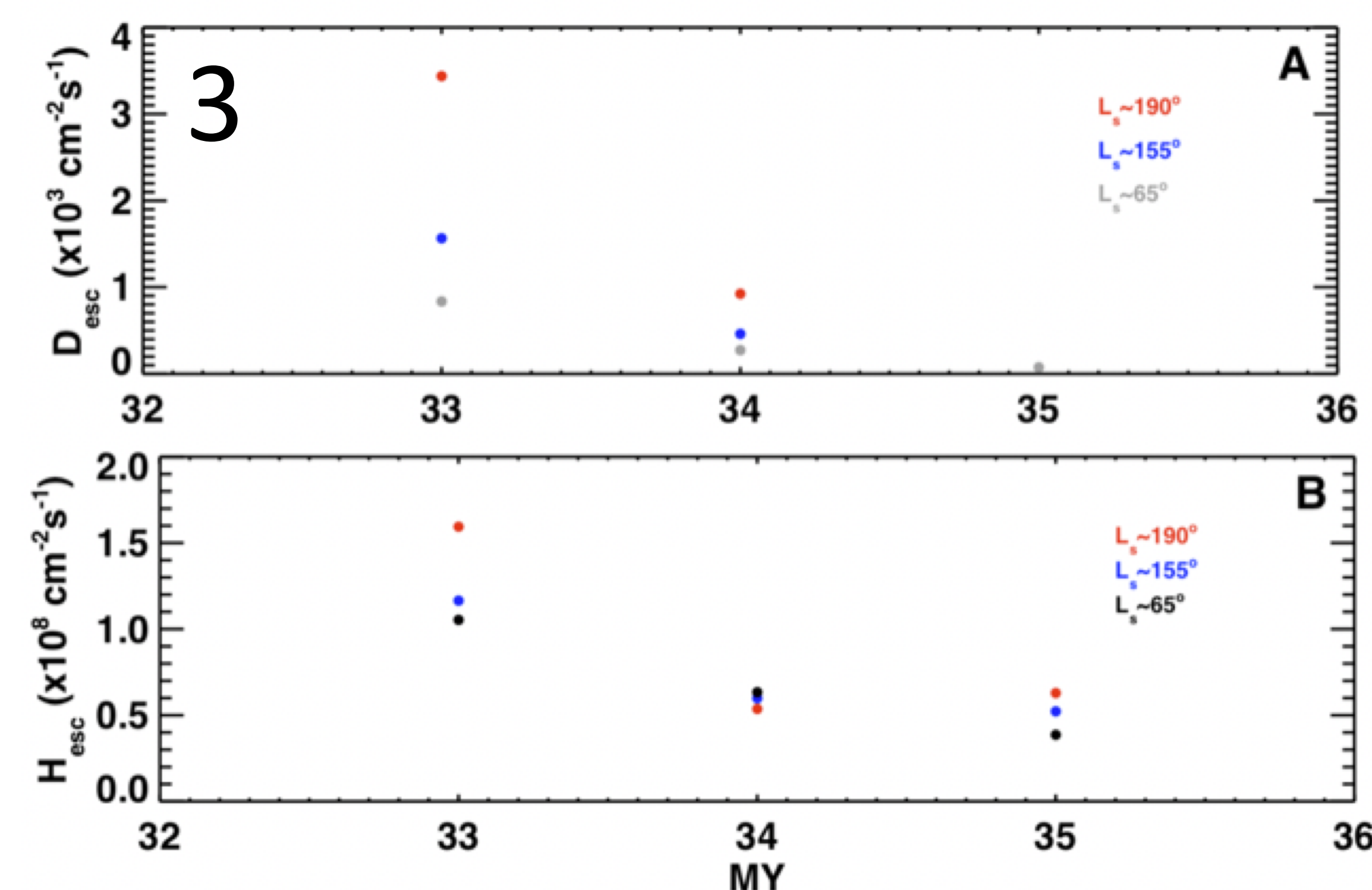


Figure 3: Escape rates derived for D (Panel A) and H (Panel B) in the seasonal ranges of 185° - $200^\circ L_s$ (red circles) and 150° - $160^\circ L_s$ (blue circles). The escape rates derived for aphelion at $65^\circ L_s$ are shown for reference (grey circles) for D, as upper limits, and in black 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 $\sim 80\%$.

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.