Evidence from the surface and atmosphere of Mars indicates that Mars was once a much wetter world. Today, we know that nearly all the water has been lost [6]. Understanding the evolution of water on Mars and its atmosphere is critical to answering questions such as: did life ever exist on Mars, or does it now? What can Mars tell us about possible futures for Earth or evolutionary pathways of exoplanet atmospheres?

Intellectual Merit

To approach these questions, we need new models that capture the complex chemistry and dynamics governing escape of water. Thermal escape of hydrogen (H) is the main loss process for both water and the atmosphere as a whole [6]. Because H escapes more efficiently than its heavier isotope, deuterium (D), **understanding variations in the D/H ratio is the key to understanding loss of Martian water**. However, the most recent atmospheric escape studies that included D chemistry only considered global averages of D/H, and were 18+ years ago [7, 10]. Since then, D/H modeling work has stalled, and no studies have investigated outgoing flux of D [6].

Twenty years of data from the Hubble Space Telescope, ground-based telescopes, and Mars orbiters, landers, and rovers have augmented our knowledge of the D/H ratio on Mars. We now know it varies with season, altitude, and geographical location ([9], and references therein). This variability is apparent in atmospheric water vapor, which can form clouds and be transported by dust storms. Studies have shown that planetary boundary layer (PBL) water ice clouds can decrease the total water column by up to 15% on timescales of a few days [4]. Orbiter data [3, 5] shows that dust storms boost water in the mesosphere, which was demonstrated by Chaffin et al. [2] to enhance loss of H within weeks. **I propose to use these new data as inputs and constraints in the first studies in nearly two decades of the role of D/H in Martian atmospheric loss**.

Research Goals

1. Explain how seasonal, altitudinal, geographical D/H variations affect atmospheric loss.
2. Understand the effects of planetary boundary layer clouds on atmospheric loss.
3. Quantify the contribution of dust storms to atmospheric loss enhancement.

Modeling Methodology, Preparation, and Current Results

Due to computational resource limitations, 1D photochemical models are required to simulate the martian atmosphere on time-scales of 10^5+ years. Though limited in space, 1D models can provide context for end-member cases of more expensive 3D calculations. During my first year in graduate school, **I expanded a 1D photochemical model** built by my advisor, Michael Chaffin, **doubling the number of chemical pathways modeled and adding deuterium chemistry**. Following Chaffin et al. [2], the model solves a photochemical system of coupled partial differential equations. Modifications to address research goals require only minor changes as follows.

1. New, high-precision data to constrain D/H in altitude and time is forthcoming from the ESA Trace Gas Orbiter to [8]; we can model this data as a time- and altitude-depndent function. Spatial variance can be estimated with this 1D model by individual runs.
2. Both diurnal and seasonal variations in water vapor abundance due to clouds and dust storms can be included with time-dependent calculations of the water vapor profile, which is prescribed in the model. Cloud altitudes can be estimated using Curiosity rover movies and the Mars Regional Atmospheric Modeling System (MRAMS) [1].

I recently **studied the effects of D chemistry and changes to the temperature profile and water**

vapor mixing ratios on escape by calculating the fractionation factor f, which represents how efficiently D escapes with respect to H. (A fractional value $0.xx$ means that D escape is 0.xx% as efficient as H escape). Selected results are shown in Figure 1. This is the **first effort to model differential escape of H and D in ~18 years**. Our results show that prior calculations greatly overestimated the relative escape of D due to systematic inaccuracies in atmospheric temperature measurements and photolysis rate coefficients available at the time. I shared these results with colleagues at the 50th meeting of the American Astronomical Society Division for Planetary Sciences (DPS), and am currently **completing work on writing these results in a lead-author publication**.

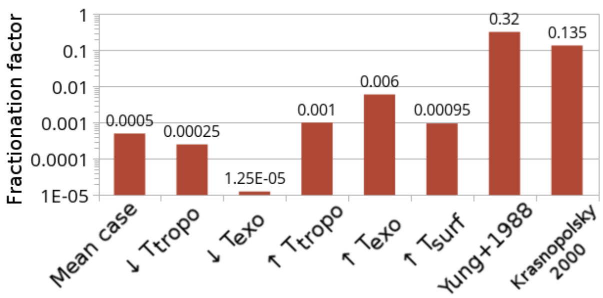

Figure 1: Fractionation factor (percent efficiency at which D escapes with respect to H) for 6 model runs, compared to two references. Labels indicate adjustments to three temperature profile control parameters: T_{surf}, T_{tropo}, and T_{exo}. "$\downarrow T_{exo}$", e.g., means the temperature at the exobase was lowered for that model run. Adjustments of $\pm 25\%$ to the mean profile were tested. The low surface temperature case produced an unstable atmosphere (photochemical system had no solution) and was discarded.

Broader Impact

The public imagination is already captivated by Mars, as a possible habitat for extraterrestrial life and a target for future crewed missions. As mentioned in my personal statement, next year I will join **CU-STARS, a departmental program that brings extracurricular science lessons to Colorado public schools**. Excitement about Mars from all ages, and the fact that atmospheric loss can be explained without complicated jargon, makes my research an excellent topic for reaching out to schools around Colorado. In terms of engaging the wider public, I also plan to make my research available to the public by giving **talks at University of Colorado's Fiske Planetarium**, a method of outreach where I can draw on my earlier training in theatre. To understand possible futures for Mars, we need to understand its history; my first talk will discuss the **history of martian atmospheric escape and implications for hypothetical future terraforming efforts (and the ethics thereof)**. I believe in making it easy for the public to access and understand the science their taxes pay for; in addition to presenting at conferences and publishing papers, I **maintain a personal website with explanations of my research for both laypeople and fellow scientists**.

Mars research contributes not only to Mars science and missions, but also to exoplanetary science. Compared to the requirements to understand exoplanet atmospheres, Mars is a cheap and readily available laboratory. It is valuable not only for scientific opportunities, but because for decades, it has captivated disparate groups of people. Now more than ever, humanity needs goals that unify us and remind us that we are all in this together; my work to understand the evolution of water and the atmosphere on Mars will advance those goals.

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