EGU General Assembly 2023

INVESTIGATING SEASONAL VARIATIONS IN MARS' HYDROGEN DENSITY DERIVED BY MODEL FITTING LYMAN ALPHA OBSERVATIONS FROM EMIRATES MARS ULTRAVIOLET SPECTROMETER (EMUS) ONBOARD THE EMIRATES MARS MISSION (EMM).

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Hamdan Bin Rashid Al Maktoum Foundation for Distinguished Academic Performance

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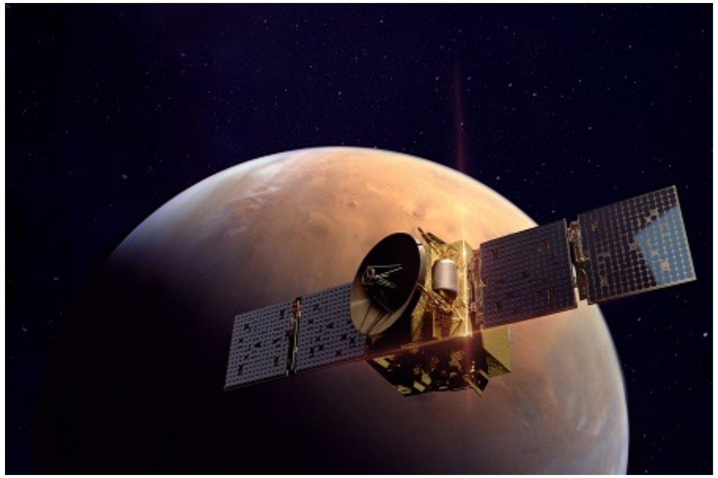
Intoduction

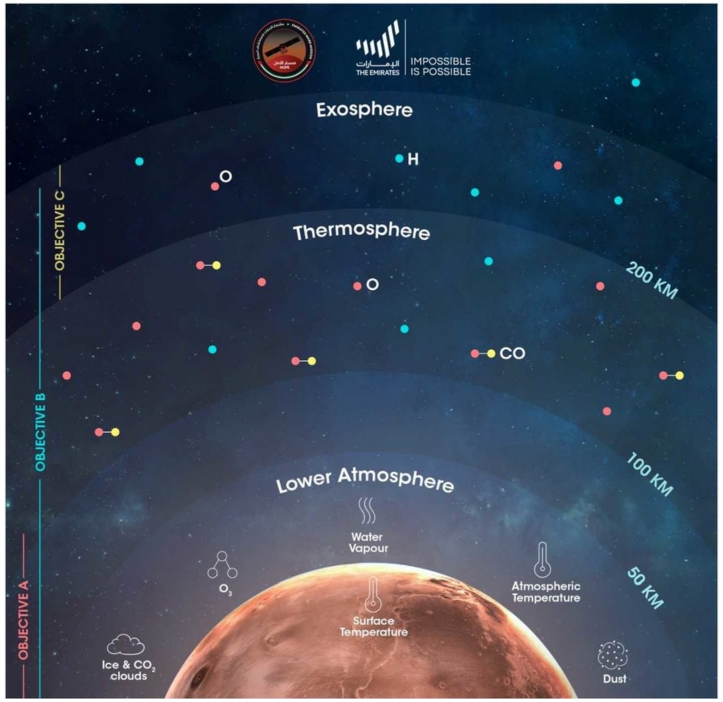
- The Martian atmosphere has long been a subject of interest, particularly in relation to the loss of hydrogen and its implications for the planet's habitability. The original research idea focused on investigating the Jeans escape mechanism, a thermal process contributing to hydrogen loss on Mars (Chaufray, 2021). However, due to changes in the research direction and authorship, the present study deviates from the initial focus on Jeans atmospheric escape and adopts an alternative approach that is more closely related to the methods employed by Zoennchen in 2010 and 2011 for studying the hydrogen density of the atmosphere which is an essential factor in deriving the jeans escape.

- The Lyman-alpha emission is a key signature of the hydrogen density in planetary atmospheres, and studying it can provide valuable insights into the distribution and dynamics of hydrogen in the Martian atmosphere. The Emirates Mars Ultraviolet Spectrometer (EMUS) onboard the Emirates Mars Mission (EMM) offers a unique opportunity to gather new data on the Martian hydrogen Lyman-alpha emission on seasonal timescales. This research aims to analyze this data to reconstruct the hydrogen density profile of the Martian atmosphere, focusing on periods of perihelion and aphelionn (LS 60-90 and LS 225<).

- By employing a similar model top the P.E.M model described in Zonnchen 2006, this study will utilize the Lyman-alpha brightness measurements from EMUS to derive the density profile of hydrogen in the Martian atmosphere. This approach has previously been used to analyze Earth's geocorona and has demonstrated its effectiveness in reconstructing the 3D structure of hydrogen distribution in a planetary atmosphere.



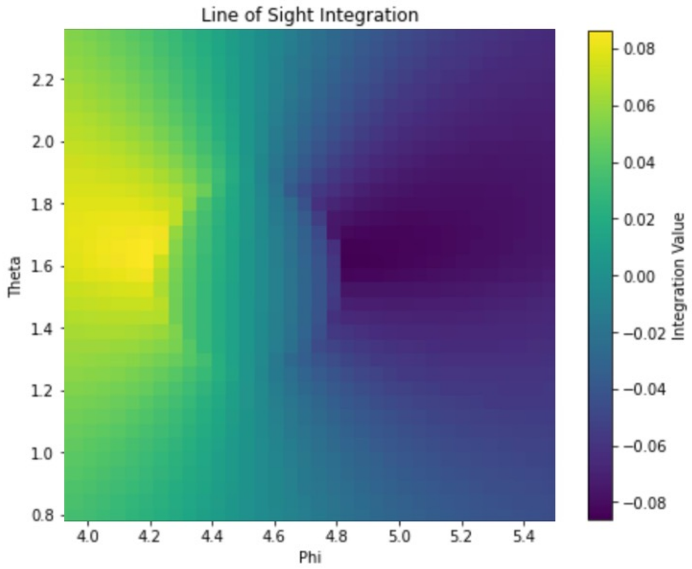
NASA and UAE Mars Missions Team UP on Science Data Analysis, SatellitePro ME. (2022)



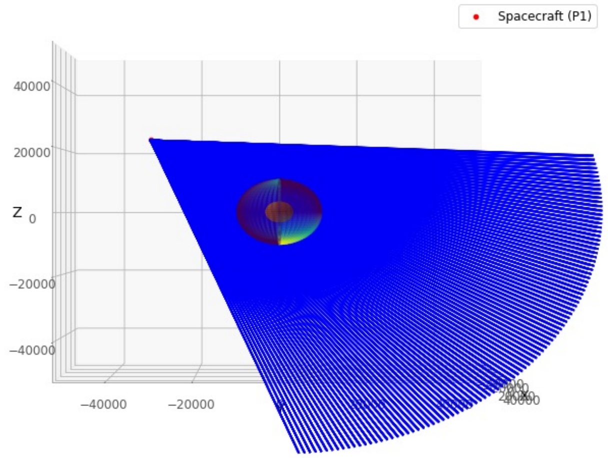
Emirates Mars Mission Characterization of Mars Atmosphere Dynamics and Processes. (2021). Space Science Reviews.

Methodology

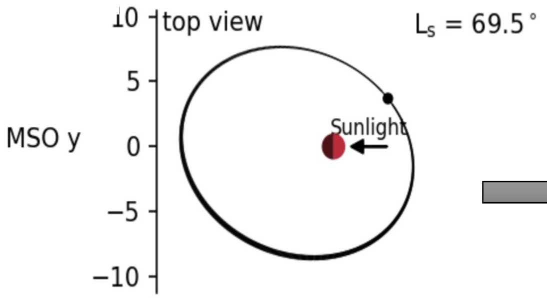
- To reconstruct the 3D hydrogen density distribution of the Martian atmosphere, Lyman-alpha column brightness measurements from the EMM mission are utilized. These measurements have been corrected for various effects, interplanetary Lyman-alpha background, sensitivity changes in the measuring instruments, and an angle-dependent scattering phase function. Following a similar approach to Zoennchen 2010 and 2011, the corrected Lyman-alpha intensities are used to derive the hydrogen density profile of the Martian atmosphere, focusing on periods of perihelion and aphelion. The methodology involves several key steps, as detailed below:



1. Data Processing: The Lyman-alpha emission data, which includes both the geocoronal and interplanetary glow, is corrected for various effects, such as self-absorption and re-emission from lower regions, contamination by UV-bright stars, interplanetary Lyman-alpha background, sensitivity changes, and an angle-dependent scattering phase function.
2. Optically Thin Regime: Following the guidelines set by Anderson and Hord Jr. (1977).
3. Integrating the LOS Data: We employ the method of enfolding the line of sight integrated data into a 3D neutral hydrogen density distribution, as detailed in Zoennchen (2006), Zoennchen et al. (2010), Zoennchen et al. (2011).
4. Seasonal Analysis: Two separate seasonal datasets are created - the summer-solstice dataset and the equinox dataset. By comparing these datasets, we aim to understand seasonal variations in the hydrogen density distribution in the Martian atmosphere.
5. Model Fitting: The 3D hydrogen density distribution model is fitted using the least squars method to the corrected Lyman-alpha intensity data, resulting in the optimize coefficients and neutral exospheric hydrogen density distributions.



The Process



Real observation geometry

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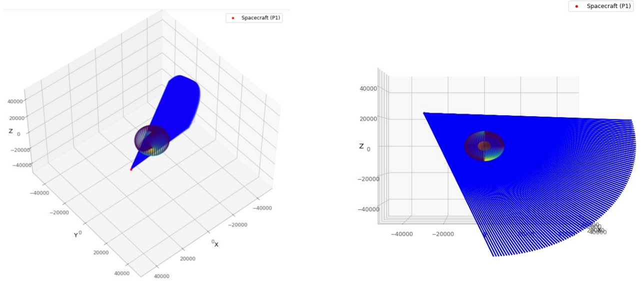
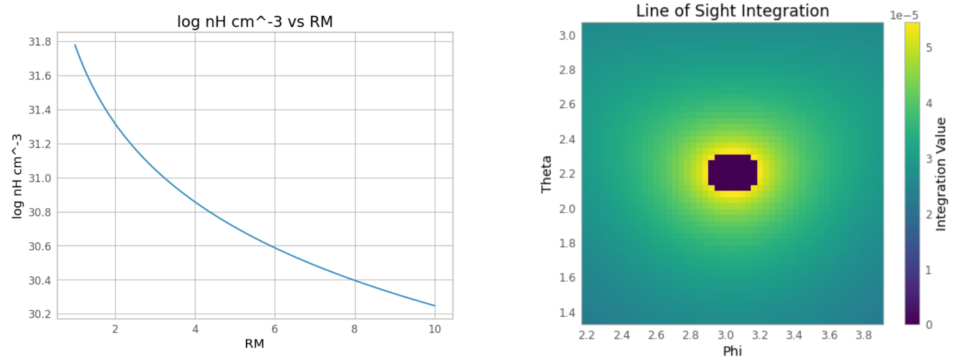
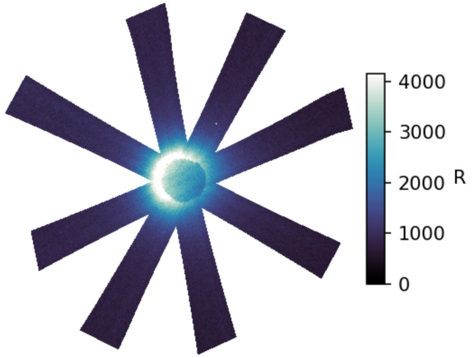


Added geometry to simulation



Planetry H density profile

Optimized coefficients



Real Lyman alpha observation

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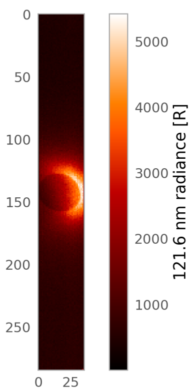
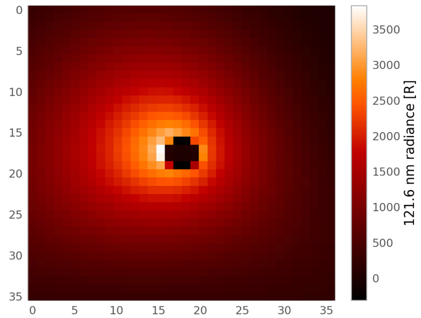
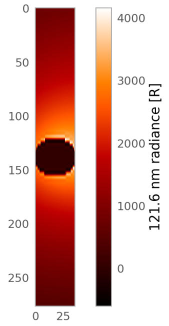






Simulating field of view integrated brightness

Fitting the simulated integrated LOS brightness with real observation using the least squars

$$4\pi I = g(r_M) \cdot \int_s n(s)\, ds = g(r_M) \cdot N$$

Fitting the coefficients

The Model

- In this research, a modified version of the Planetary Exosphere Model (PEM) presented in Zoennchen (2006) Chapter 5. The original model, referred to as the PEM model, employed a spherical harmonic expansion with a degree of 2 to represent the hydrogen density distribution in planetary atmospheres. However, due to the need for optimization and feasibility in Python, the model used in this research has undergone significant alterations . The number of coefficients has been substantially reduced, and the spherical harmonic degree has been lowered to 1.
- The modified model is built using Python and is adapted from the PEM model mentioned in Zoennchen (2006). It incorporates a simplified version of the Hodges model, as presented in Zoennchen et al. (2010) and Zoennchen et al. (2011), to represent the hydrogen density distribution in the Martian atmosphere. This model represents the hydrogen density as a function of geocentric distance (r), latitude (θ), and longitude (ϕ). The simplifications employed in the model include setting the Blm(r) coefficients to zero, reducing the order of expansion from 3 to 2 in the P.E.M model and further reduced to 1 in this research, and replacing the r-dependence of the Alm(r) coefficients with linear functions.
- By implementing these modifications, the model maintains its effectiveness in reconstructing the 3D structure of hydrogen distribution in the Martian atmosphere while being optimized for implementation in Python.

$$n_{\mathrm{H}}(r,\theta,\phi) = N(r)\sqrt{4\pi}\sum_{l=0}^{2}\sum_{m=0}^{l} Z(r,\theta,\phi)$$

$$Z = [\mathrm{A}_{\mathrm{lm}}(r)\cos(m\phi) + B_{\mathrm{lm}}(r)\sin(m\phi)]\, Y_{\mathrm{lm}}(\theta)$$

$$A_{\mathrm{lm}} = (a_{\mathrm{lm}} + b_{\mathrm{lm}}\cdot\ln(r))\times 10^{-4} \qquad N(r) = a\cdot r^{b}$$

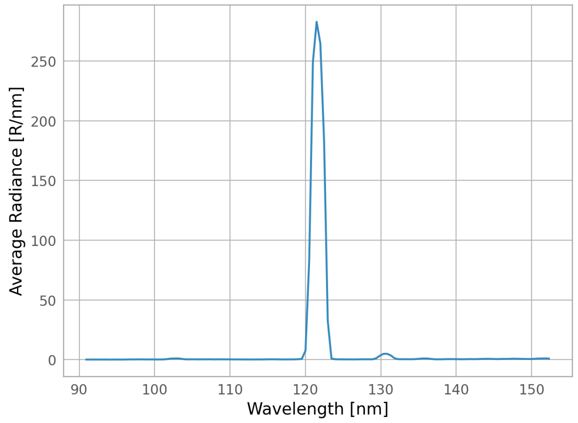
$$B_{\mathrm{lm}} = (p_{\mathrm{lm}} + q_{\mathrm{lm}}\cdot\ln(r))\times 10^{-4} \;= 0$$

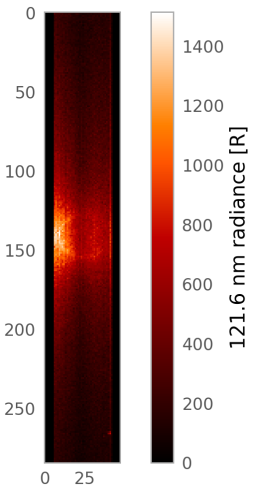
Uncertainties in model

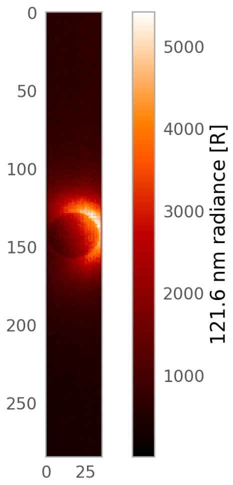
Optimization of the model, while improving computational efficiency and feasibility in Python, has led to higher uncertainties in the hydrogen density distribution. The simplifications and reduction of coefficients may introduce inaccuracies. These uncertainties should be taken into account when interpreting the results and drawing conclusions from the analysis.

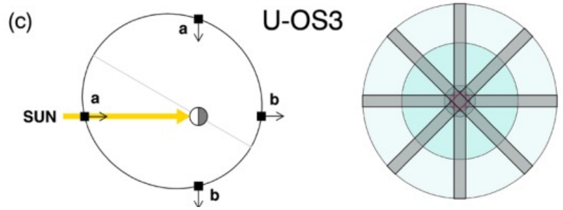
Data Acquisition

- Data used for this study is Level L2a processed data, comprising four observations (LS 69.48°, 76.38°, 301.74°, 293.50°) in U-OS3a mode. Two of these observations were taken during the summer solstice, and the other two during the equinox. U-OS3a mode observations measure the three-dimensional structure and temporal variability of hydrogen (H I 121.6 nm) in the middle and outer exosphere, using a slew pattern that covers tangent altitudes from 0 to at least 7 RM. This mode allows for the hydrogen from the Martian exosphere to be distinguished from the hydrogen that fills the solar system.

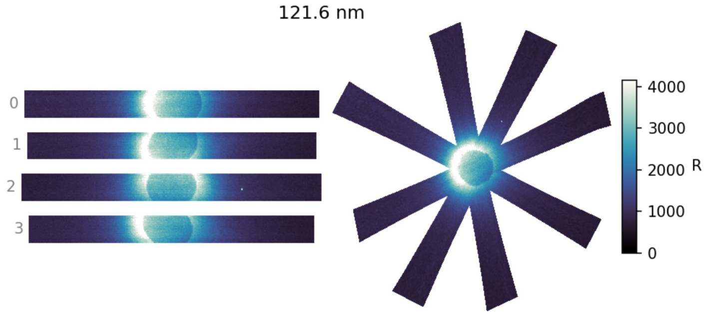








Holsclaw et al., “The Emirates Mars Ultraviolet Spectrometer (EMUS) for the EMM Mission,”



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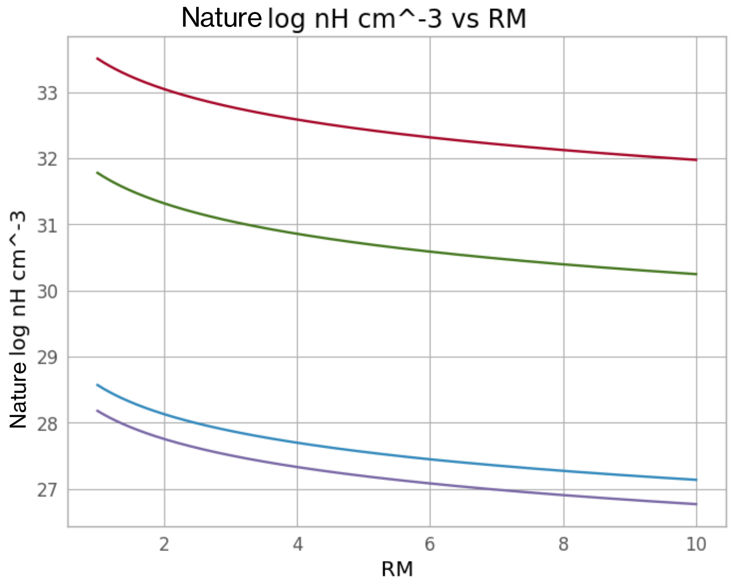
Results And Conclousons

- The reconstructed hydrogen density profiles showed noticeable differences between the periods of perihelion and aphelion. These variations in hydrogen density distribution were illustrated in the following figure, which allows for the identification of significant seasonal trends and patterns in the Martian atmosphere.
- Comparing the results with previous Martian atmospheric studies like (Anderson & Hord, 1971) revealed both similarities and differences in hydrogen distribution. The findings of this study contribute to the understanding of the Martian exospheric hydrogen profile Uncertainties and assumptions in the PEM model affected the results. Sensitivity analyses were conducted to assess the impact of parameter uncertainties on the reconstructed hydrogen density profiles.
- Thee analyses indicated the model is extremely sensitive to the initial coefficients which leads to inaccuracies in results. The uncertainties and assumptions associated with the angular dependent model provide insight into the limitations of the current analysis process and potential improvements for future researches.



Red, Green - LS 69.48°, 76.38°
Blue, Purple - LS 301.74°, 293.50°

Coefficients for LS 301.74 = {'A00': (1, 0), always (1,0)
'A10': (124541181.0846859, -692853.7093859019),
'A11': (864486528.098507, 929743.4644560025),
'a': 856289116.9992955, 'b': -1.6116174198812703}

Coefficients for LS 293.50 = {'A00': (1, 0), always (1,0)
'A10': (-2584951.244868066, 1557528.221350712),
'A11': (-6510074.063433075, 2274964.433179914),
'a': 262081680.08238143, 'b': -1.612434523401}

Coefficients for LS 69.48 = {'A00': (1, 0), always (1,0)
'A10': (917506631.7840357, -78240224.99334237),
'A11': (-1200339503.5775225, 202630212.67772815),
'a': 1357366230.9853623, 'b': -1.665567462497189}

Coefficients for LS 76.38 = {'A00': (1, 0), always (1,0)
'A10': (-75262982.1323792115, 10142321.73995985574),
'A11': (22931248.745874003, 143191.48859838693),
'a': 2364575900.124842577, 'b': -1.6656291297346112}

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Acknowledgements

- The author would like to express their gratitude to the Hamdan Bin Rashid Foundation for Distinguished Academic Performance and and Hamdan Bin Rashid Al Maktoum Centre For Giftedness and Innovation and the Mohammed Bin Rashid Space Centre for their support and contributions to this research.

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