Oxygen's control on hydrogen escape in Earth-like atmospheres across GKM dwarf stars

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Introduction

The Great Oxidation Event (GOE) was a transition to near modern-day concentrations of atmospheric molecular oxygen (O_2) roughly 2.4 billion years ago [1]. It is thought to have substantially throttled hydrogen (H) escape and its associated water (H_2O) loss to negligible loss rates since [2]. But how has hydrogen escape changed over the last 2.4 billion years, and how can different levels of O_2 affect it on various exoplanets?

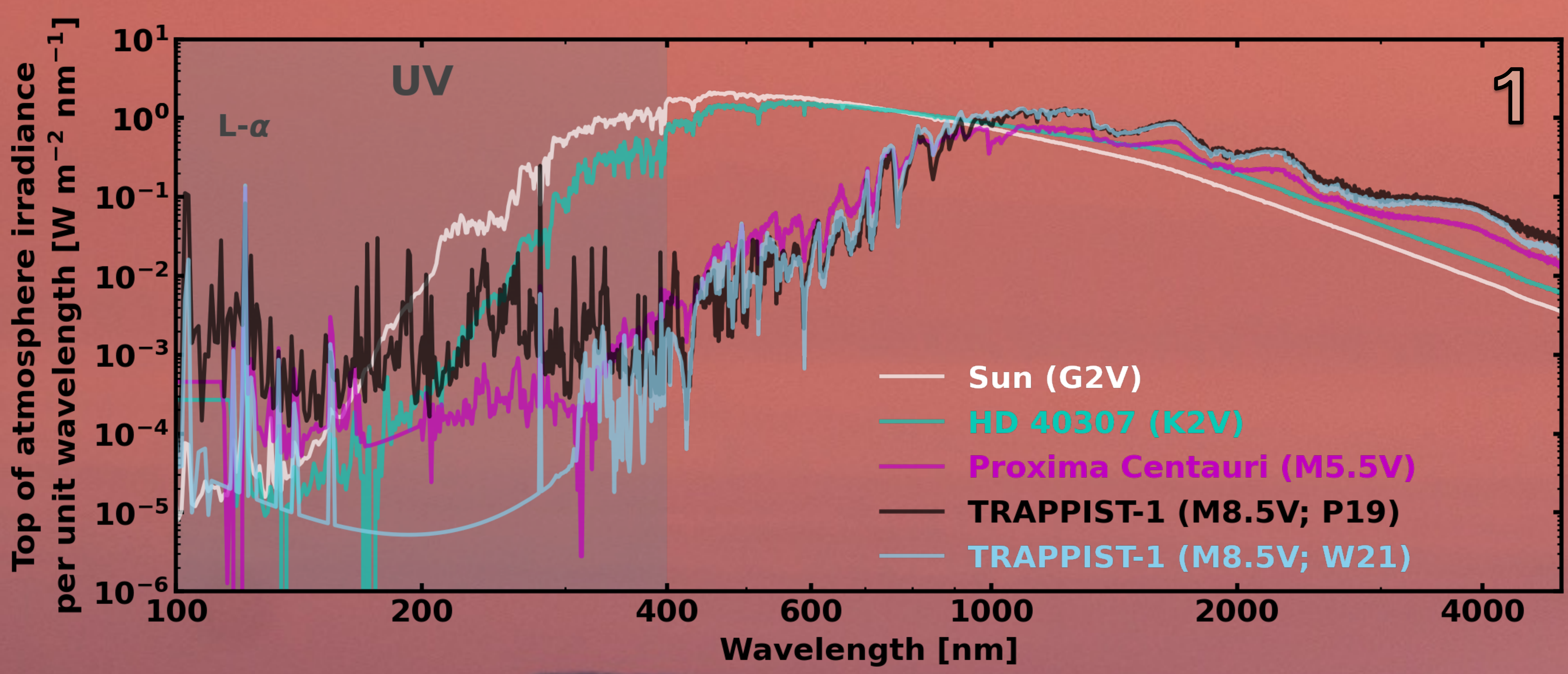
In this study we use WACCM6, a three-dimensional Earth System Model employing atmospheric chemistry [3], to simulate terrestrial exoplanet atmospheres in the habitable zone of GKM stars which have Earth-like 1-bar atmospheres. We consider O_2 mixing ratios based on the range present since the GOE [1], ranging between 0.1% PAL to 150% PAL, where PAL is the present atmospheric level of 21% by volume. This affects the ozone (O_3) layer [4, 5], possible future observations [6], and can result in lethal O_3 concentrations at the surface [7].

Simulations & stellar spectra

The figure to the left shows the different stellar spectra used for the simulations, ranging from a G2V star to a M8.5V star.

We simulate Earth-like atmospheres for an Earth around the Sun and a K2V star. Then, we change the planet to the properties of TRAPPIST-1 e and Proxima Centauri b, assuming tidal locking and their associated spectra (two for TRAPPIST-1).

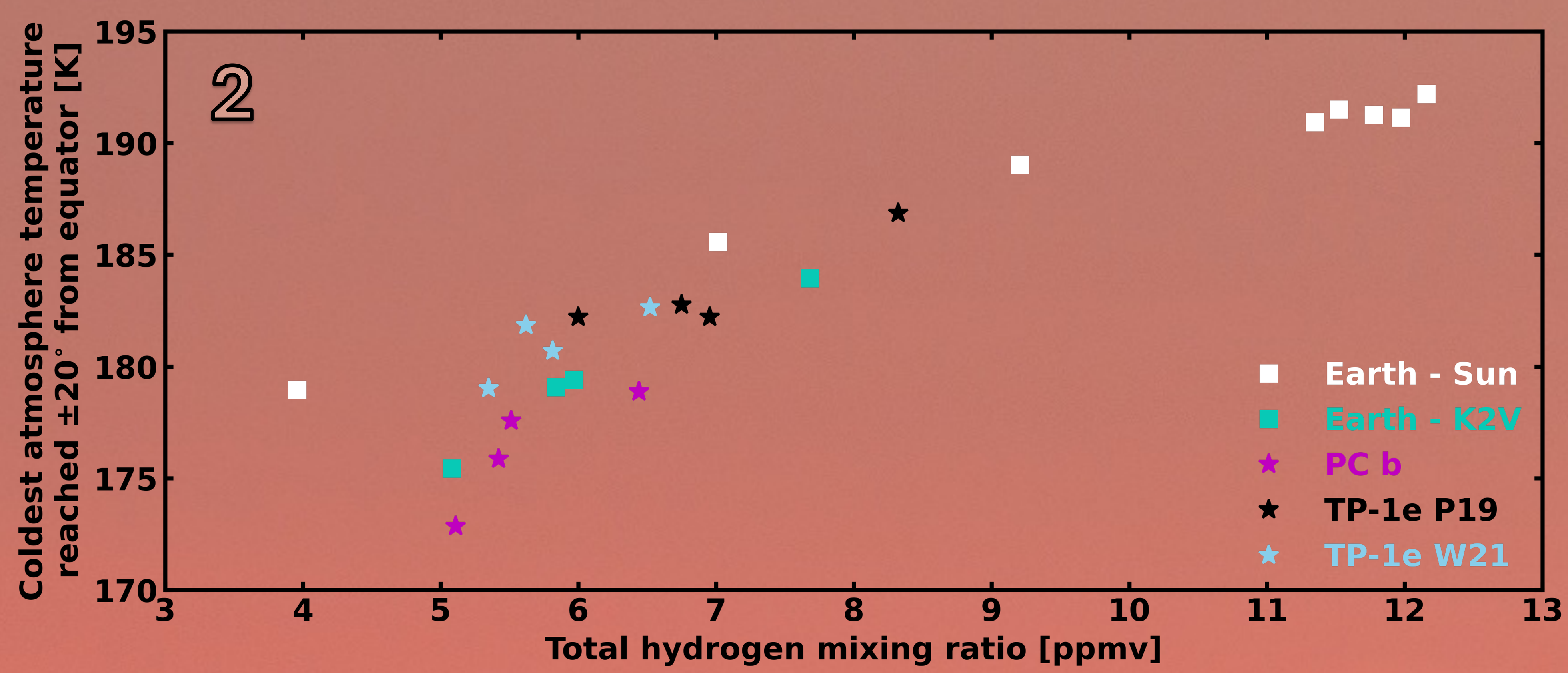
All simulations have the Earth's land and ocean configuration.

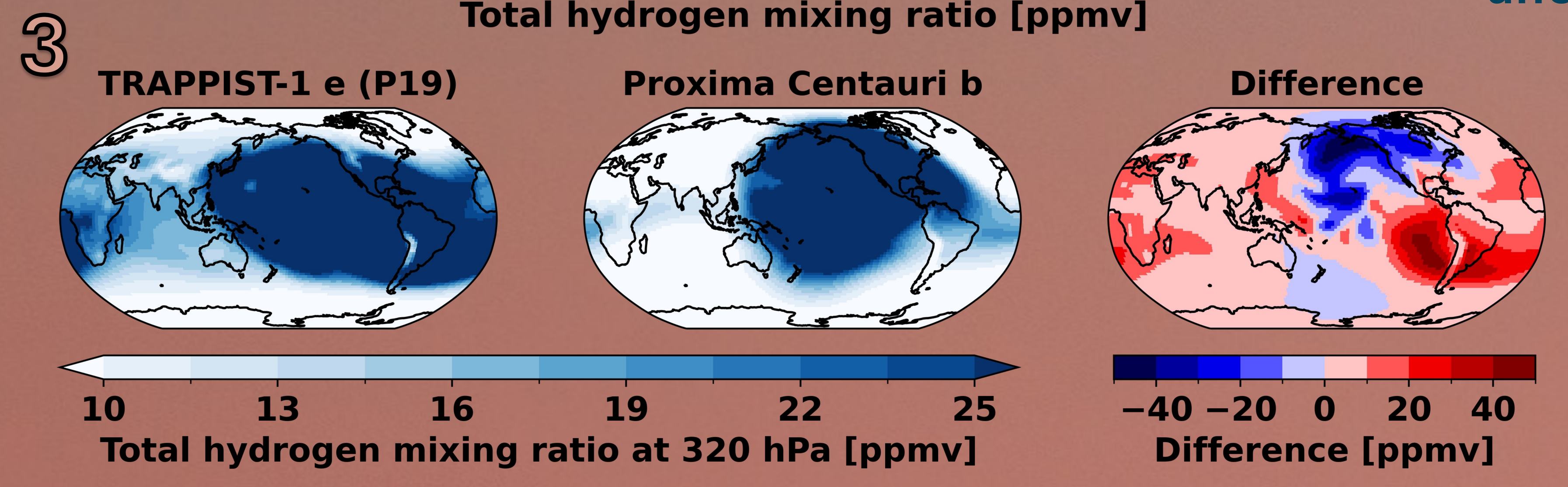


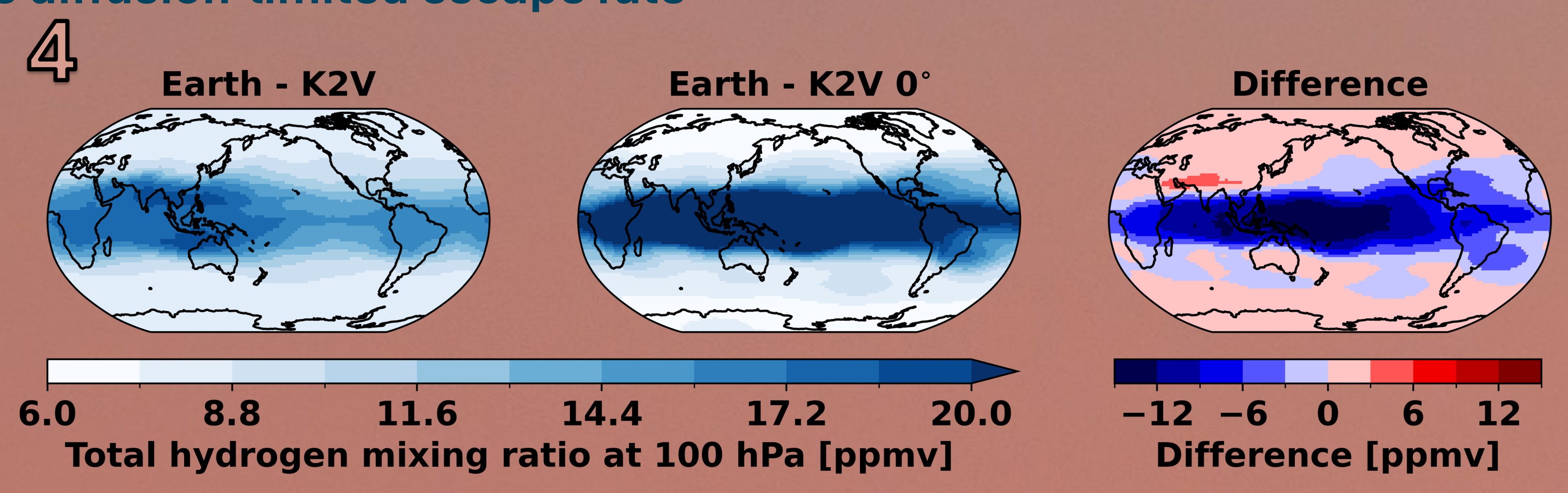
The cold trap

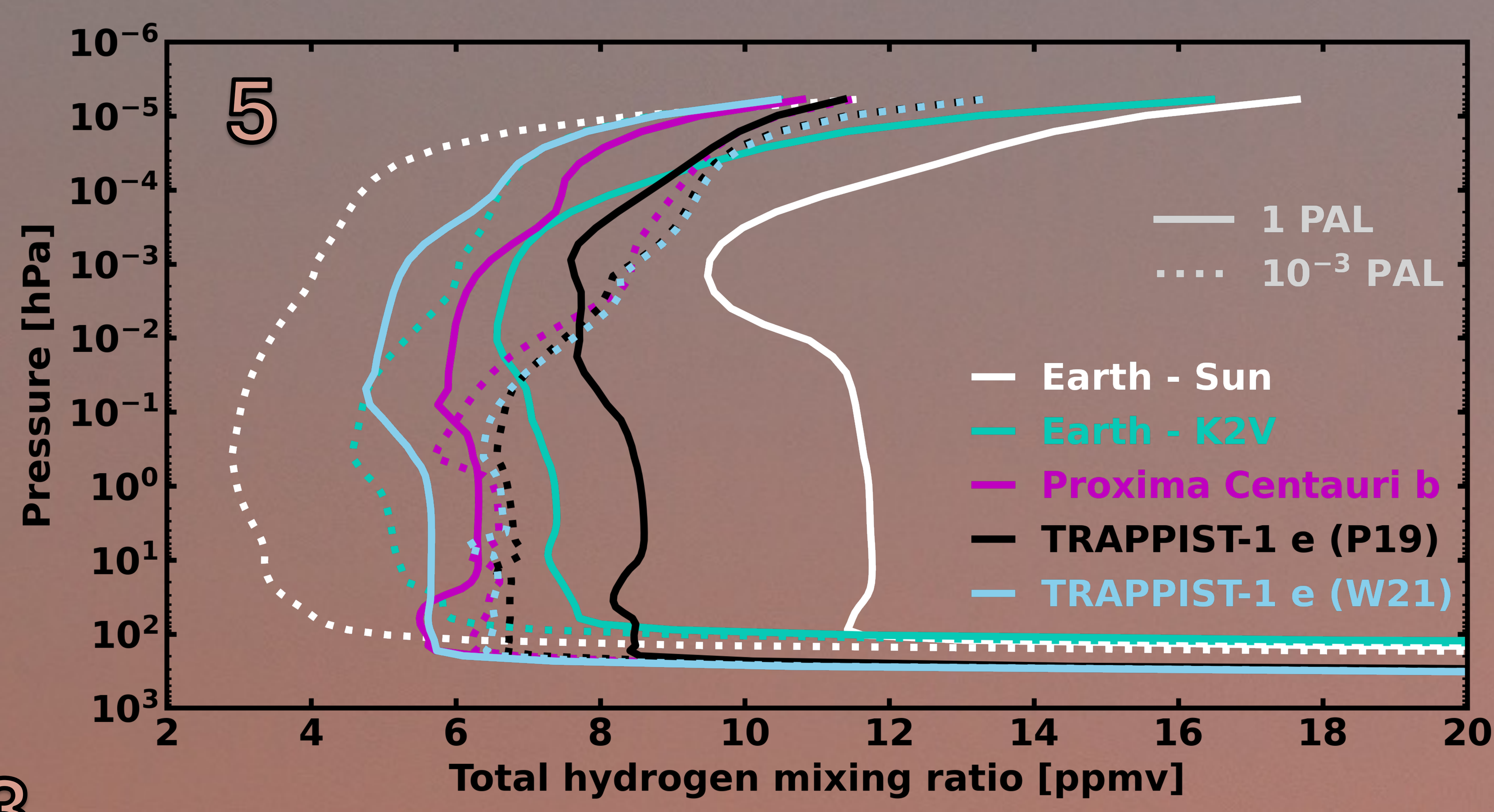
On Earth, the cold trap (also known as the tropical tropopause layer – TTL), is a region in Earths atmosphere which condenses out atmospheric water vapour, resulting in a dry stratosphere.

O_3 causes the temperature inversion in Earth's atmosphere and applies warming to the TTL. Previous work has involved assessing how ozone (O_3) changes in the stratosphere [1] and at the surface [2]. Changes in the amount of O_2 and incoming UV radiation affect the O_3 layer and atmospheric stratospheric heating around the TTL.





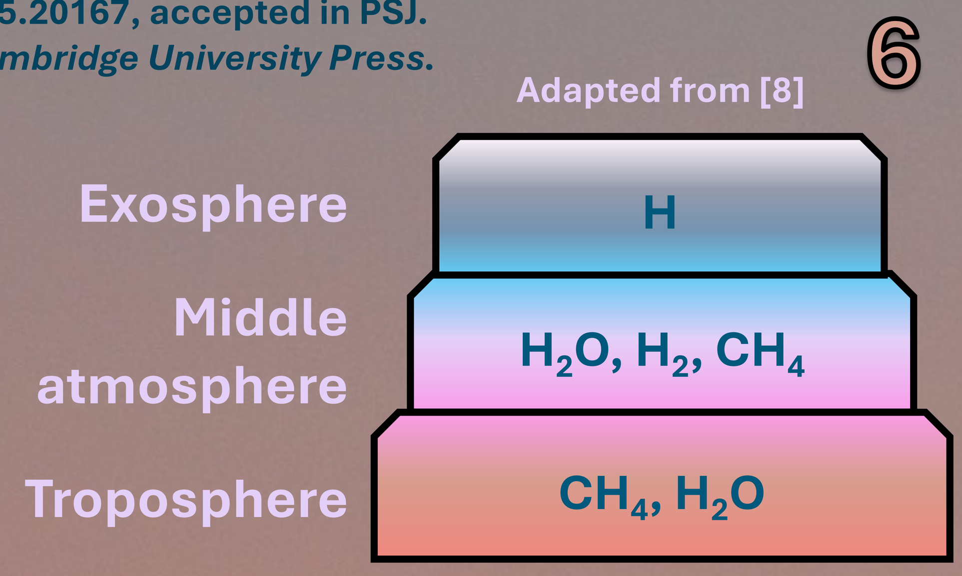




Hydrogen atoms go up

The major hydrogen bearing species on Earth are H_2O, CH_4, H_2, and H, together making up 'total hydrogen'.

The cold trap sets the amount of water (and thus hydrogen) reaching the middle atmosphere (see figs 2 - 4). A second bottleneck is the diffusion above the homopause, which sets a diffusion-limited escape rate in the exosphere, where hydrogen escapes from (see top of fig 5). Obliquity, oxygen concentration, and UV radiation all affect the diffusion-limited escape rate



Next Steps (start reading at the bottom, hydrogen is busy escaping from here)

- How does the tropical water vapour tape recorder respond on different exoplanets in terms of strength and temporal variability?
- Are there any detectable observational differences?
- What happens when composition other than O_2 (e.g., CO_2, CH_4) is altered?
- Write the paper!

References

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