SPICAM UV Observations of H Corona and Airglow Variability

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Jean-Loup Bertaux, and the SPICAM team

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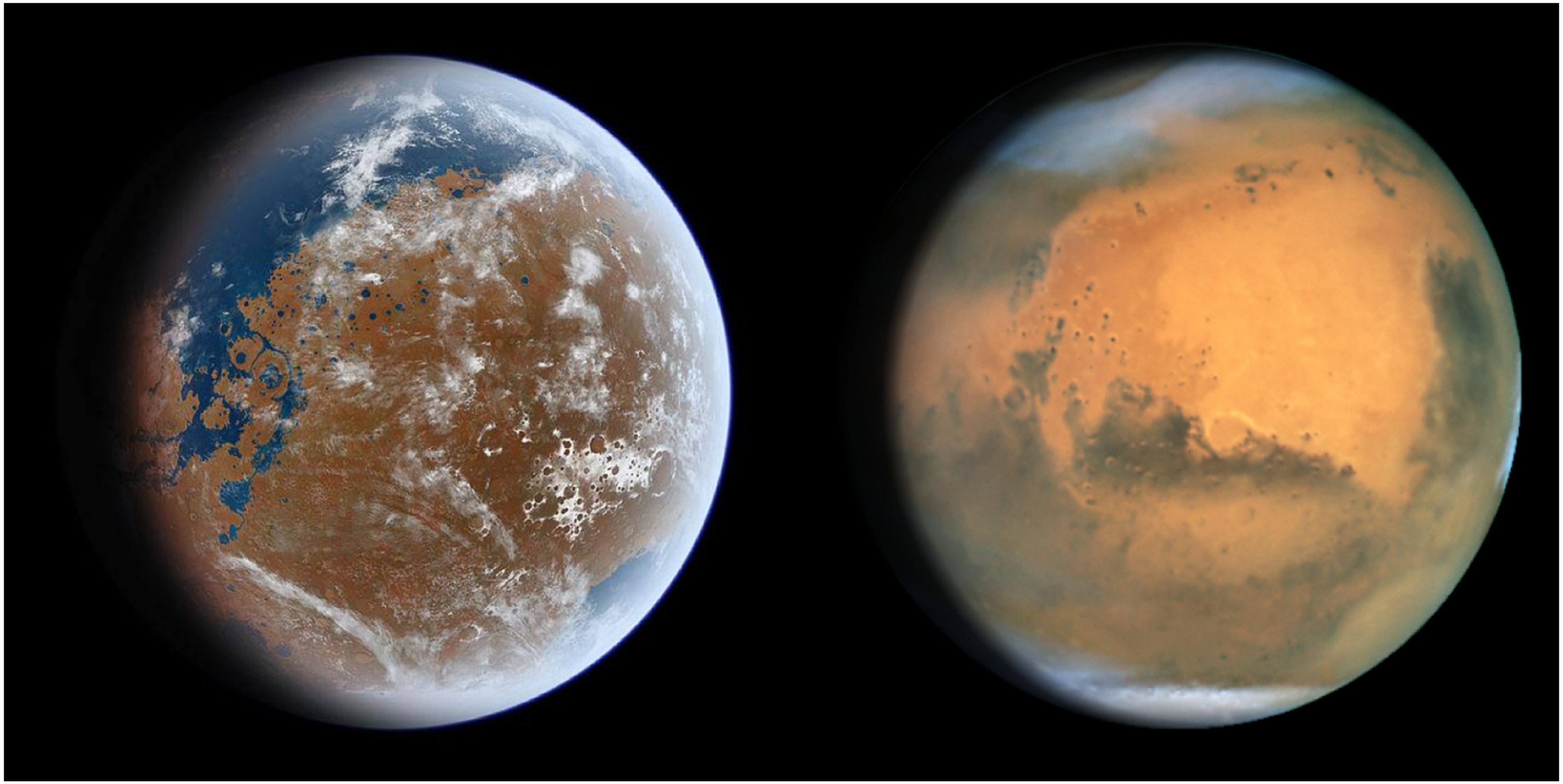
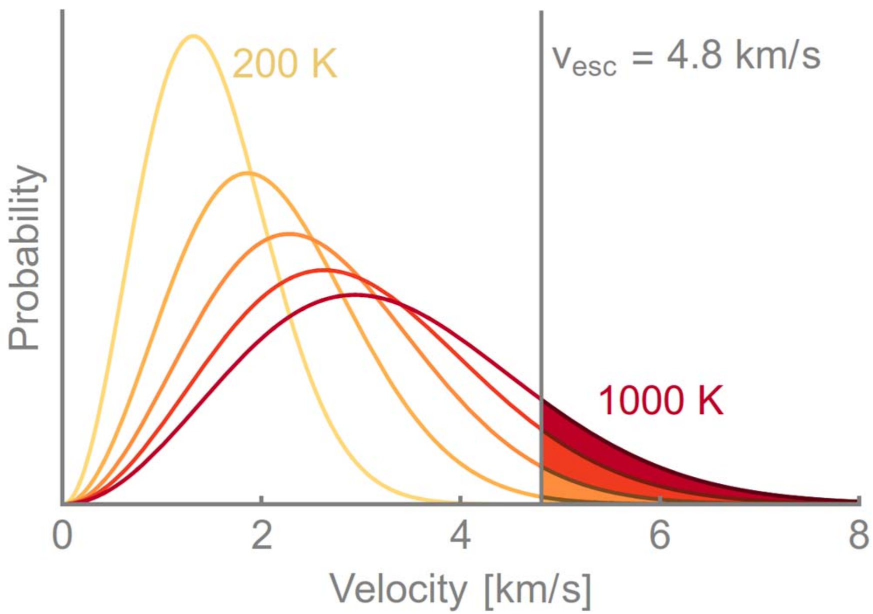
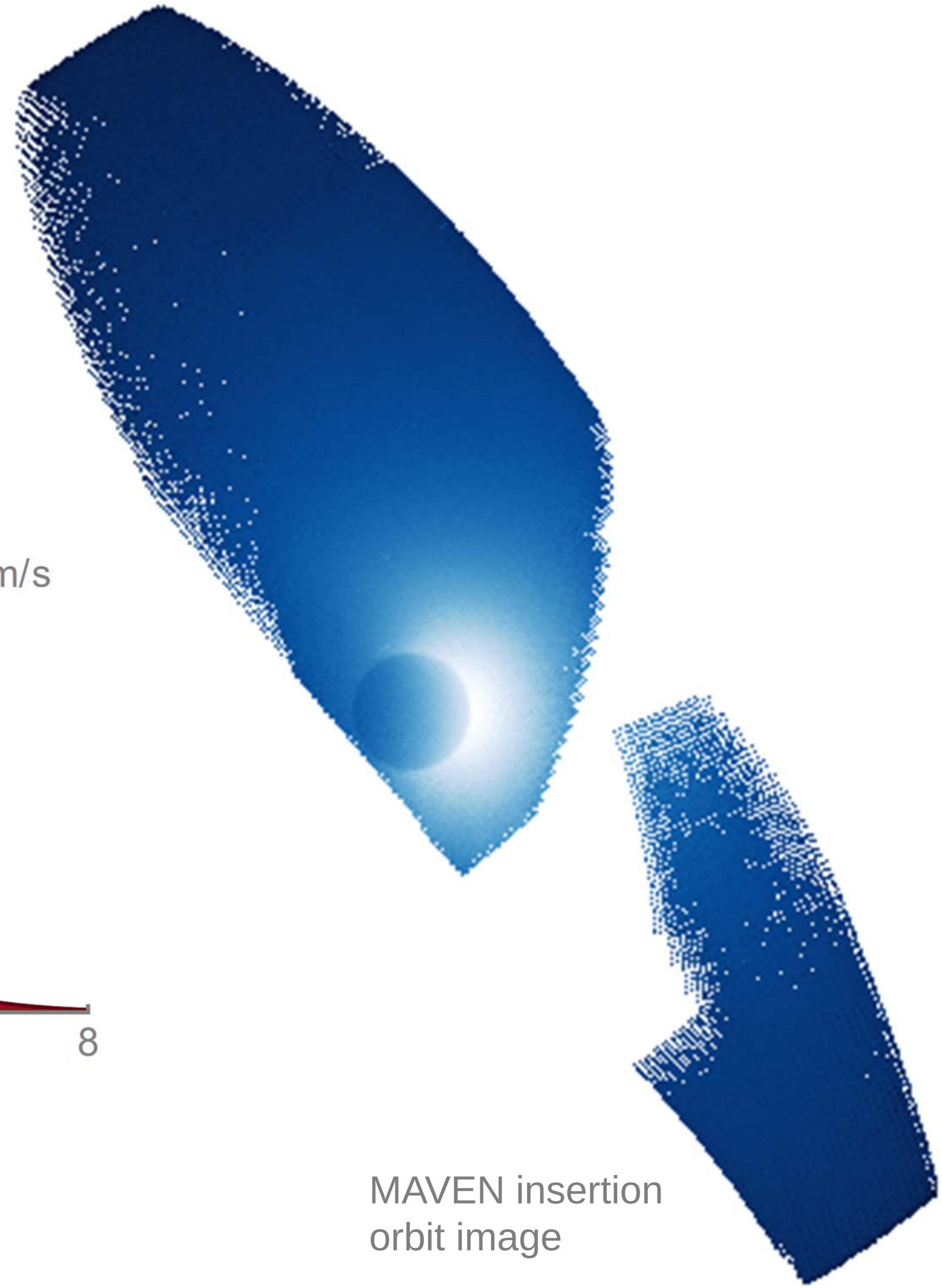
MEX to TGO workshop



Escape to space has removed Martian water; measurements of the upper atmosphere may reveal how

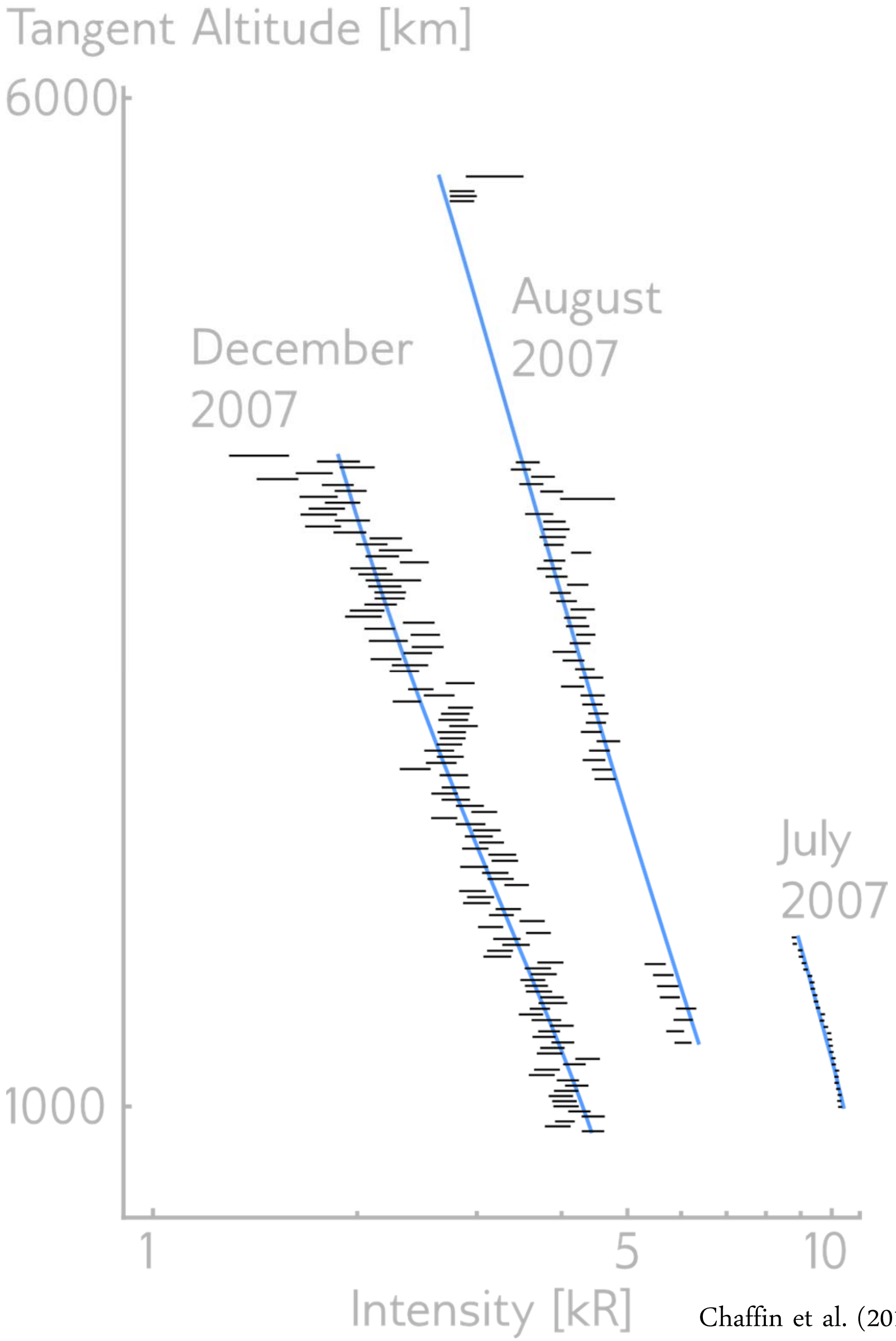
H is escaping from Mars today via Jeans escape





MAVEN insertion orbit image

In 2007, the H Corona dimmed by a factor of 2



Chaffin et al. (2014)

AGU PUBLICATIONS

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Unexpected variability of Martian hydrogen escape

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Key Points:

- A large decline in hydrogen escape flux from Mars to space is seen in late 2007
- This variation is not explained by prior models or measurements
- Lower atmospheric dust storms may greatly enhance water escape from Mars

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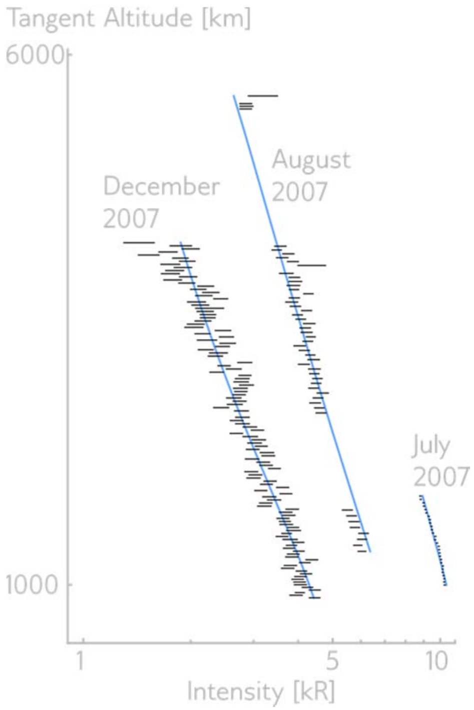
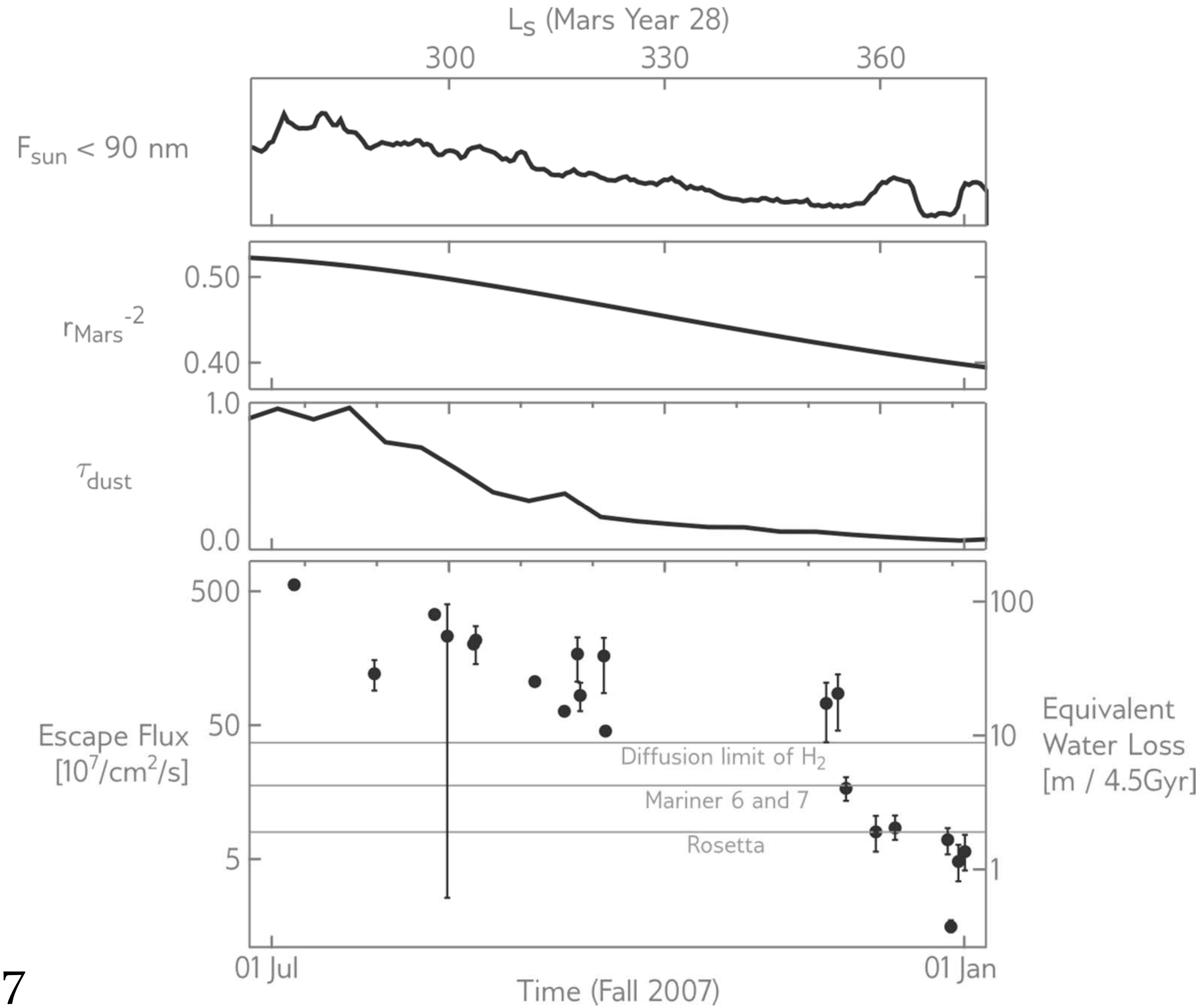
Abstract Mars today is much drier than the Earth, though they likely began with similar relative amounts of water. One potential cause for this discrepancy is hydrogen loss to space, which may have removed a large fraction of Mars' initial water. Here we demonstrate an order-of-magnitude change in the Martian hydrogen escape rate in 2007, inconsistent with established models for the source of escaping hydrogen. We analyze 121.6 nm (hydrogen Lyman-α) airglow observations made by the ultraviolet spectrometer on the Mars Express spacecraft over the second half of 2007. The enhanced escape rates we observe may be due to lower atmospheric heating and overturn during the 2007 (Mars Year 28) global dust storm, suggesting that hydrogen escape from Mars during dust storms may dominate loss of the planet's water inventory. This scenario has major implications for reconstructing the total amount of water lost to space over Martian history.

1. Introduction

The first observations of atomic hydrogen in the upper atmosphere of Mars were made by Mariners 6, 7, and 9, which observed 121.6 nm (hydrogen Lyman-α) sunlight scattered by the outer fringes of the Martian atmosphere, known as the hydrogen corona [*Anderson*, 1974]. More recent investigations have been performed with the ultraviolet spectrometer on the European Space Agency's Mars Express mission, SPICAM (Spectroscopy for the Investigation of the Characteristics of the Atmosphere of Mars) [*Bertaux et al.*, 2000, 2006]. Previous work studying the hydrogen corona using SPICAM by *Chaufray et al.* [2008] focused on seven observations; we extend their method to analyze 21 observations in time sequence, taken over the second half of 2007. All of these previous studies were limited in time resolution; the longest contiguous time span previously studied spanned 30 days beginning in March 2005. Ours is thus the first study with the potential to determine the long-term average H escape rate from Mars and the first capable of detecting its time variability on the scale of months.

These observations were selected for analysis to determine the escape rate of hydrogen from the atmosphere of Mars, which is thought to be controlled by near-surface and ionospheric chemistry and diffusion through the thermosphere. Soon after the discovery that Mars has a CO_2 atmosphere, early work established that this atmosphere remained stable against photochemical conversion of CO_2 into CO and O_2 through the odd hydrogen cycle, which catalyzes the recombination of CO and O species into carbon dioxide via photodissociation products of water near the Martian surface [*McElroy and Donahue*, 1972; *Parkinson and Hunten*, 1972]. As a by-product, this cycle produces molecular hydrogen, which has an atmospheric lifetime of hundreds of years [*Hunten and McElroy*, 1970]. Because molecular hydrogen is light and volatile, it can be mixed upward into the ionosphere, whereas water is trapped close to the surface by the cold trap at the tropopause [*Clancy et al.*, 1996]. Once it arrives in the ionosphere, most of this molecular hydrogen is quickly destroyed through reaction with CO_2^+ [*Krasnopolsky*, 2002], producing atomic hydrogen which diffuses toward the exobase. At the exobase, the fraction of the hydrogen atoms with velocities greater than Martian escape velocity can escape to space. In this model, because the escaping hydrogen is sourced from long-lived molecular hydrogen, its escape rate should not be a strong function of season or solar cycle but should only respond modestly to changes in the solar extreme ultraviolet flux that drive the dissociation and ionization processes relevant to hydrogen.



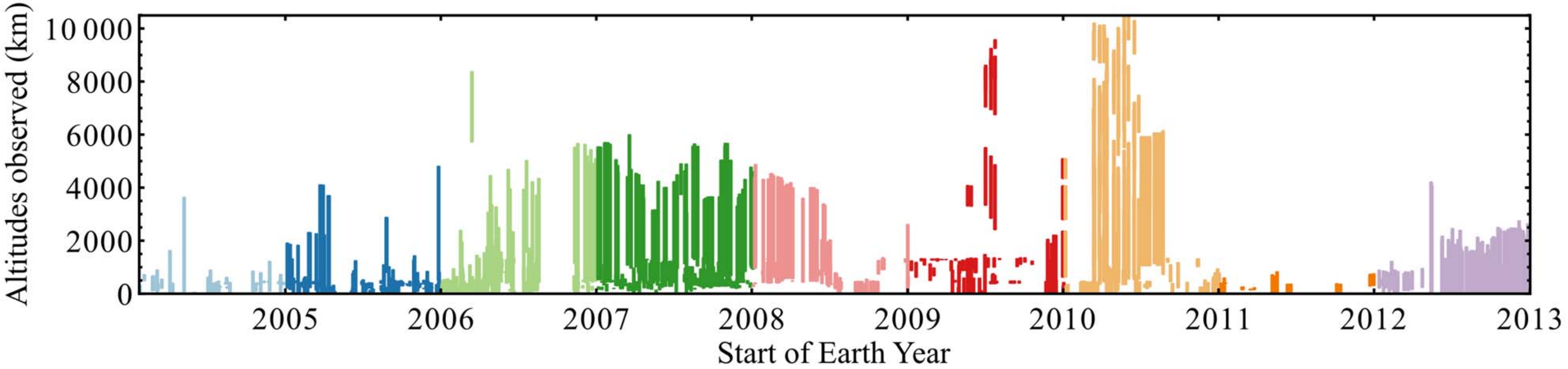


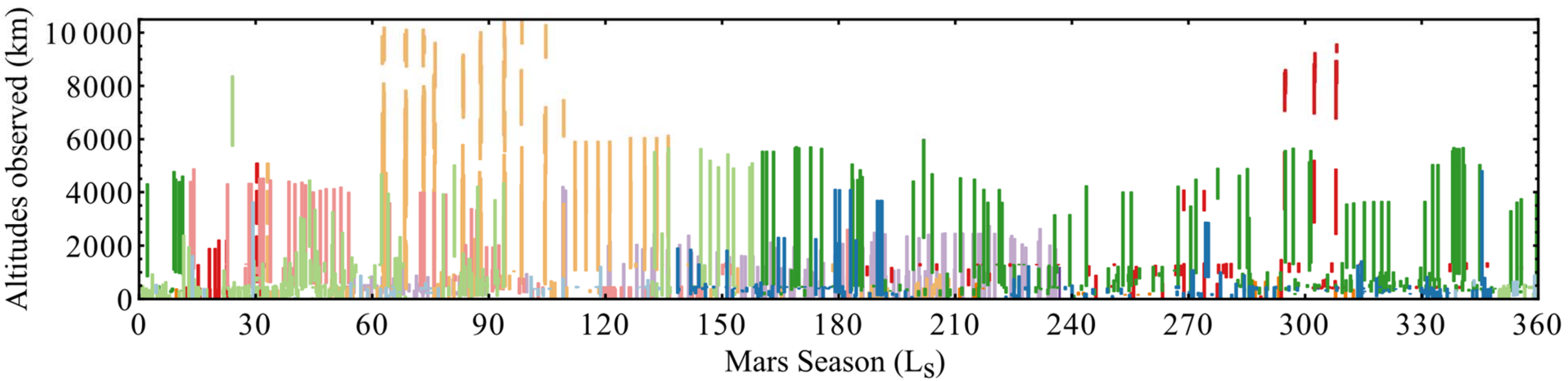
High escape in 2007

is correlated with Southern summer

and a global dust storm

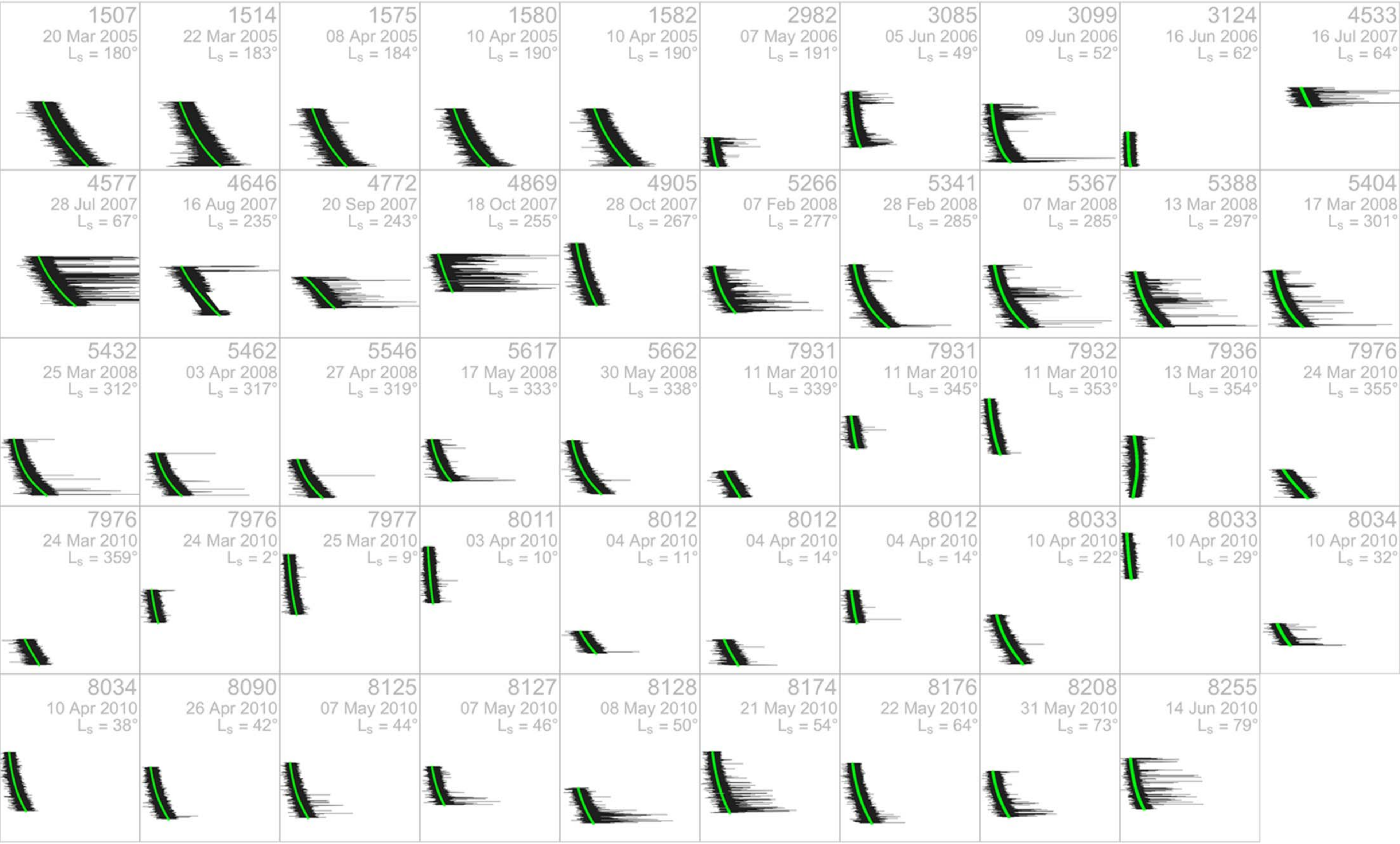
Let's expand our search to the rest of the SPICAM dataset…



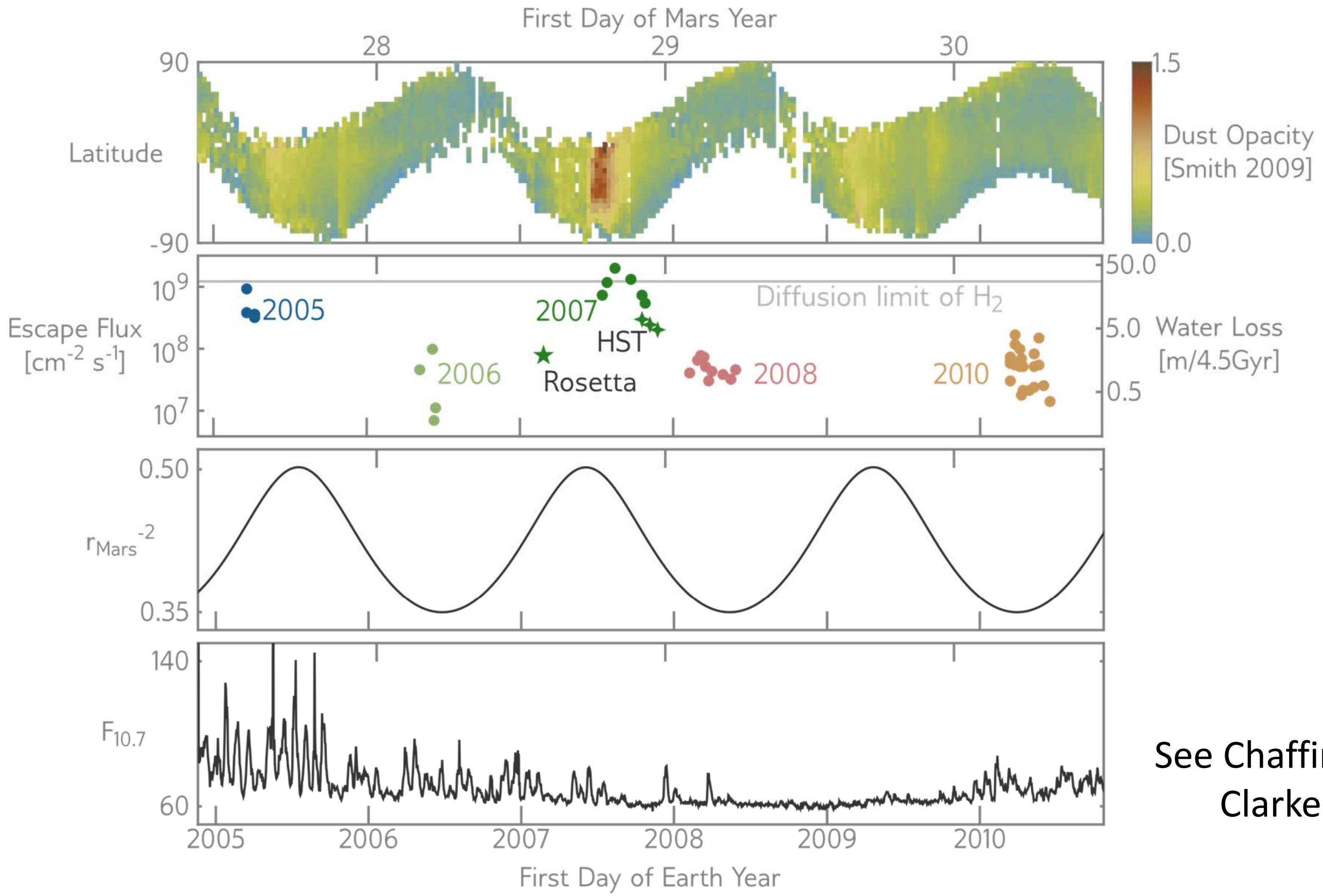


…unfortunately, Southern summer is poorly covered by SPICAM H observations

The complete reduced SPICAM H dataset



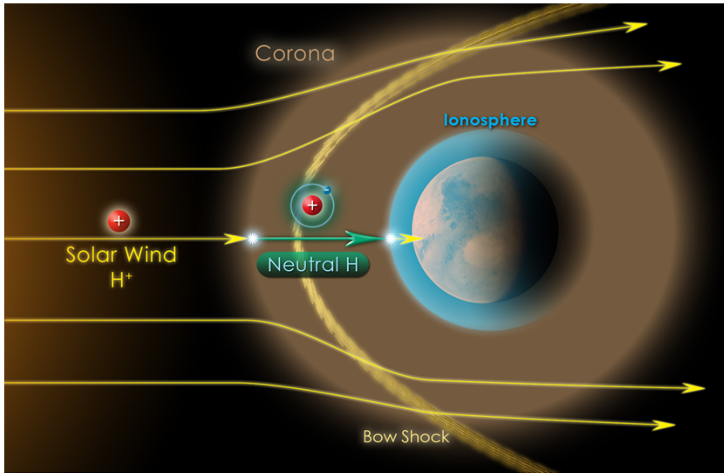
Southern summer is poorly covered by SPICAM H observations…

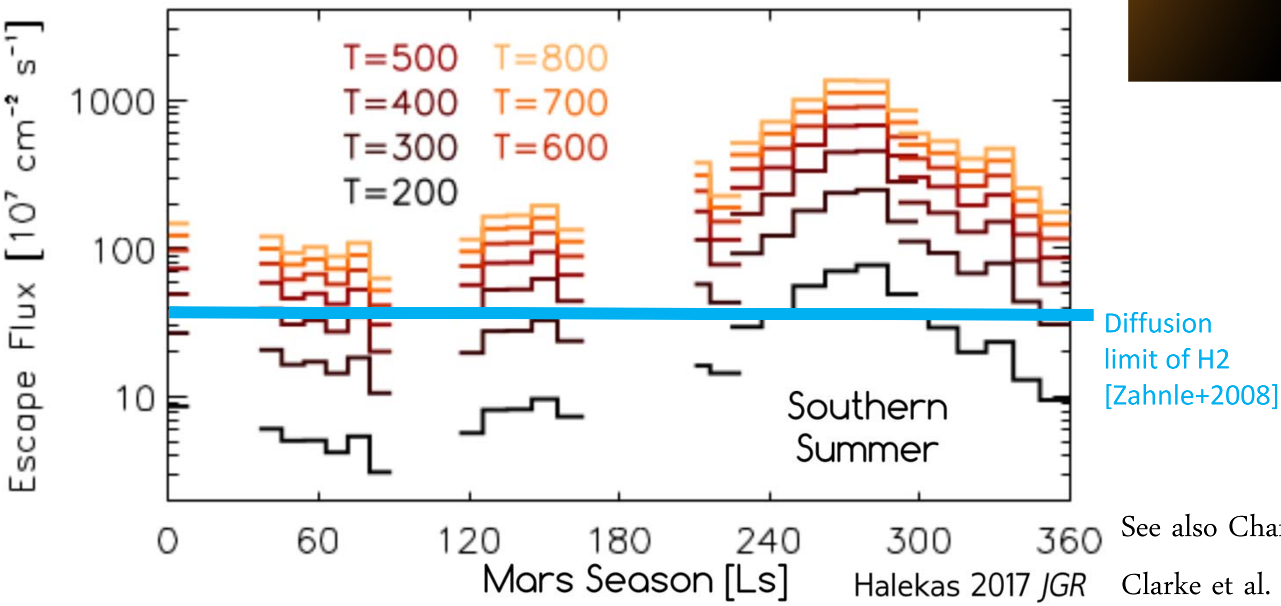


See Chaffin+2014
Clarke+2014

…MAVEN is beginning to fill this gap

Southern summer is poorly covered by SPICAM H observations…





Halekas 2017 *JGR*

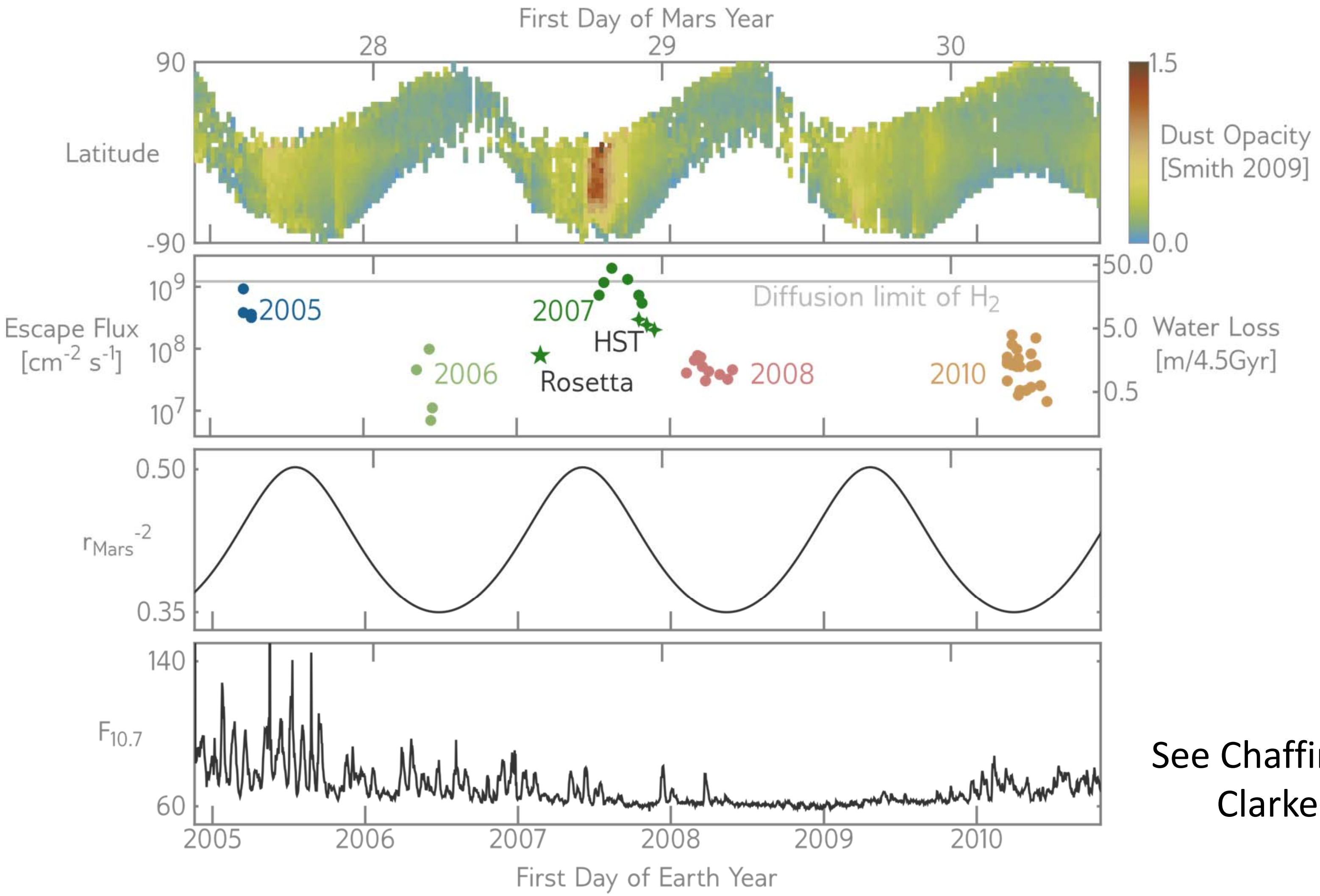
See also Chaffin et al. (2014) GRL

Clarke et al. (2014) GRL,

Bhattacharyya et al (2015) GRL

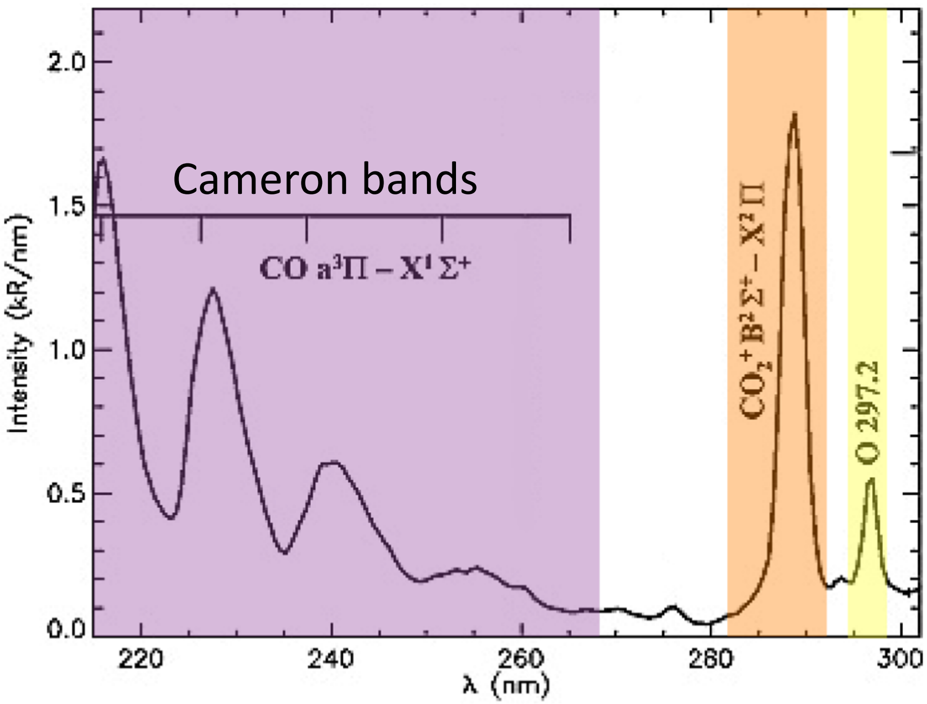
…MAVEN is beginning to fill this gap

What else can the 2007 dust storm data tell us?

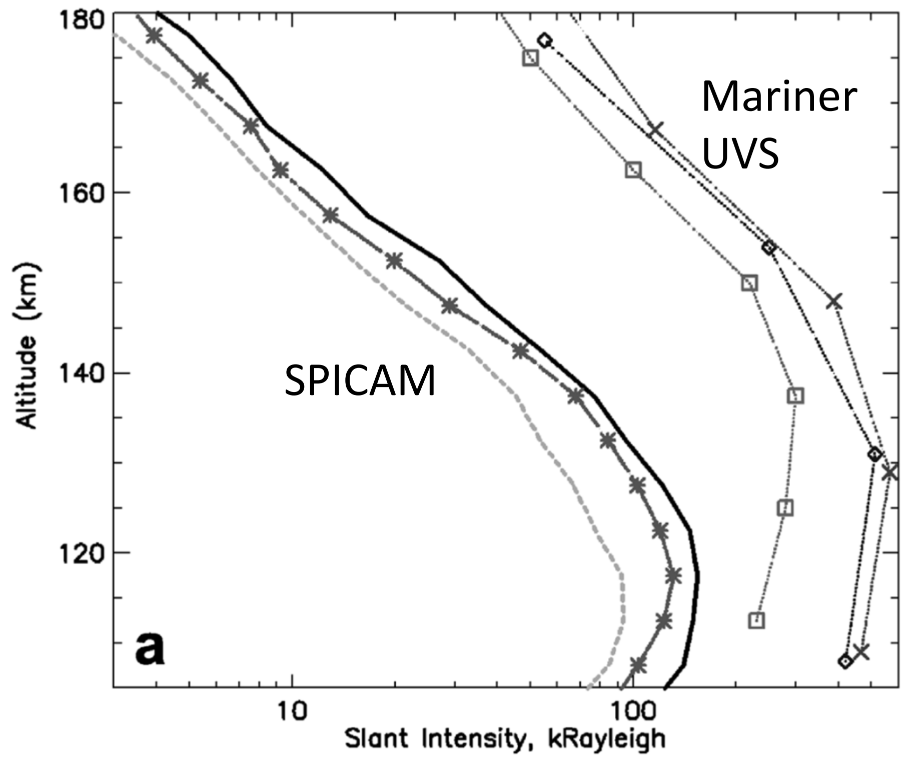


See Chaffin+2014
Clarke+2014

Intensities and altitude profiles of MUV emission reveal thermospheric structure

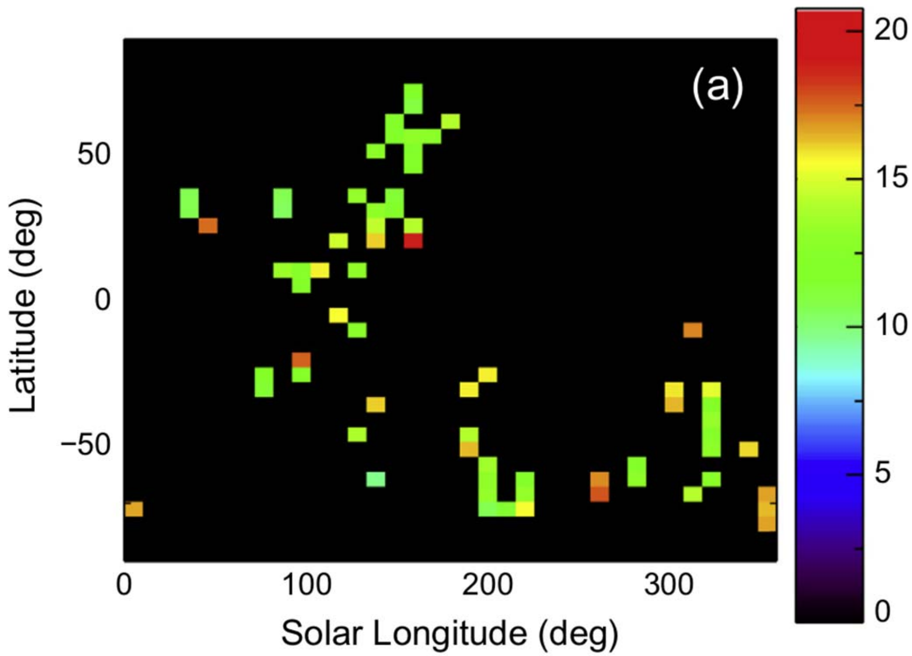


Cameron band altitude profiles



Leblanc+2006

Previous analysis found no trend with season

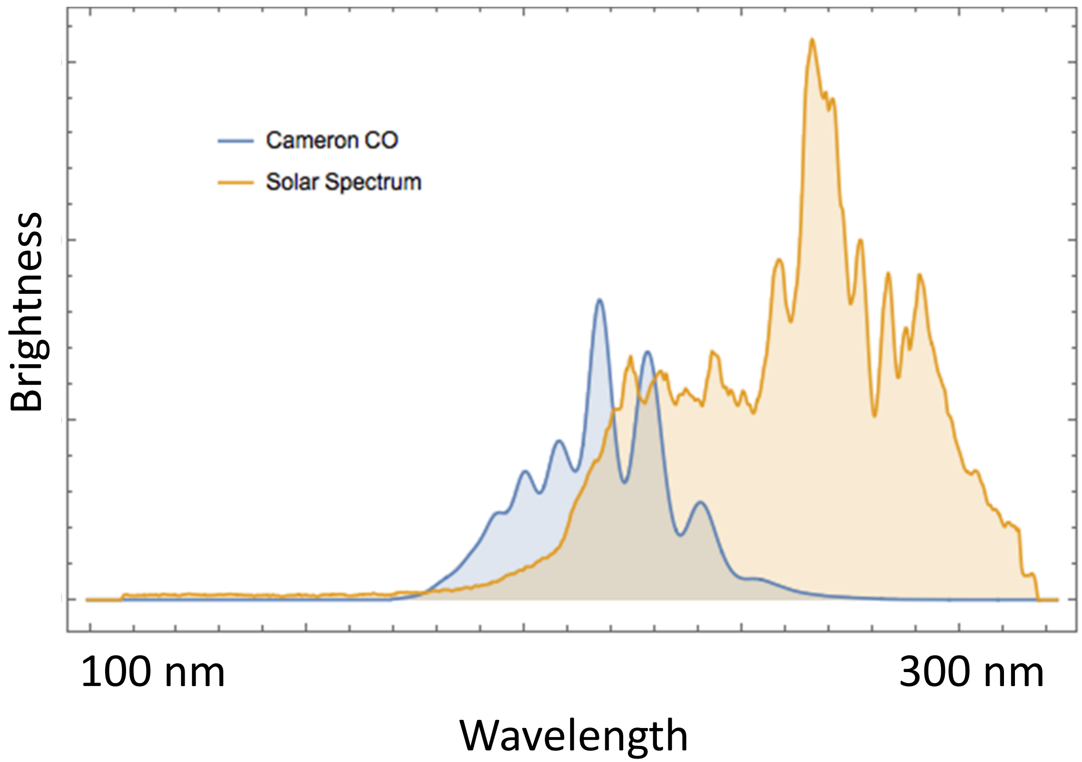


Cameron band scale height [km]

During the major dust storm of 2007, the CO_2 and dust densities in the atmosphere greatly remained unusually high for a long time. This CO_2 density increase may be correlated with an increase of the thermospheric temperature at a given altitude as the atmosphere expands, as suggested by Stewart et al. (1972) and modeled by Bougher et al. (2000). We found however no such correlation.

Stiepen+2015

Emissions are extracted using multiple linear regression

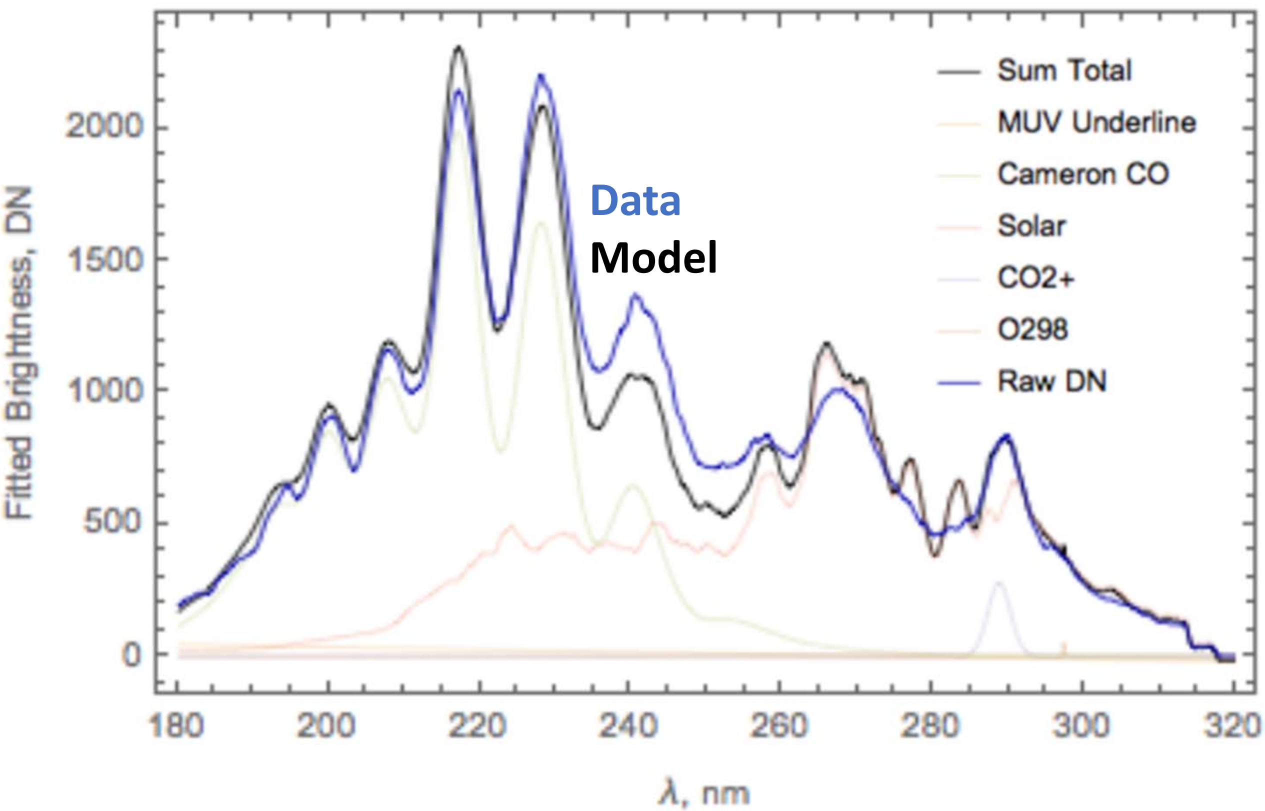


Template Cameron band model from Mike Stevens, degraded to SPICAM resolution

Template solar stray light compiled from SPICAM nadir observations

CO2+ UVD modeled as unconstrained Gaussian

Emissions are extracted using multiple linear regression



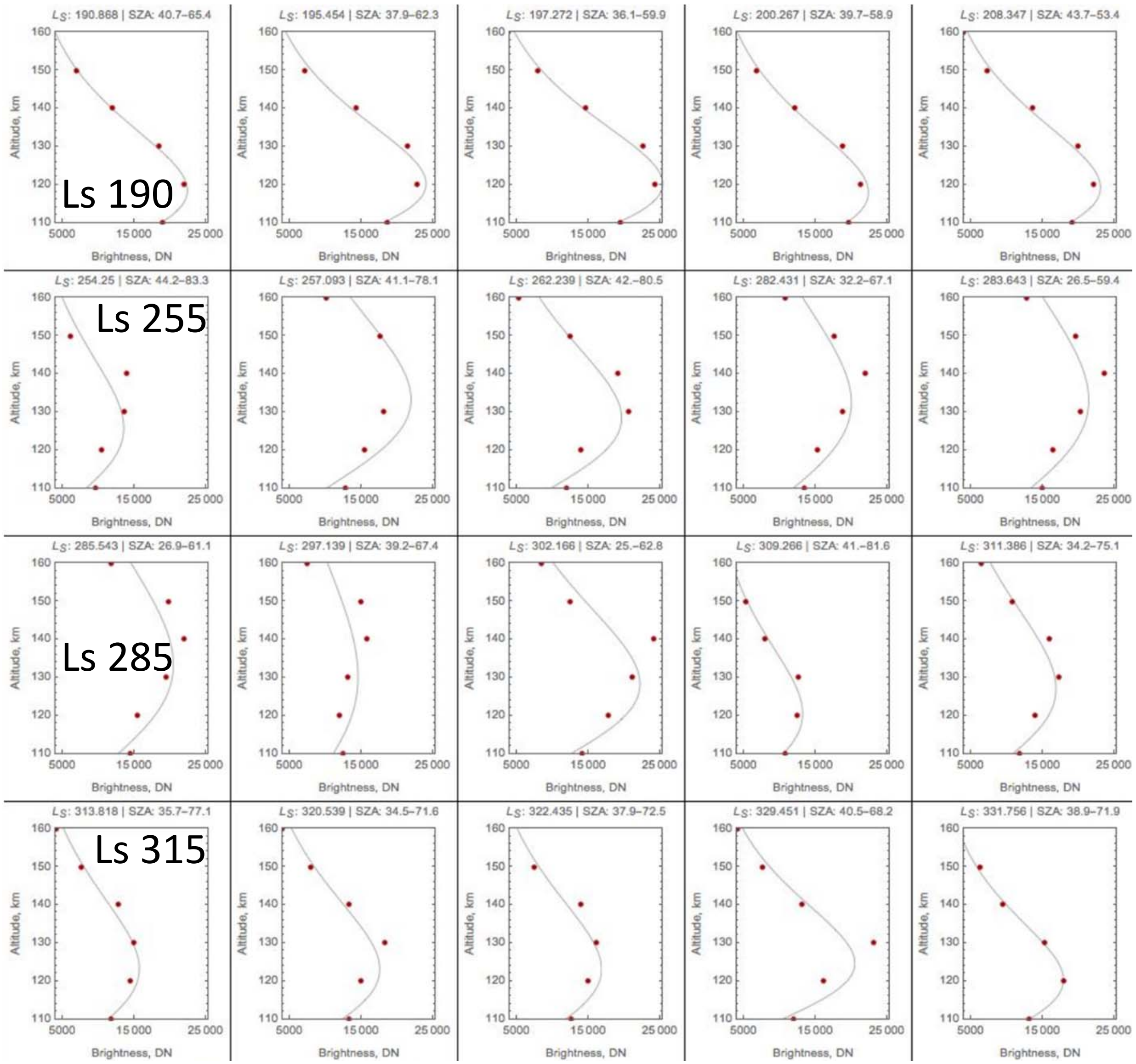
Model fits underestimate brightness at 230-260 nm due to poor solar component.

Cameron bands generally fit well.

CO_2^+ UVD is typically a small perturbation on solar component.

Other emissions unretrievable.

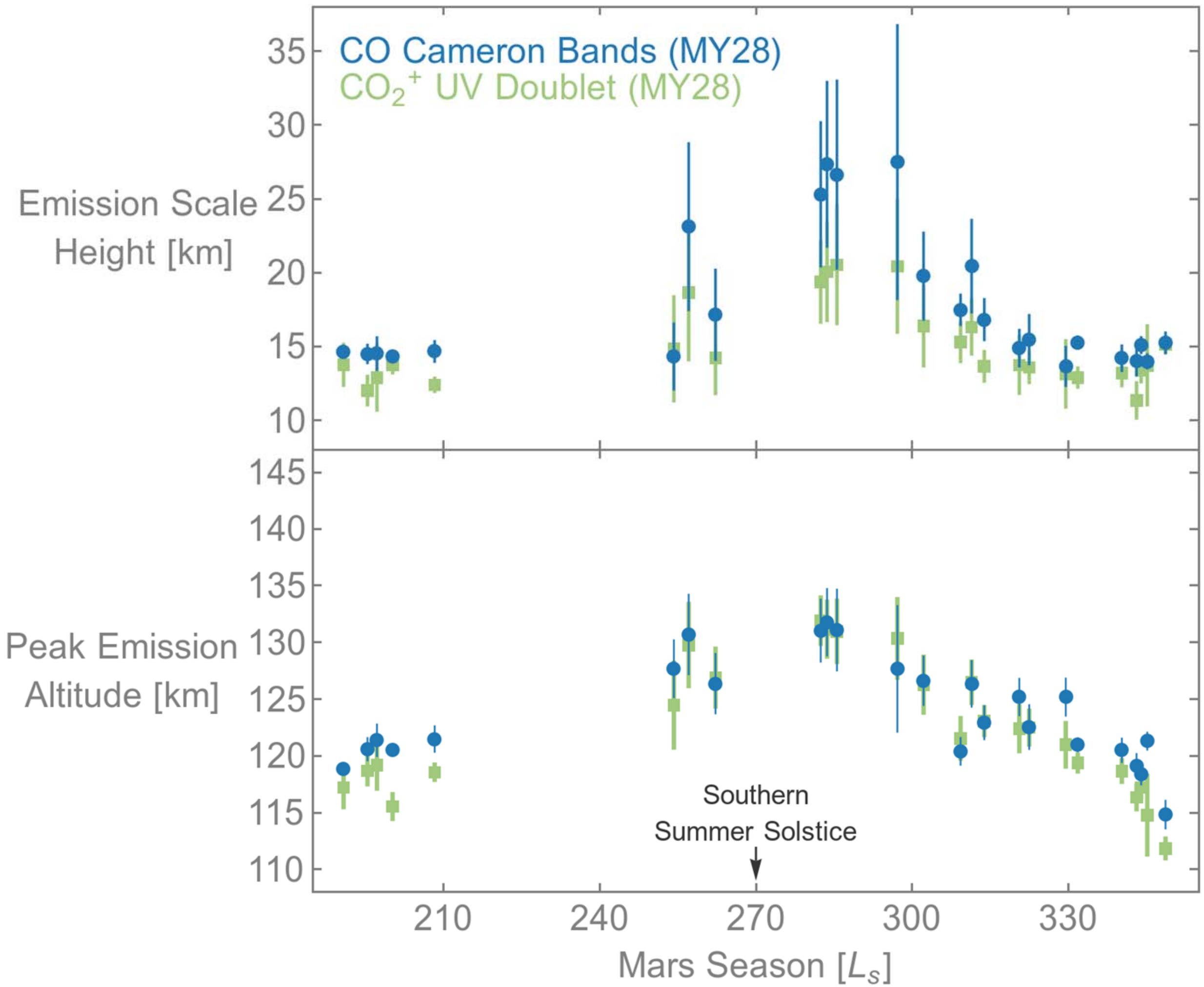
Profiles are fit with a Chapman model



Profile peak altitude shows trend with season in binned data.

Difference with prior work may result from different treatment of solar component.

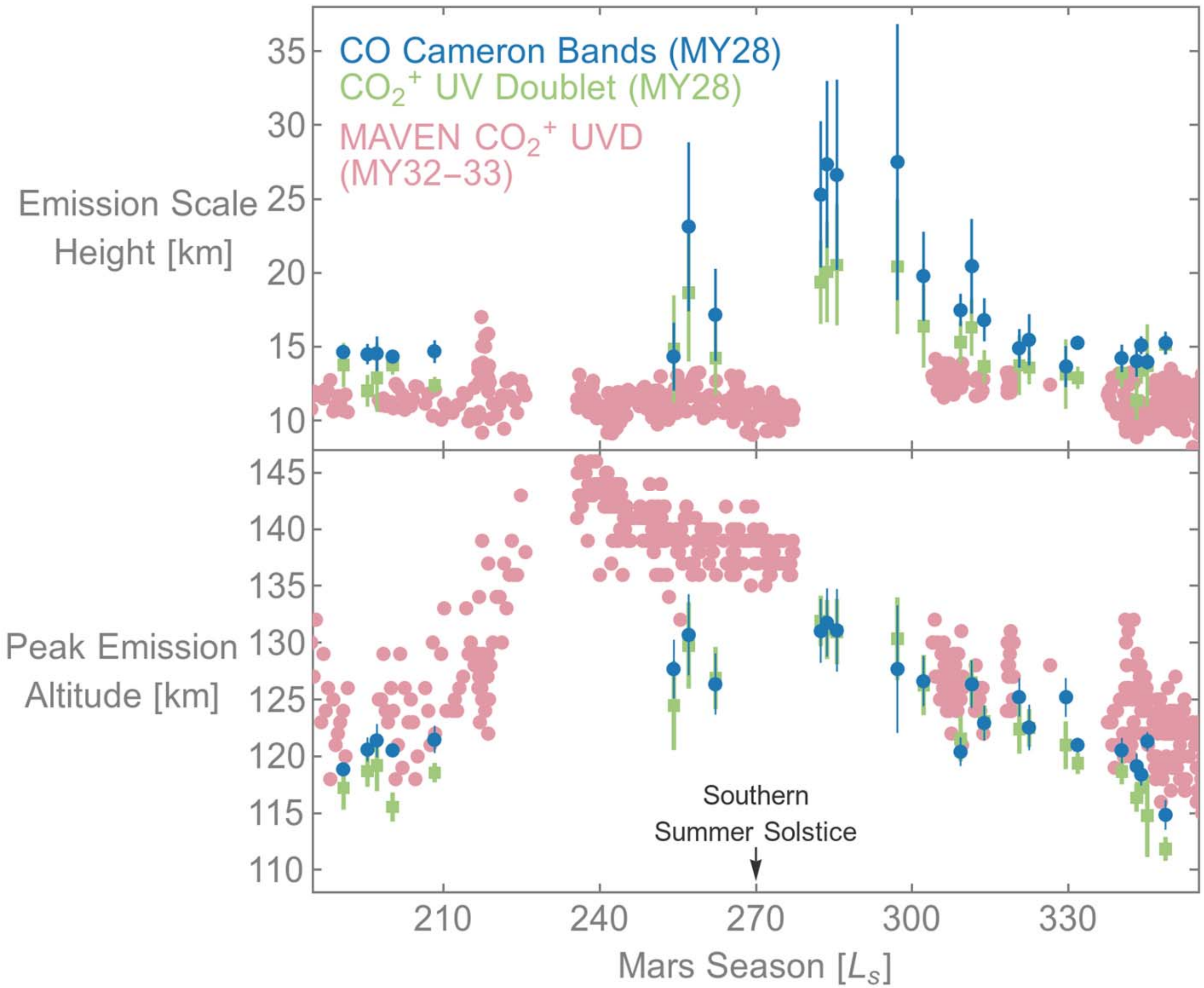
Resulting scale heights and altitudes peak near solstice during dust storm



Scale heights increase for both emissions, but uncertainty is large.

Peak altitude increases by ~15 km, roughly one scale height.

Comparison with MAVEN data suggests spatial variation may swamp seasonal signal

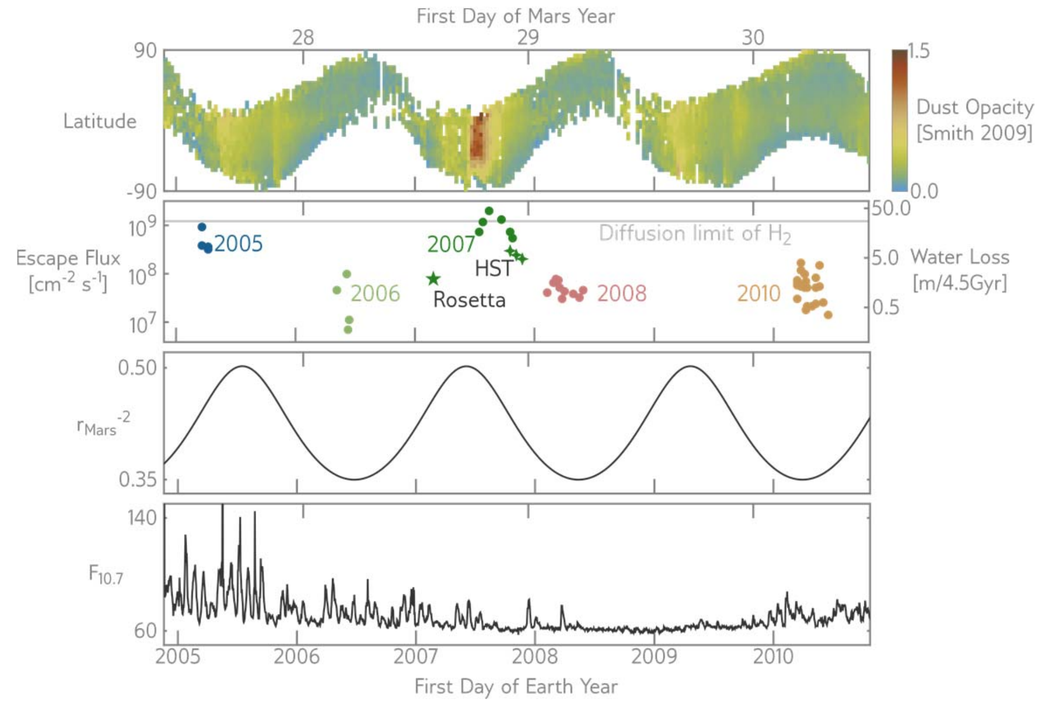


IUVS scale heights are nearly constant

IUVS altitudes are systematically higher, more variable despite less dust in MY 32-33.

Summary

MEX/SPICAM was the first to quantify seasonal variability in H escape [Chaffin+2014,Clarke+2014]



SPICAM data show seasonal trend in CO/CO2+ peak alt and scale height.

Discrepancies with other measurements may result from methodology or spatial variation; more analysis required.