Lyman alpha image of Mars;
Some of this H is escaping
[Chaffin+15]

Mars Hydrogen Loss: A Template for Exoplanet Escape

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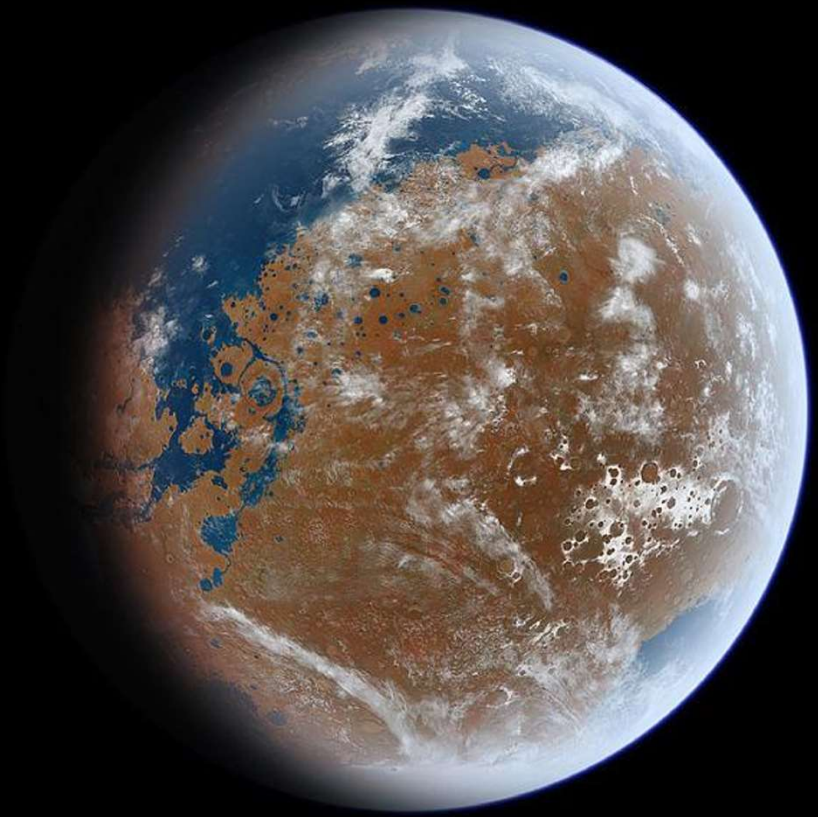
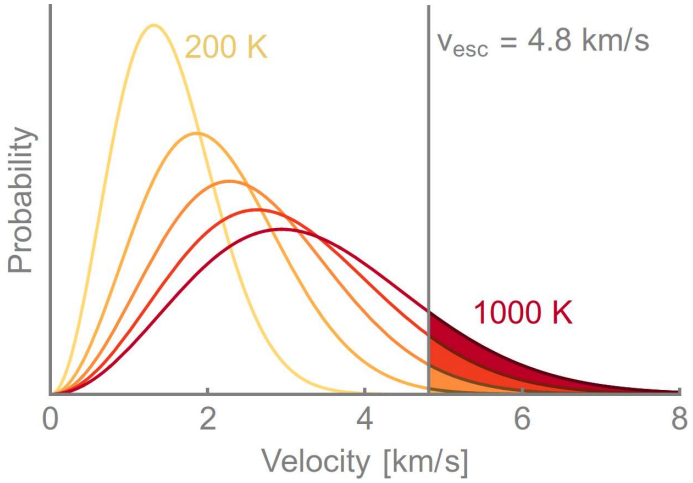
and the MAVEN/IUVS, Mars Express/SPICAM,
and EMM/EMUS science teams

How much water has Mars lost?



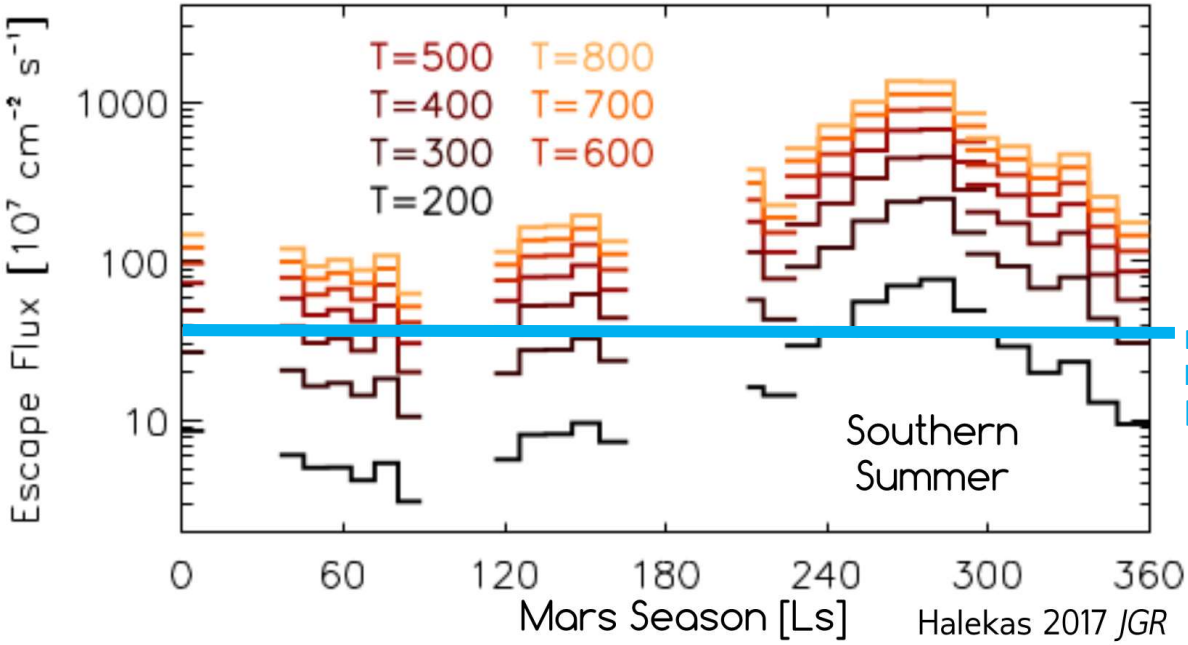
How much H is Mars losing today?

What controls the rate?



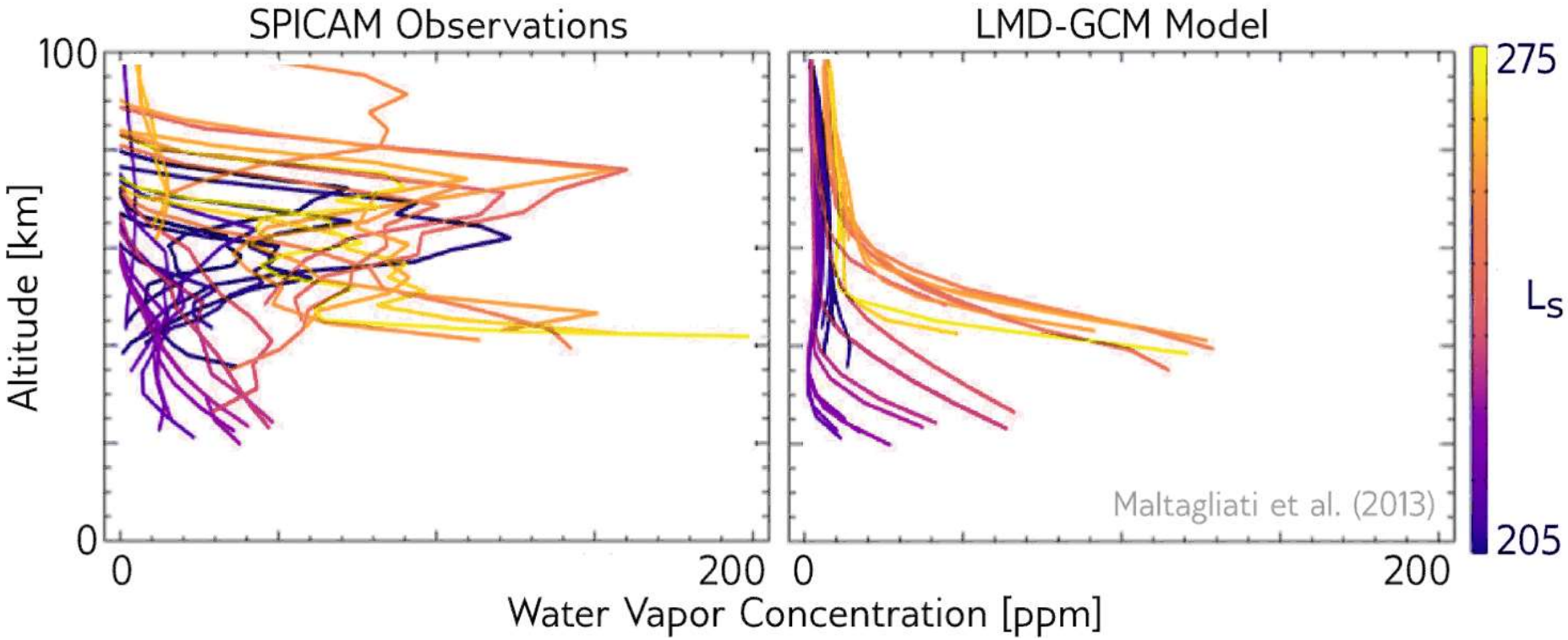
H is escaping from Mars via thermal (Jeans) escape.

Early models of H escape at Mars predicted steady H loss sourced from H2 diffusion [eg McElroy+1972]



But H Escape varies by >10x with season, requiring a different explanation [Chaffin+14,Clarke+14].

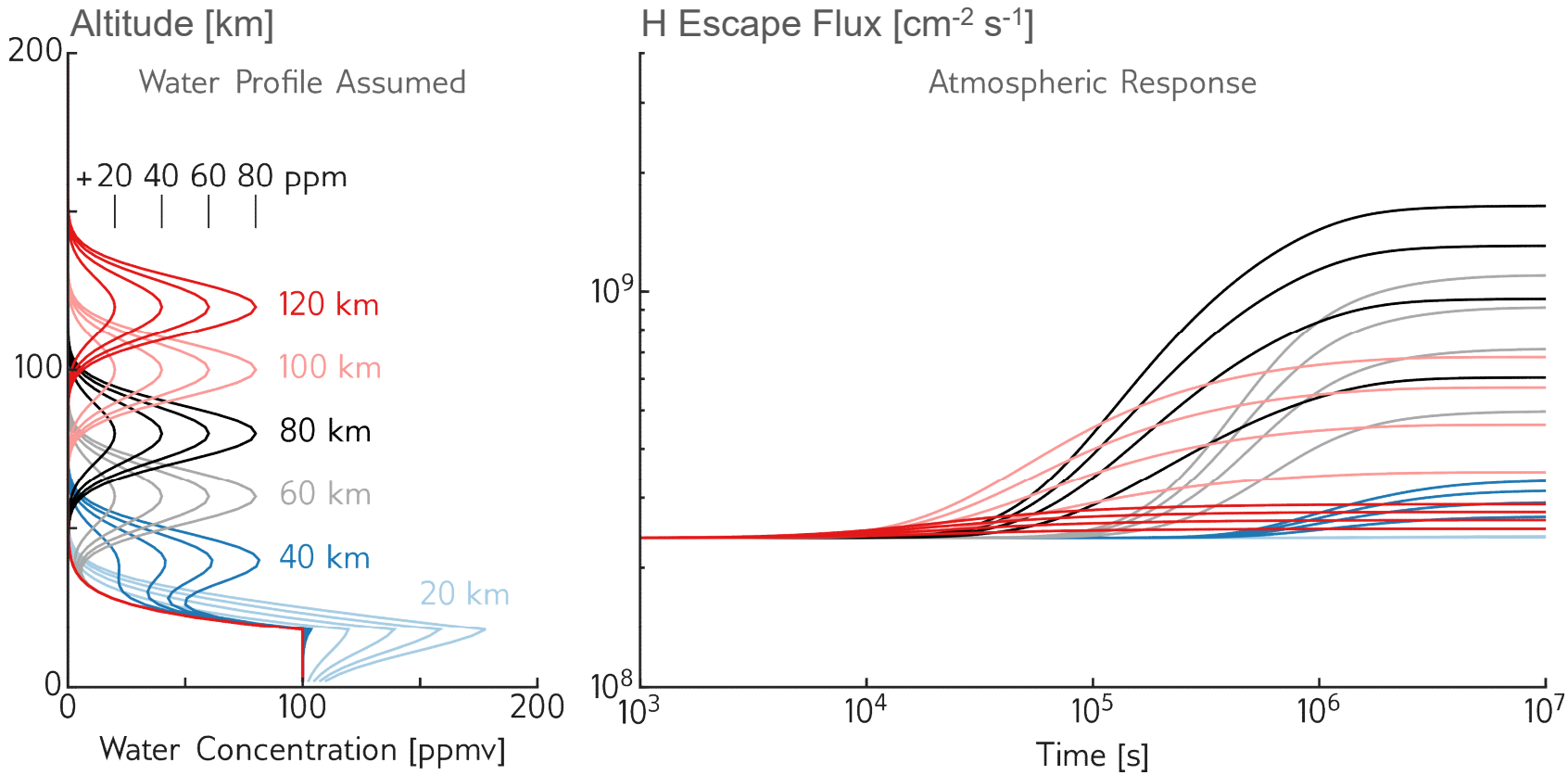
High-altitude water is a likely candidate
for powering enhanced H escape.



Observations of high-altitude water exceed model predictions;
This excess H2O can carry water to the upper atmosphere.

Mechanism that carries water to high altitude still unknown.

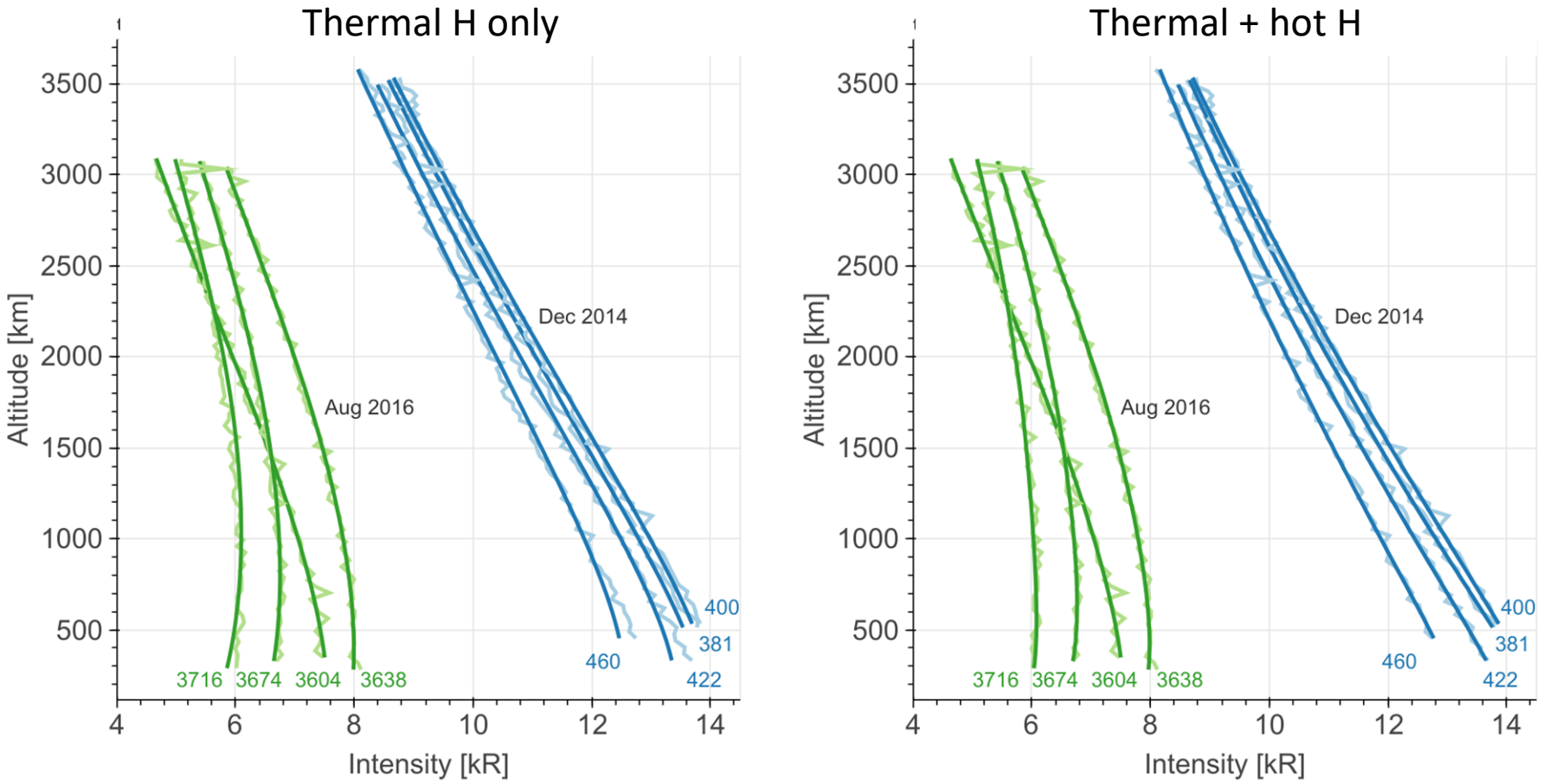
Short-term variability in H escape was thought to be unlikely due to a long-lived H2 source for escaping H



Chaffin et al. 2017 Nature Geoscience

H escape is enhanced by 5-10x within weeks of adding small amounts of water at high altitude.

MAVEN H corona profiles require hot H or deuterium



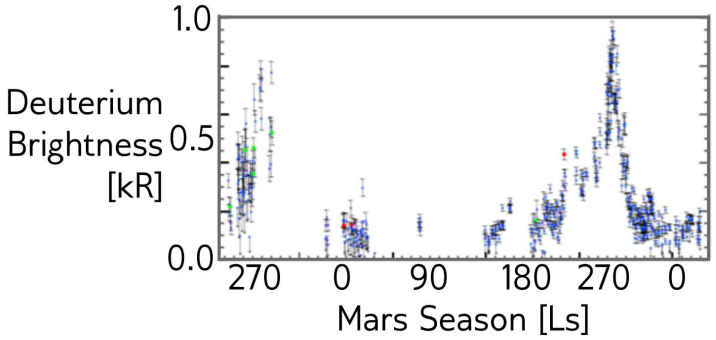
Lyman alpha brightness observations from MAVEN/IUVS
require nonthermal H escape or significant D. [Chaffin+18, JGR, submitted]

This suggests that Jeans escape is not the complete story even at low mass planets:
Nonthermal escape at Venus may provide clues for future work [Anderson+1976,Hodges1999]

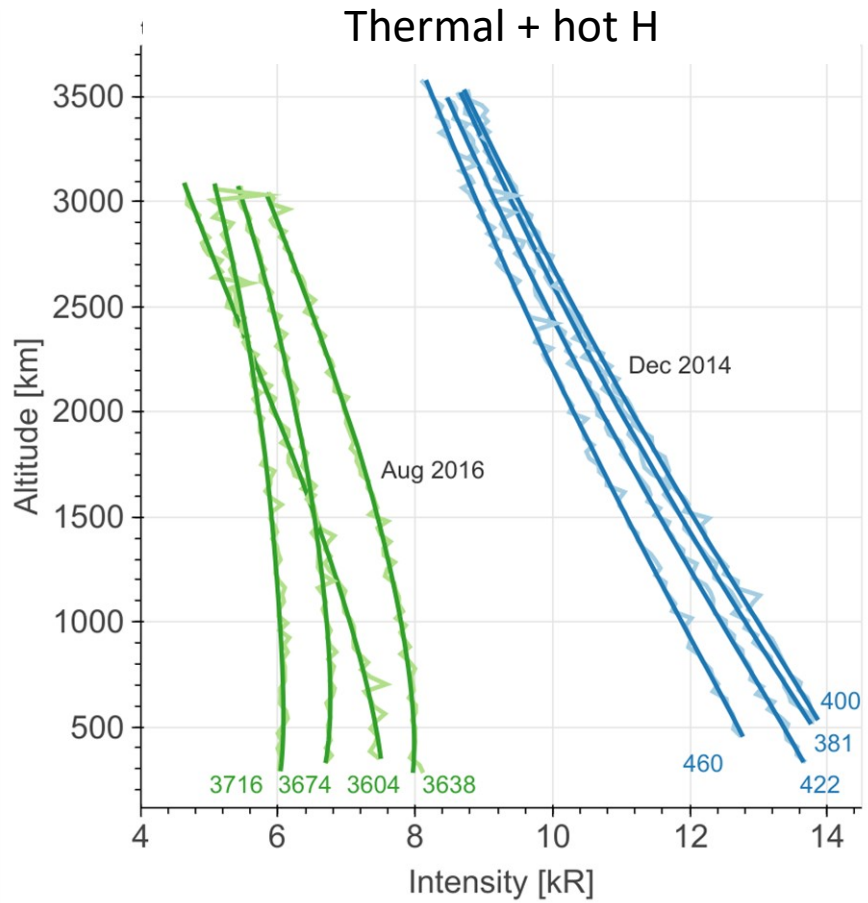
MAVEN H corona profiles require hot H or deuterium

1. D and hot H are degenerate, requiring additional constraints.

2. IUVS Echelle measurements of D/H could constrain D [Mayyasi+2017 JGR]

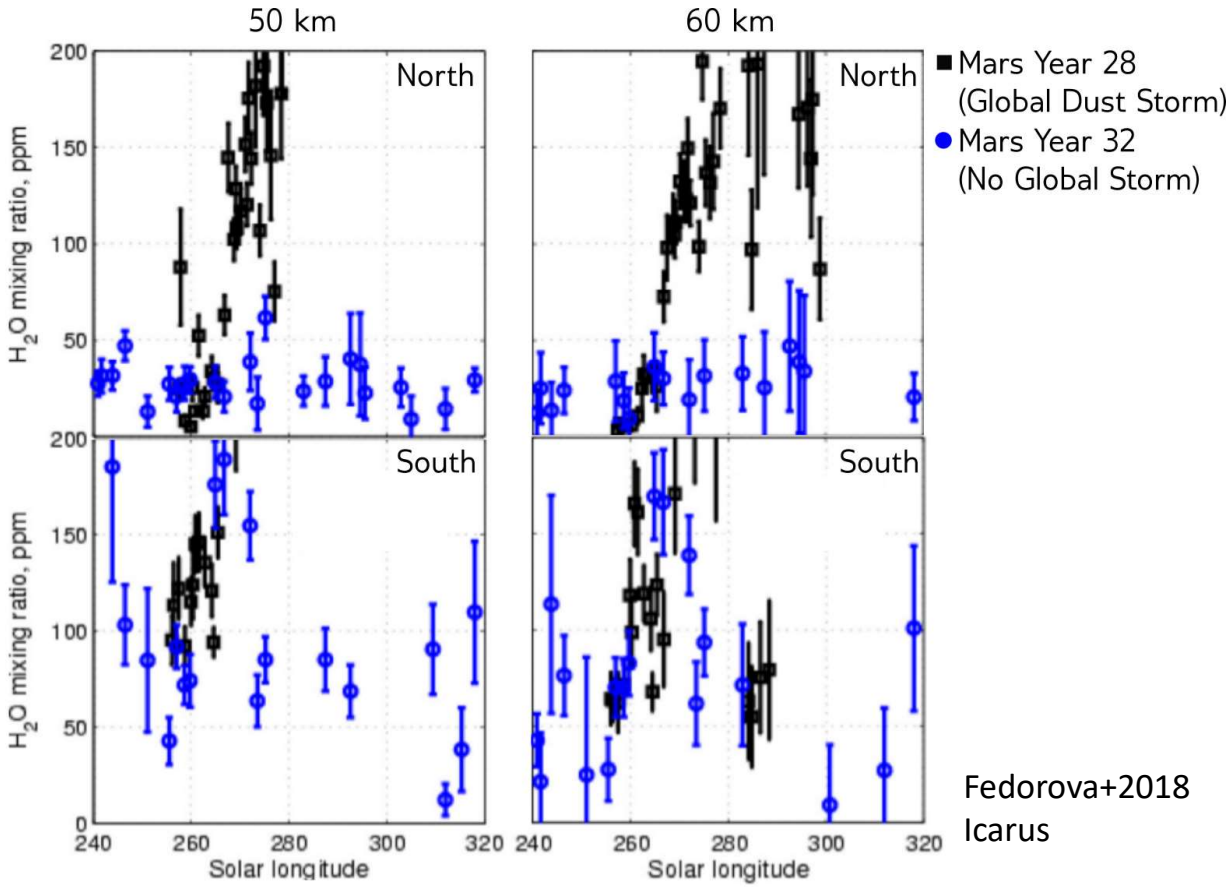


3. Presence of hot H requires heating mechanism, potentially charge exchange--- new modeling required.



Mars Climate may drive H escape

SPICAM occultations reveal
water at high altitude
in Southern Summer

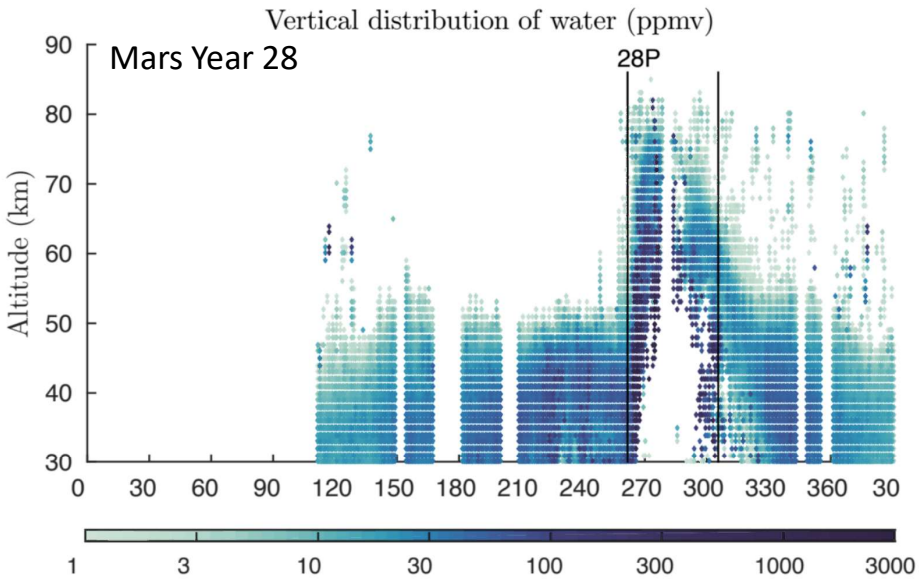


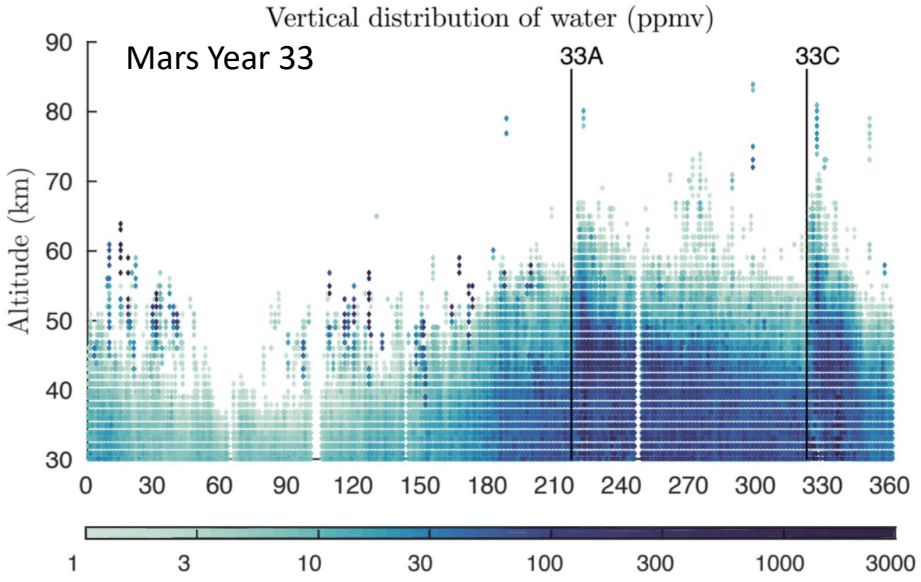
Fedorova+2018
Icarus

In dust storm years water increase is global,
not confined to Southern Hemisphere

No consistent observations of H escape in dust storm and non dust storm years.

MRO/MCS observations indicate hygropause is >20 km higher in dust storm Mars Year 28





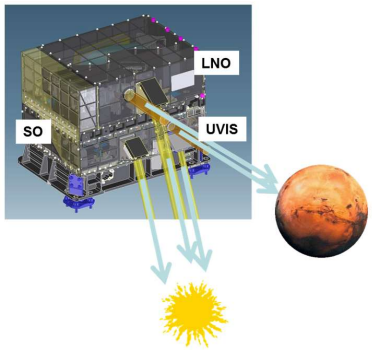
Small Mars-like planets may all have significant feedback between climate and escape

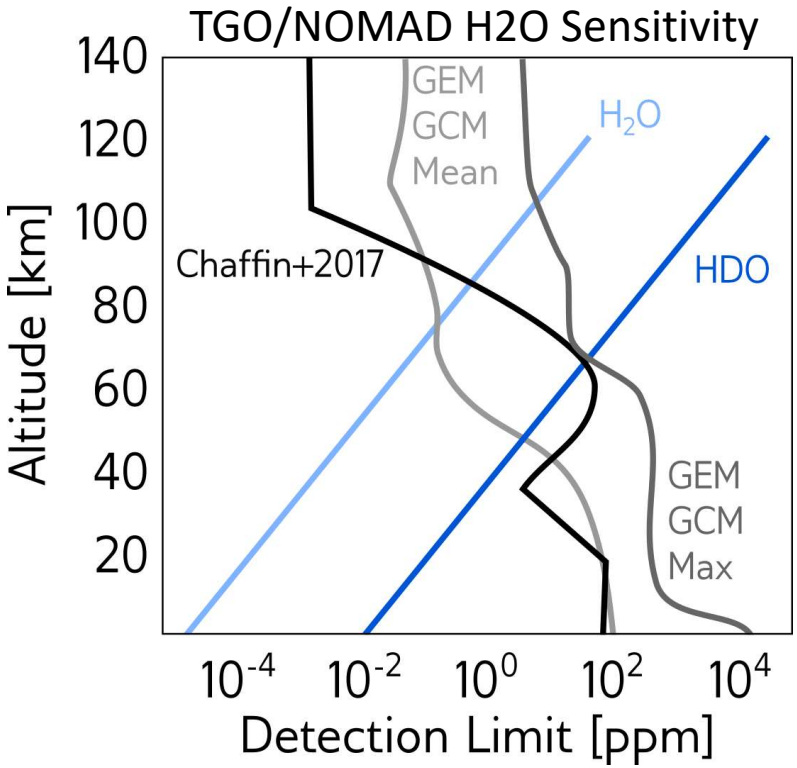
Heavens+2018
(in press,
Nature Astronomy)

ESA's Trace Gas Orbiter will observe water to ~100 km, HDO/H2O

Chemical composition

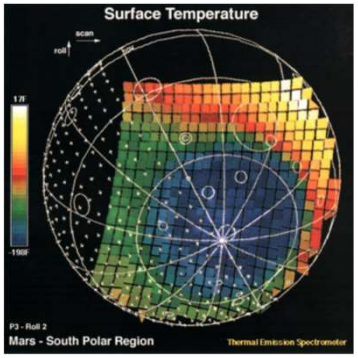
- Detection of a broad suite of trace gases and key isotopes
  - CO_2, CO, O_3
  - CH_4 related : CH_4, $^{13}CH_4$, CH_3D, C_2H_2, C_2H_4, C_2H_6, H_2CO
  - Escape processes : H_2O, HDO -> D/H
  - Volcanism related : SO_2, H_2S, HCl

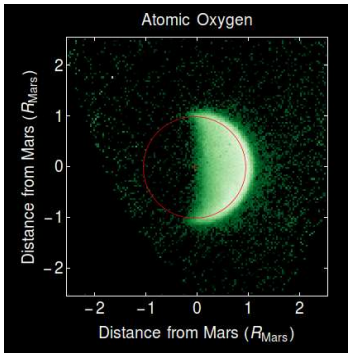


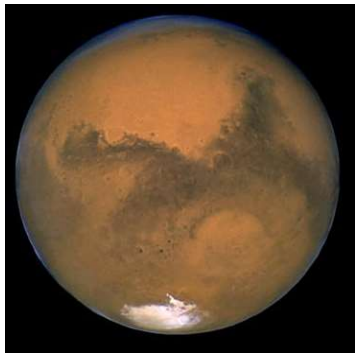


Combined with MAVEN observations of escape, we may be able to observe complete H2O→H escape chain.

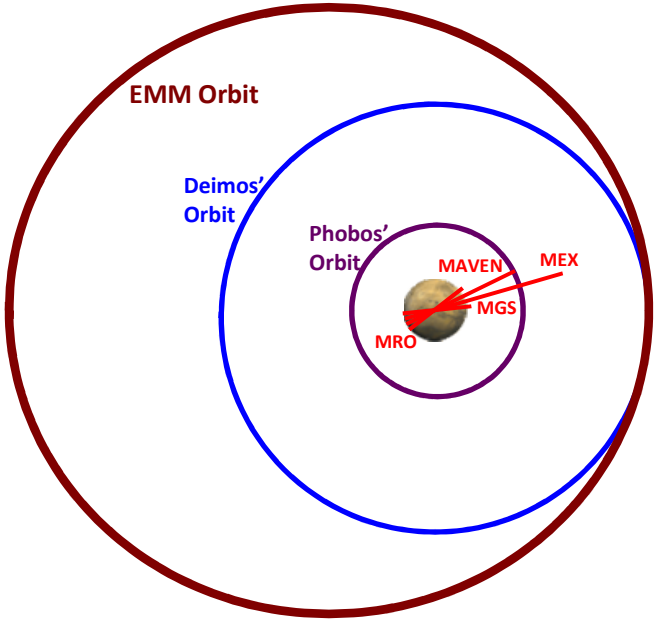
Emirates Mars Mission Science





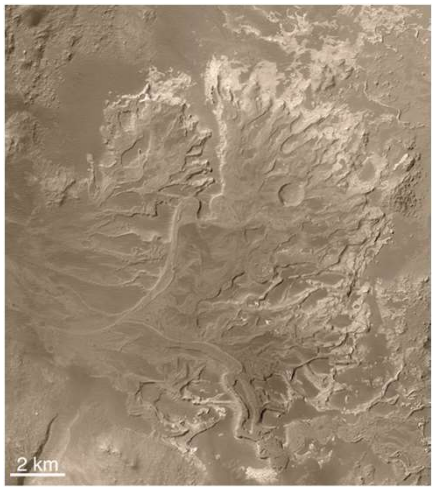


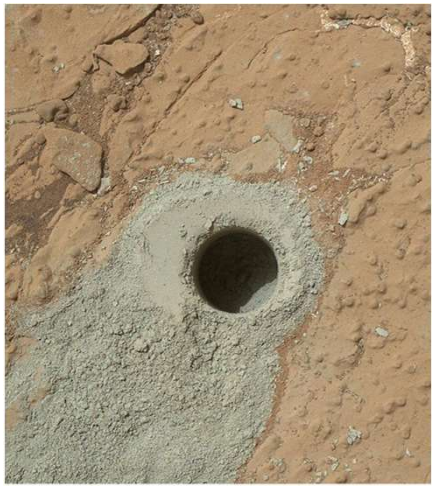
EMIRS (ASU/MBRSC)	EMUS (LASP/MBRSC)	EXI (LASP/MBRSC)
Fourier Transform IR Spectrometer	Ultra Violet Imaging Spectrometer	Imager with 12 MP camera with 6 bandpass filters (VIS/UV)



EMM will enable weekly monitoring of the Mars atmosphere in 3D, including the H and O corona, lower atmosphere water content, and lower atmosphere temperature profiles.

Implications





Water at high altitudes can produce enhanced H loss,
could explain greater H escape in Mars Southern summer.

Significant D or hot H is present in the Mars corona, requiring additional constraints on loss mechanisms.

Climate controls on high altitude water may control H escape; climate/escape feedback needs to be captured with future observations.