ATMOSPHERIC ESCAPE FROM MARS

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esa
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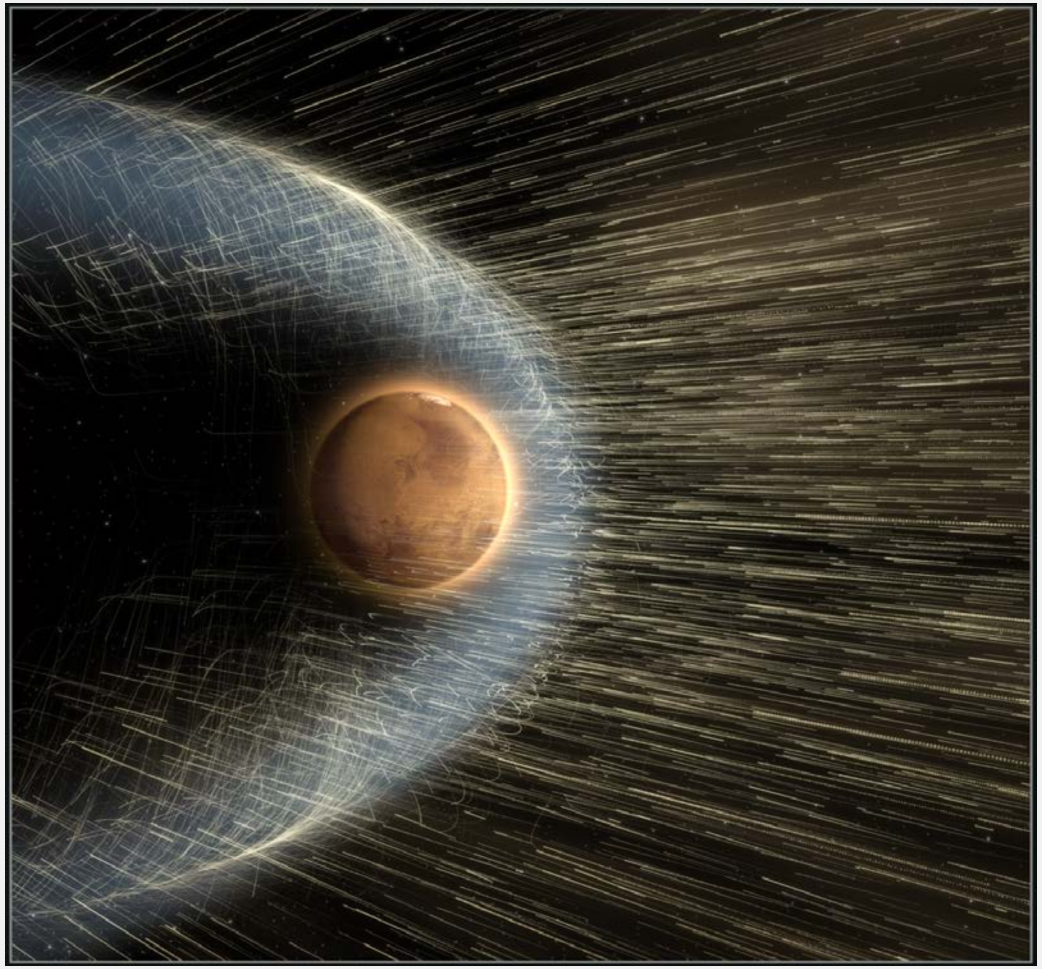
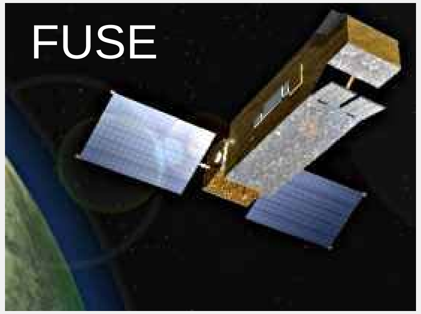
Mars is the Most Comprehensively Studied Planet

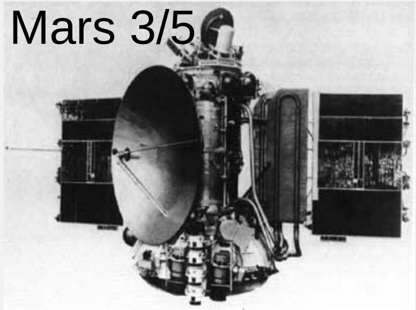
(for atmospheric escape)



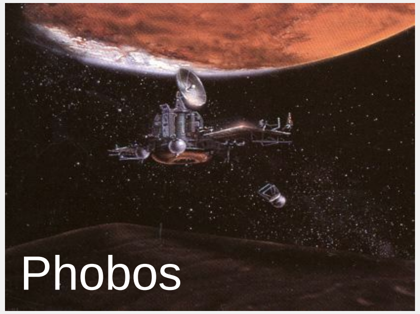
- Escape is “extra” important at Mars?
  - The Mars surface was habitable long ago
  - The atmosphere was once thicker
  - Mars is smaller than Earth
  - Mars lacks a global dynamo field
- We’ve been to Mars a lot (relatively)?
- Trivia
  - First mention of atmos. escape: JJW, 1846
  - First mention of escape for Mars(?): JWC, 1962

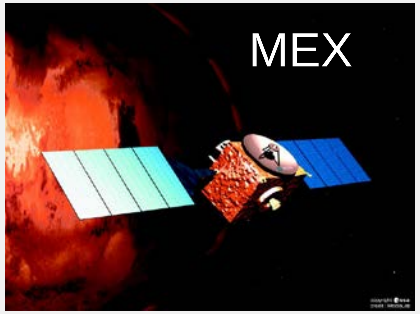
Measurements of Escape





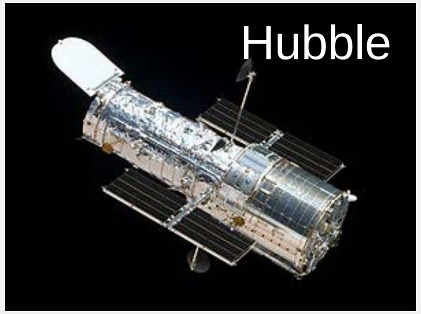
Jeans +
Photochemical





+ ion loss

+ sputtering



Models of Escape

Jeans escape calculations

Photochemical models

Monte Carlo exosphere

DSMC exosphere

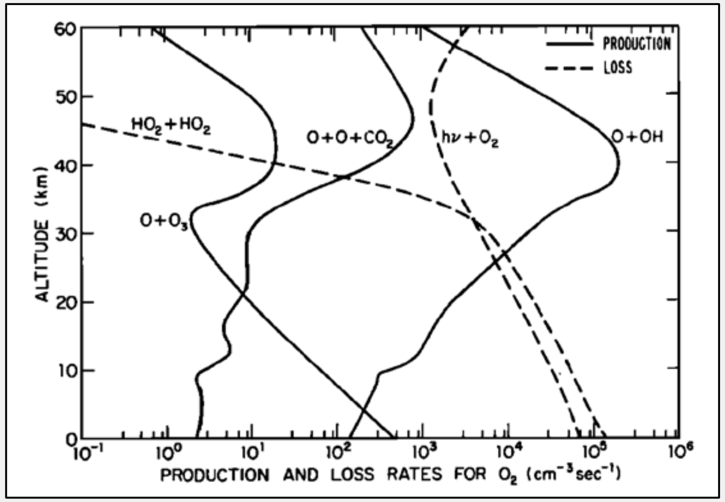
Momentum Conservation

MHD

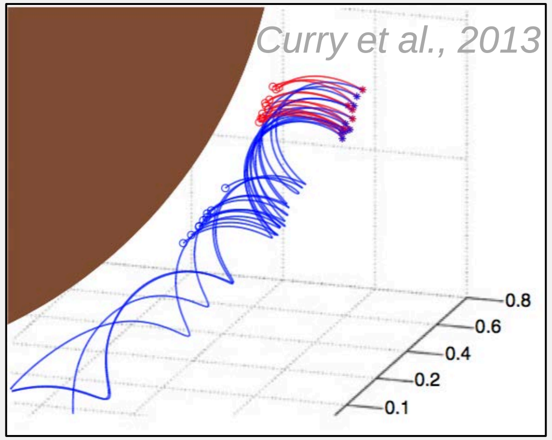
Mutli-fluid MHD

Hybrid

Test particle

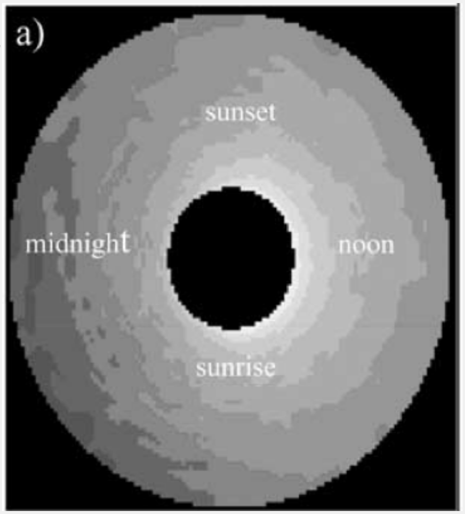


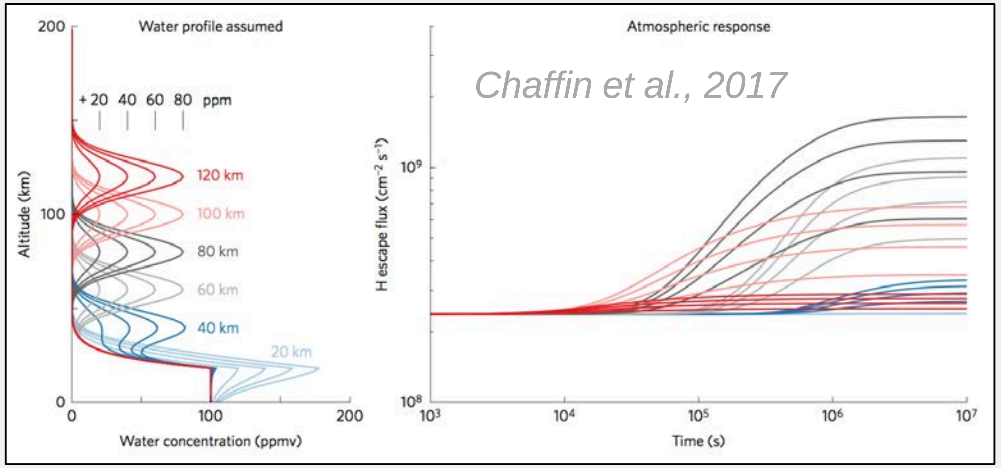
McElroy et al., 1977



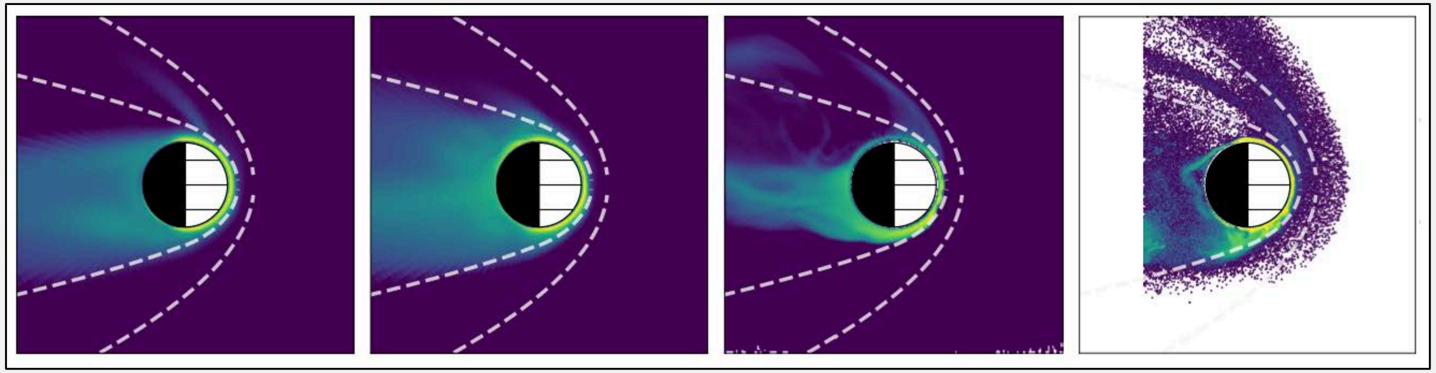
Curry et al., 2013

Chaufray et al., 2007



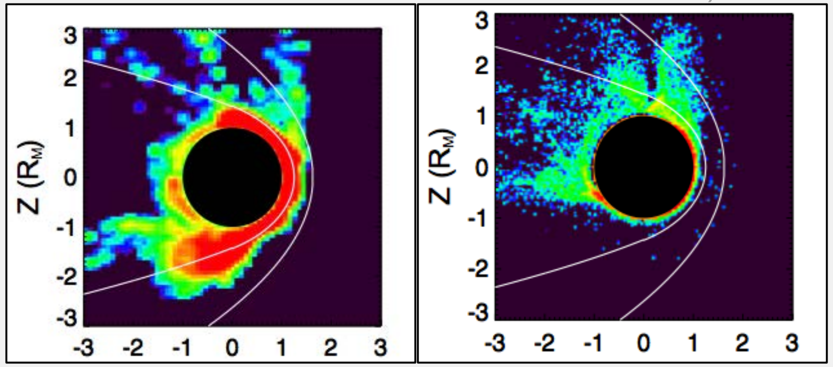


Chaffin et al., 2017

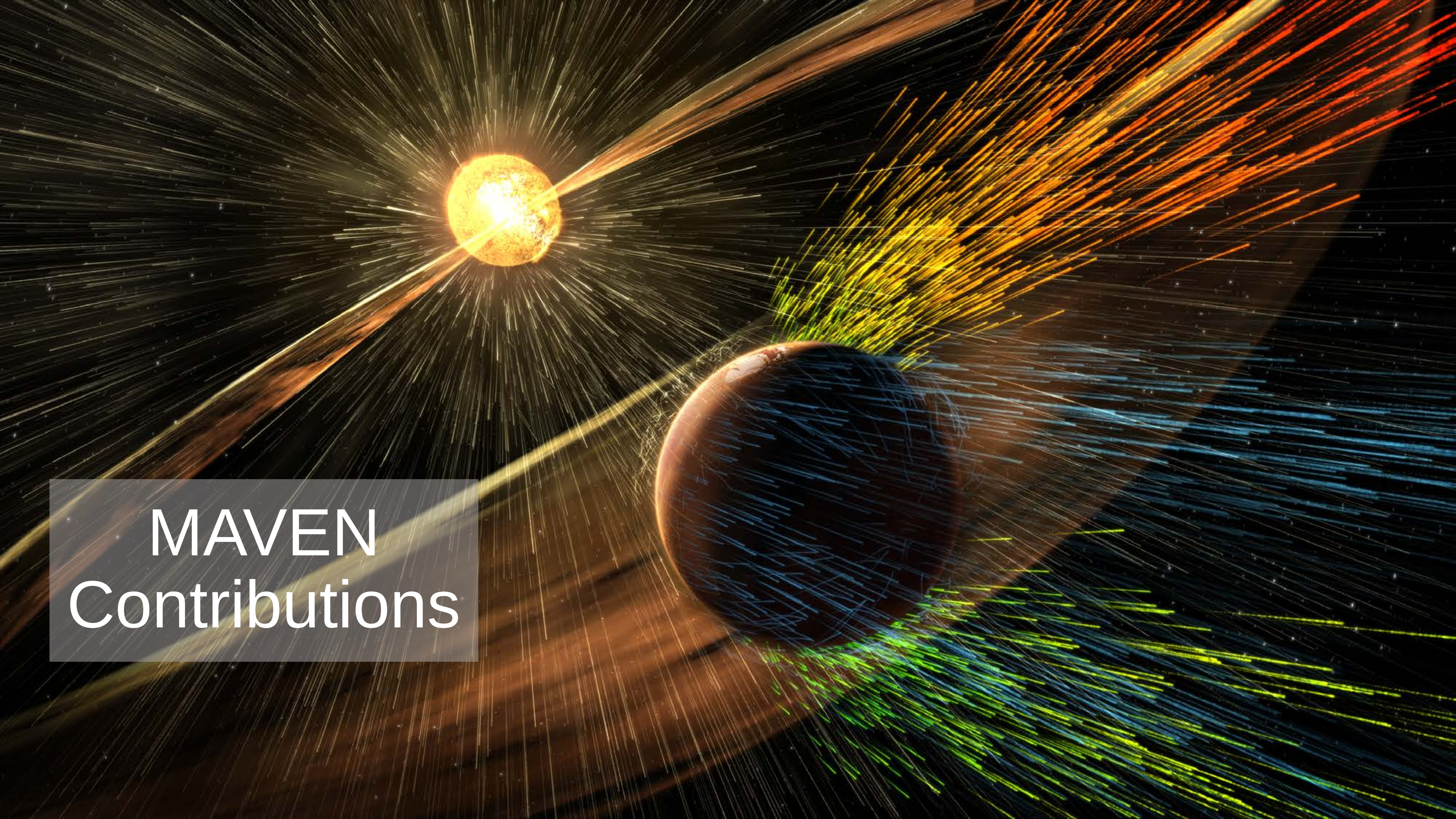


Egan et al., 2018

Brain et al., 2010



MAVEN Contributions



Jeans Escape

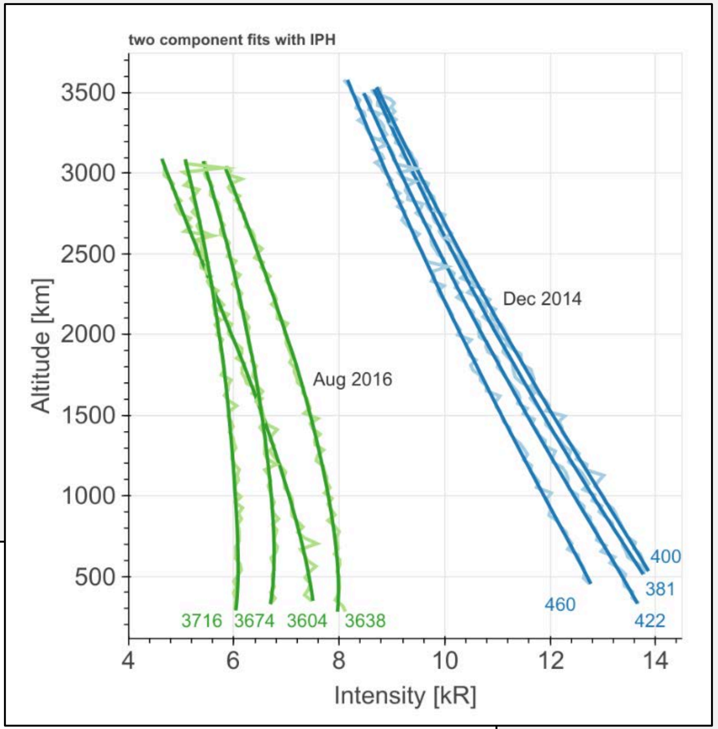
Hydrogen escape inferred from UV observations of exospheric intensity profiles

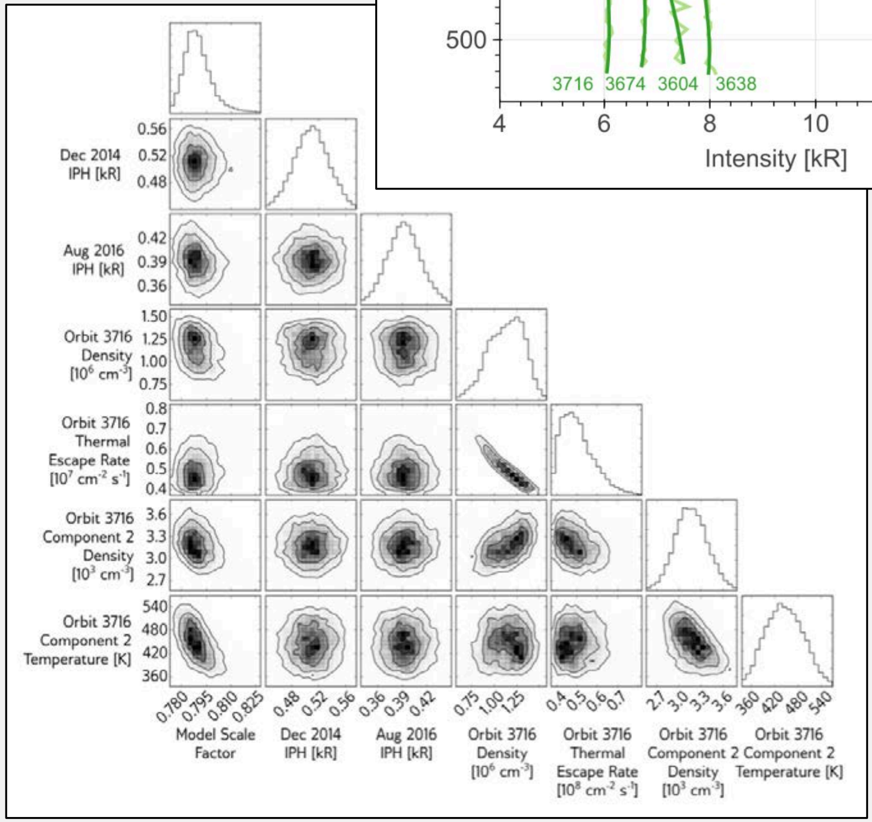
Exosphere varies spatially and temporally

Observations fit best by two populations: “cold” H + (D or “hot” H)

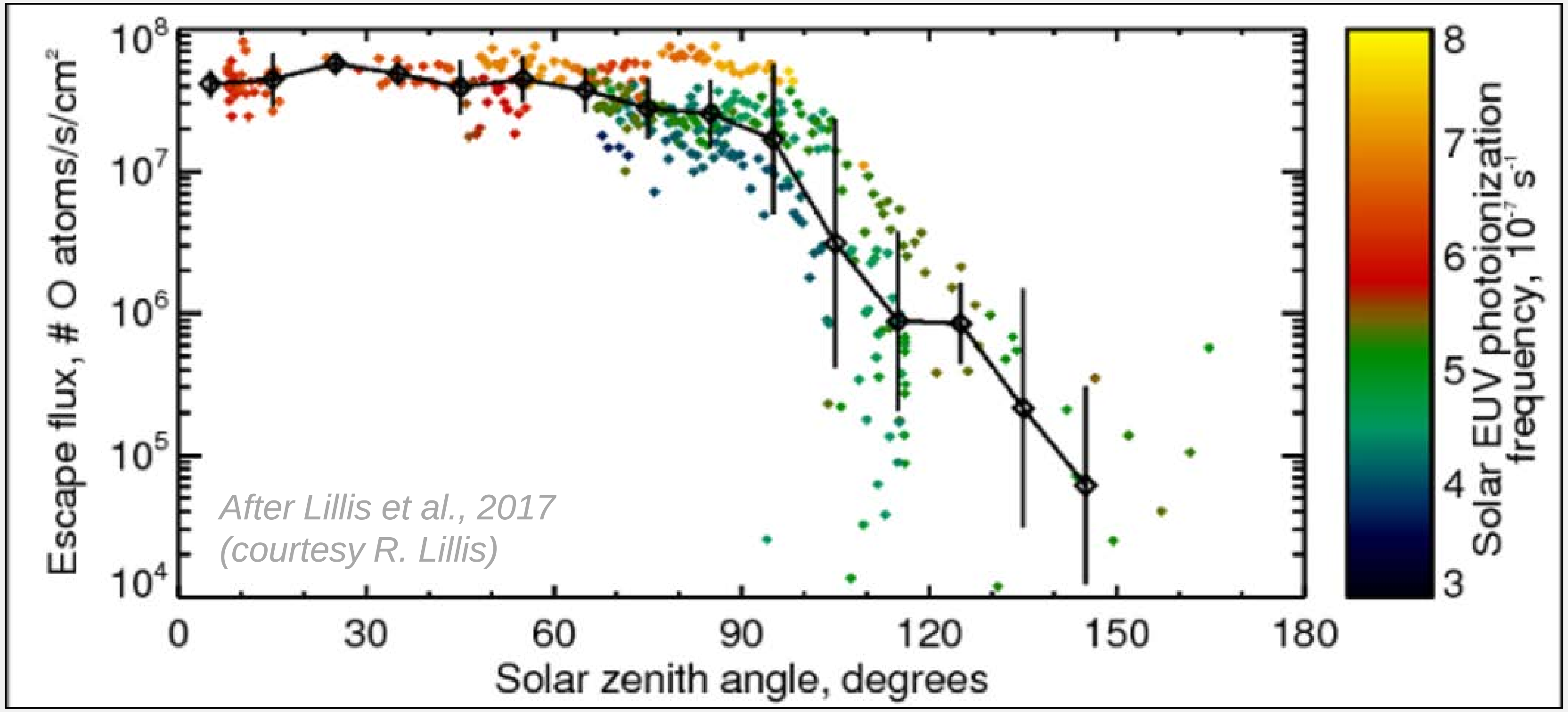
Escape rate ~few × 10^{26} s^{-1}

Chaffin et al., submitted 2018





Photochemical Escape



Require MAVEN observations of T_e, $[O_2^+]$, neutral column

Compute oxygen production and escape rate

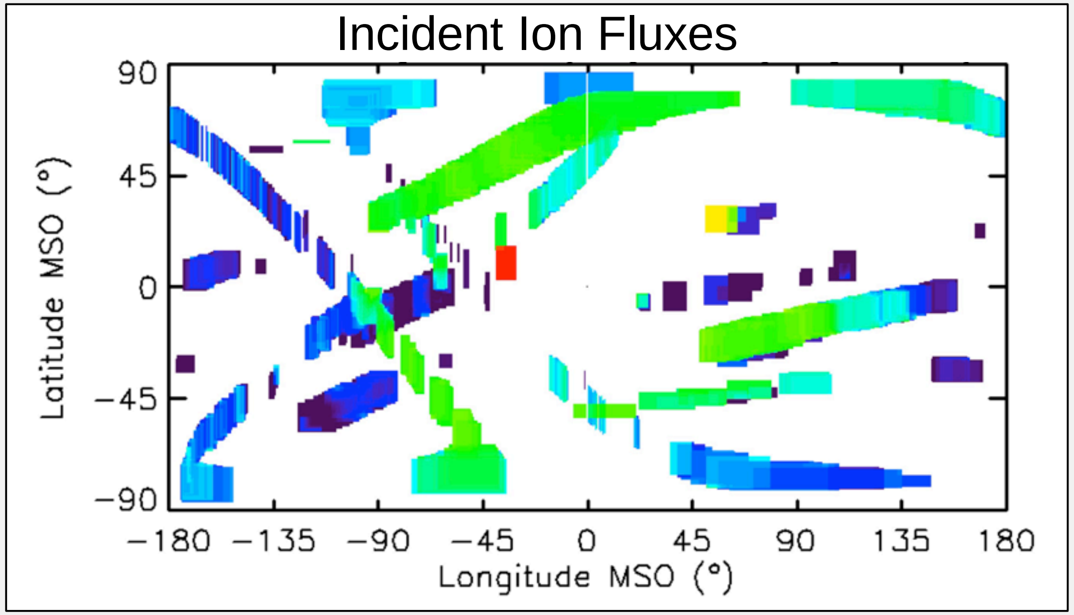
Escape rate ~1-5 × 10^{25} s^{-1}

Sputtering

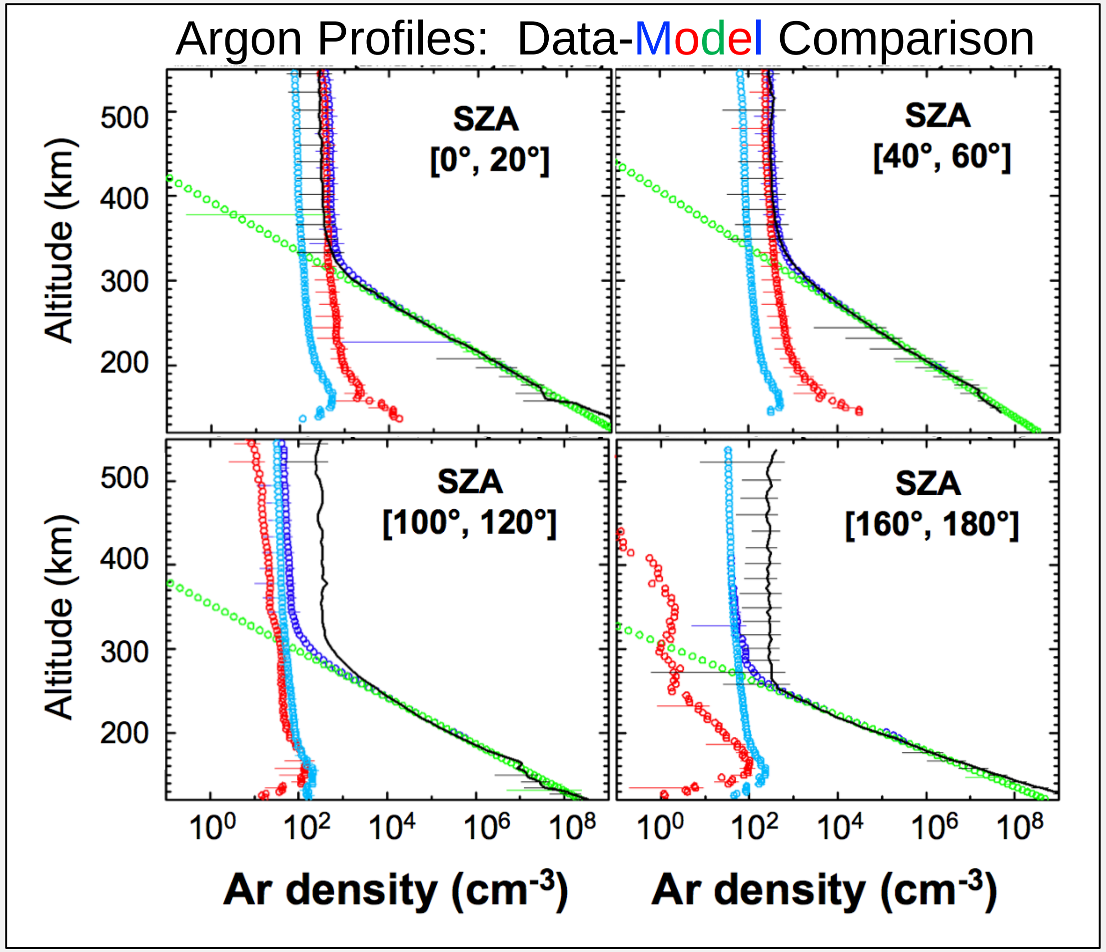
Require precipitating ion flux from MAVEN, target atmosphere profiles

Model sputtered particles (escaping / exospheric)

Escape rate ~$2 \times 10^{22} – 8 \times 10^{23}$ s^{-1}
(depends on species, season)

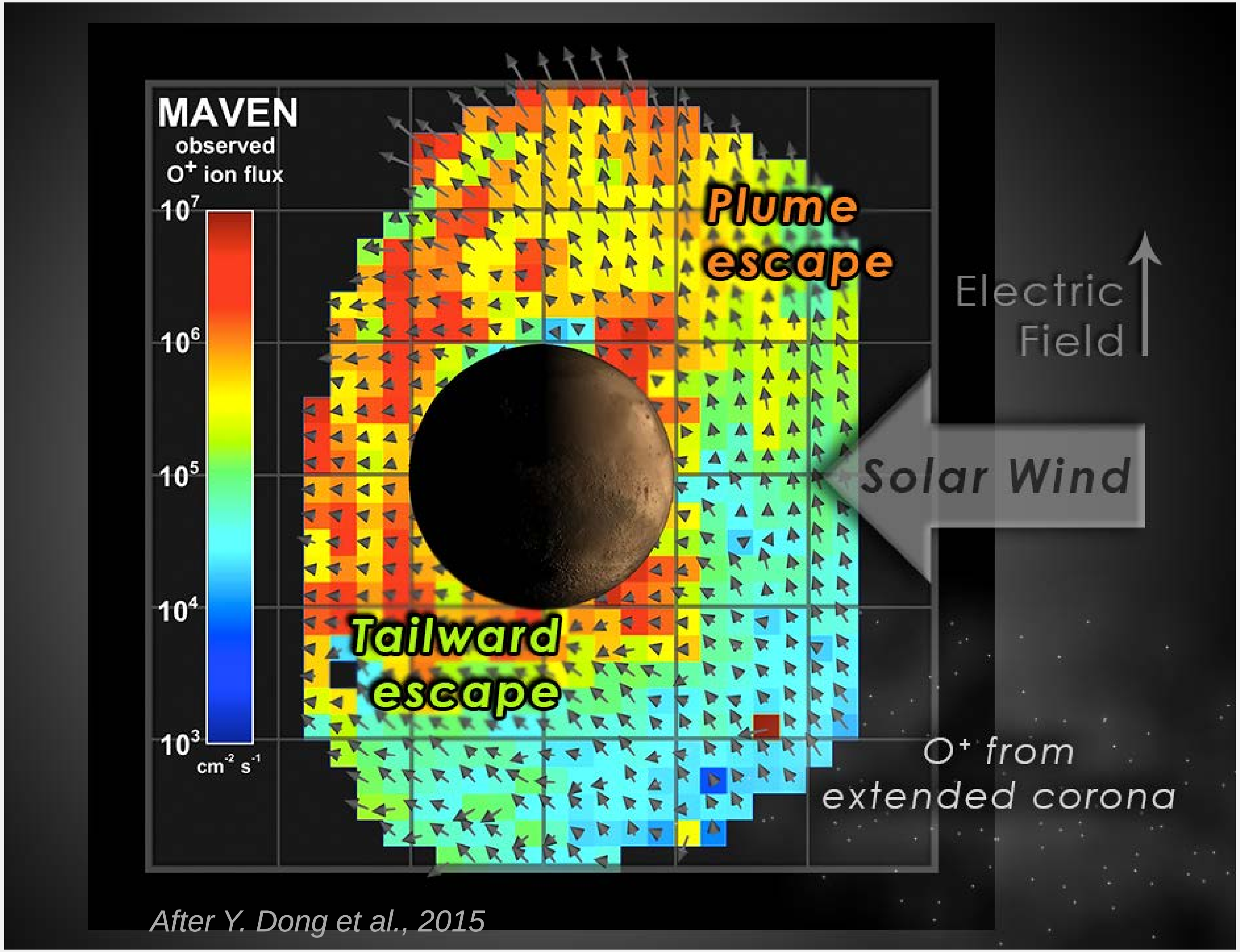


After Leblanc et al., 2015



Courtesy F. Leblanc

Ion Loss



Measure ions in situ
(mass, energy, direction)

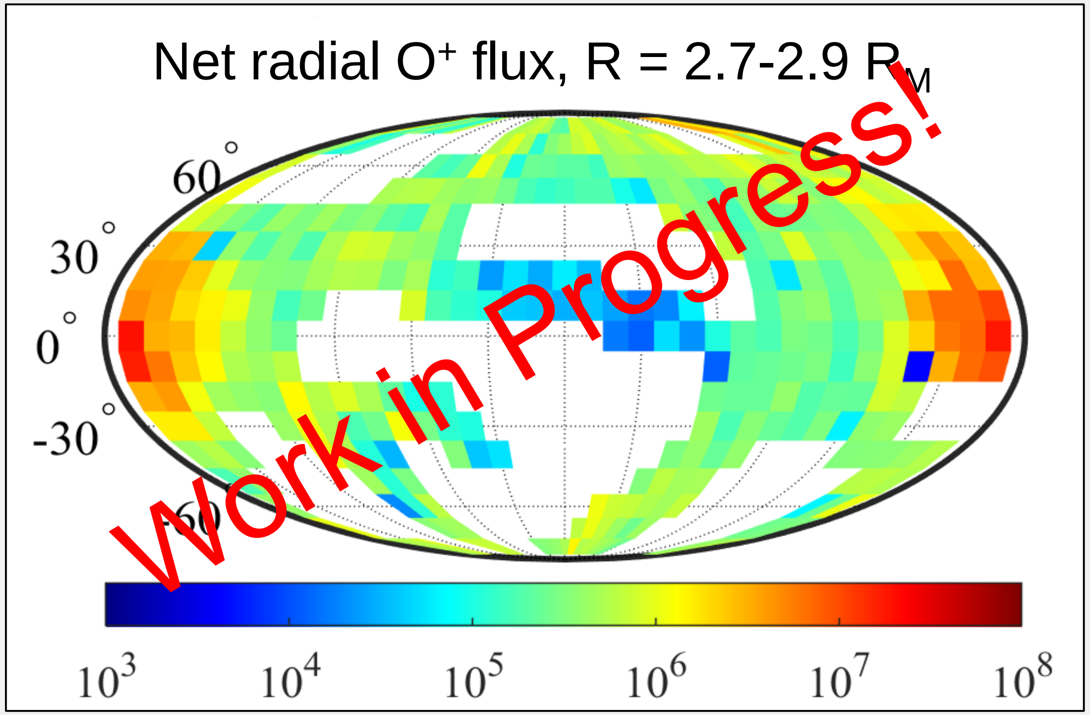
Observe multiple escape channels (processes)

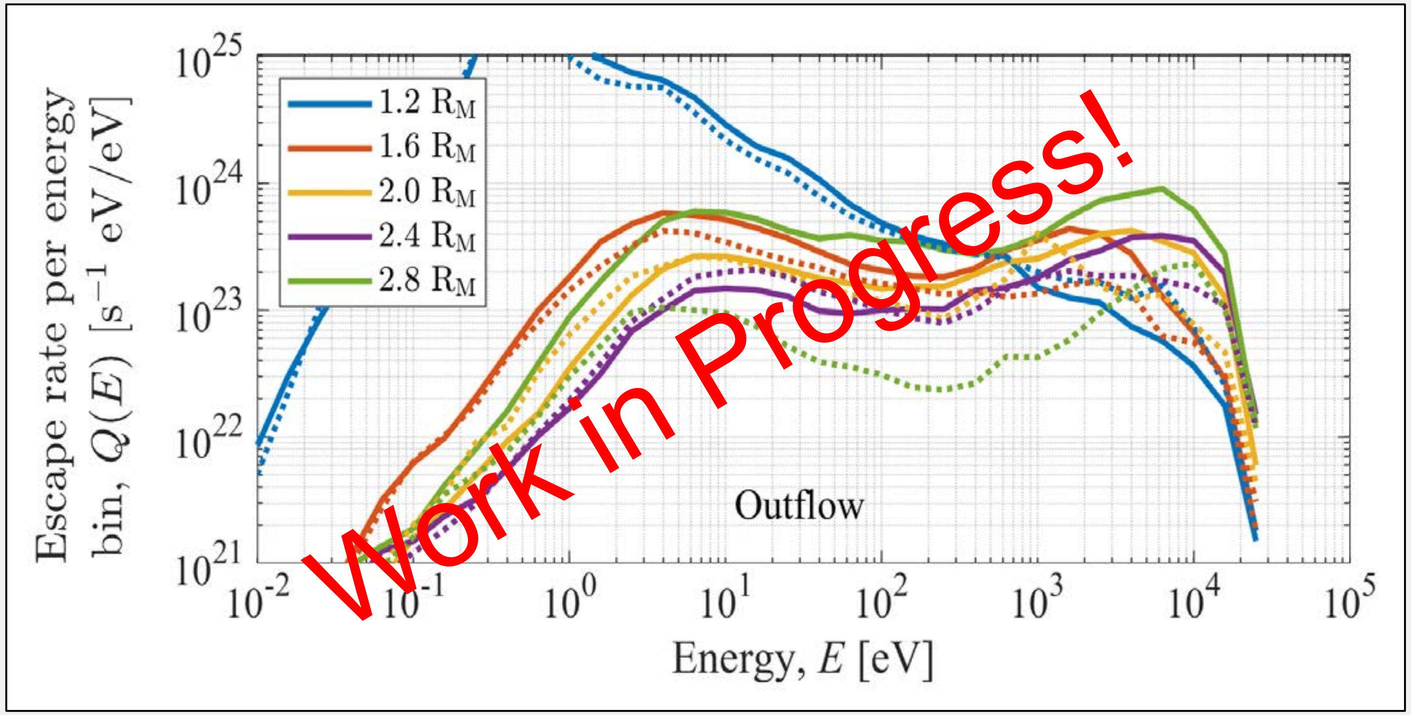
Escape rate ~6-7 × 10^{23} s^{-1}
(E > 6 eV)

Factor of ~2-4* higher when all energies considered

Ion Loss

Plots courtesy R. Ramstad





New ion escape “database” in progress by R. Ramstad, Y. Dong, D. Brain

New outflow most concentrated in central tail far from Mars

Ion acceleration in steady state > ~1.6 R_M; Significant inflow at all energies

Variability

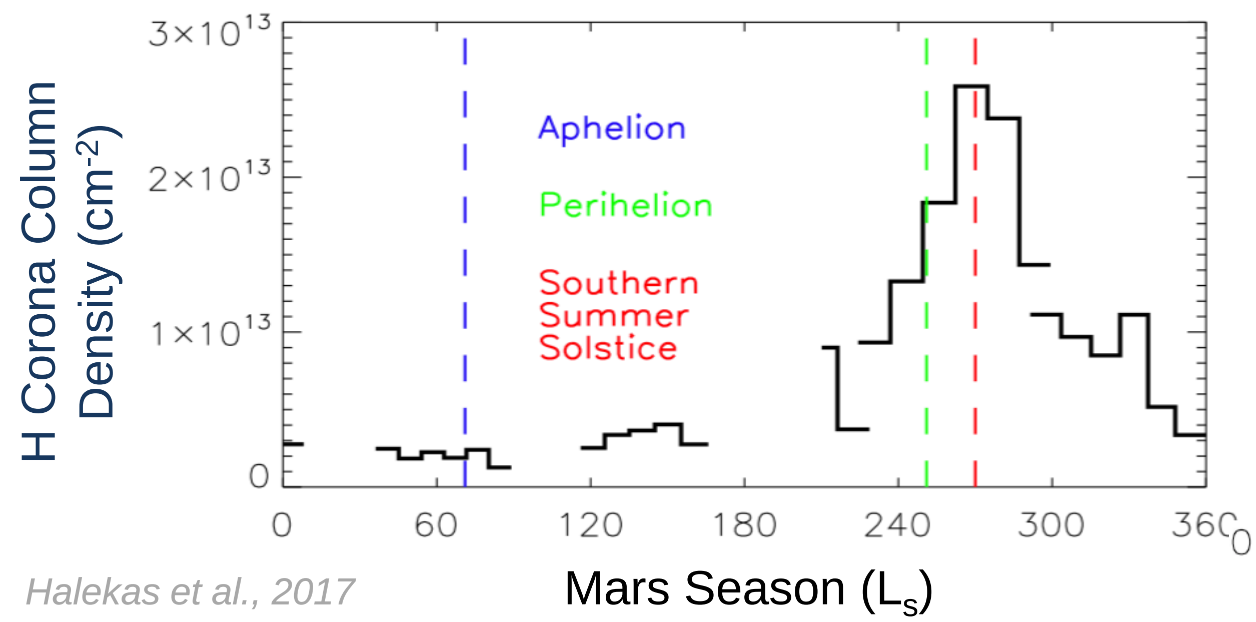
Escape rates vary with drivers from the Sun, solar wind, and Mars

Variability in both neutral and ion escape processes

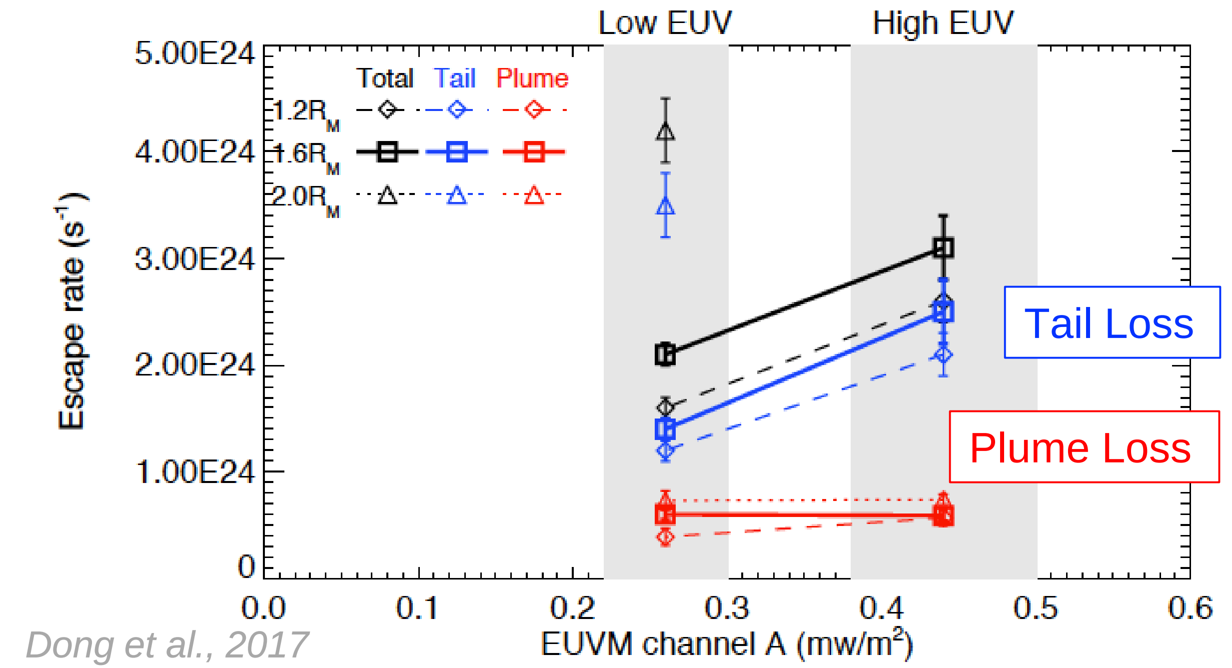
Different variability in different escape channels

→ Can't simply extrapolate "escape rate" back in time

→ must extrapolate rates from each process/channel individually, accounting for interdependencies

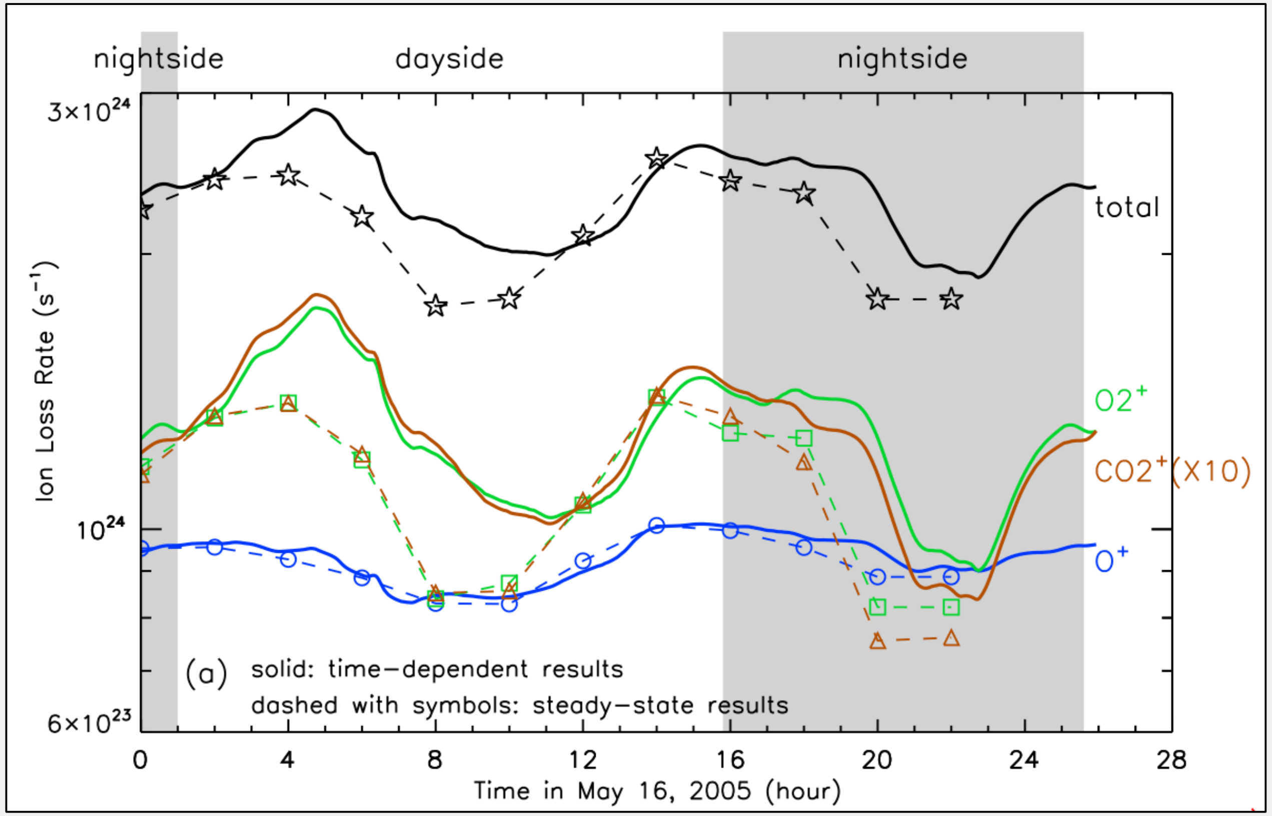


Halekas et al., 2017



Dong et al., 2017

Crustal Field Influences



Fang et al., 2015

Measured global ion loss:

- Models predict variations of 10% to 30×*
- MAVEN: Varies 30% as Mars rotates*
- Mars Express: Varies 2.5×*

No reported influence on neutral loss processes (but no relevant analysis so far?)

Non-Steady Escape

	Jeans Escape	Photochemical Escape	Sputtering	Ion Escape
EUV / X-ray	↑	↑	↑	↑
Solar Wind	?	?	?	↑
IMF strength	?	?	?	↑
IMF orientation	?	?	?	?
Crustal Fields	?	?	↓	↑ ↓

After S. Curry and the MAVEN team

- Solar storms (CIR/CME/SEPs) omitted – See Jakosky presentation
- Seasonal variability omitted – convolved with EUV

Implications

Mars

- Total escape: few × 10^{26} s^{-1} for H ~4 × 10^{25} s^{-1} for O ~2 × 10^{25} s^{-1} for O^+, O_2^+, CO_2^+
- Loss rate today is small (~10 mbar, ~2 m H_2O over 4 GY)
- Variability → Total escape through time is significant (see Jakosky presentation this afternoon)

Planets

- Mars measurements can be (are being) used to validate physics-based models that can be applied elsewhere
- Simultaneous measurements of all processes *and* inputs allow a system-wide approach
- Mars now provides a baseline for comparison to other planets

Closing Thoughts

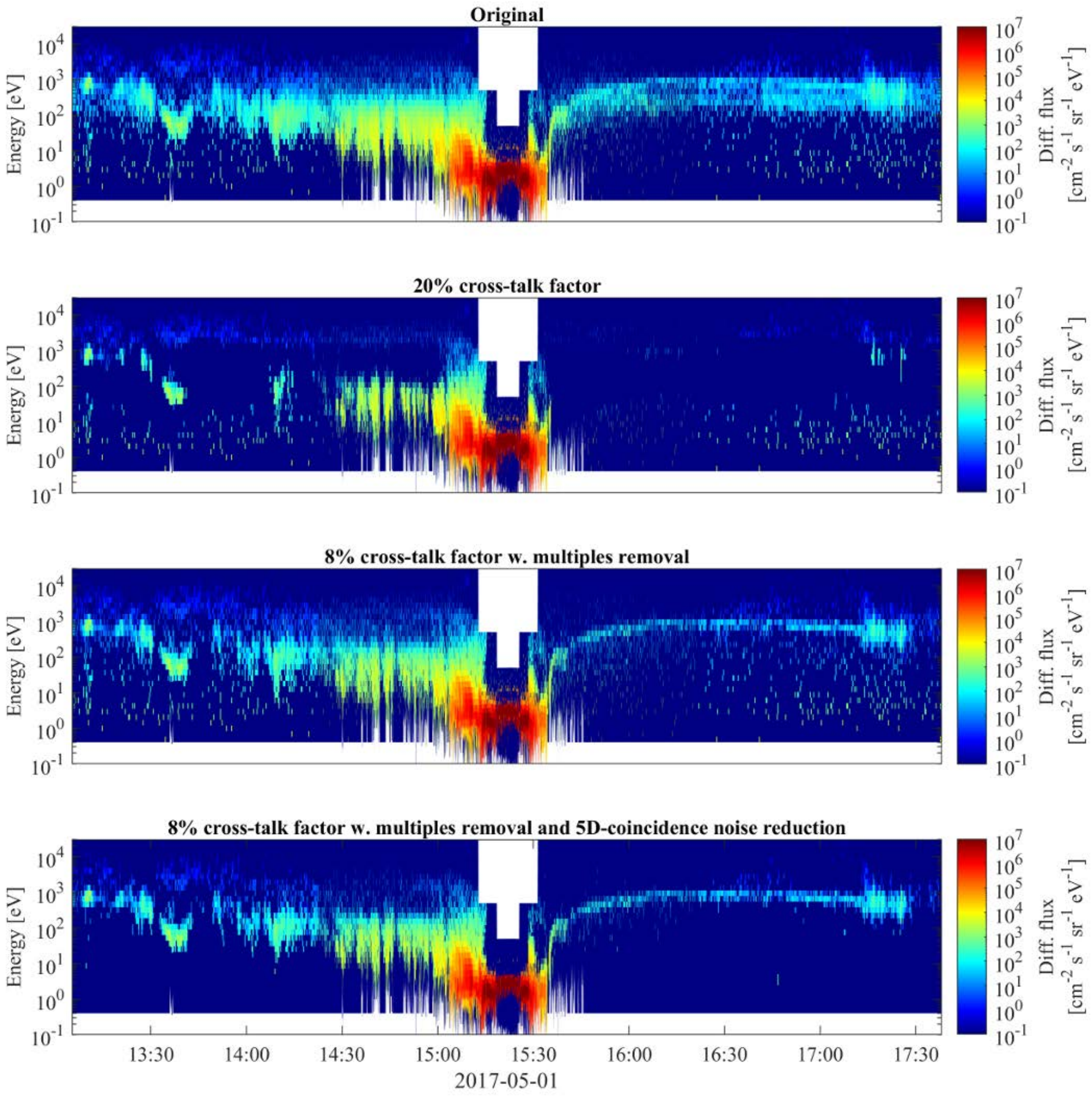
Particles can escape the Mars atmosphere via myriad pathways/processes

MAVEN is measuring or inferring rates and variability for every known process

There's a lot left to do at the "most comprehensively studied" solar system body

- Better quantification of non-steady escape and drivers
- Ion loss processes
- Particle acceleration near the exobase region
- The role of crustal fields
- Sputtering smoking gun
- Escape of key species: H^+, N, CO
- Correlation with lower atmosphere water, waves, dust storms
- Detailed extrapolation back in time
- Comparative planetology (VAVEN? EAVEN?)

Backup



Original
20% cross-talk factor
8% cross-talk factor w. multiples removal
8% cross-talk factor w. multiples removal and 5D-coincidence noise reduction
Energy [eV]
Diff. flux
[cm^{-2} s^{-1} sr^{-1} eV^{-1}]
13:30
14:00
14:30
15:00
15:30
16:00
16:30
17:00
17:30
2017-05-01

Ion Loss