H^+/O^+ escape rates in the Venusian magnetotail and their dependence on upstream conditions

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2019-06-03

International Venus Conference, Niseko, Hokkaido, Japan

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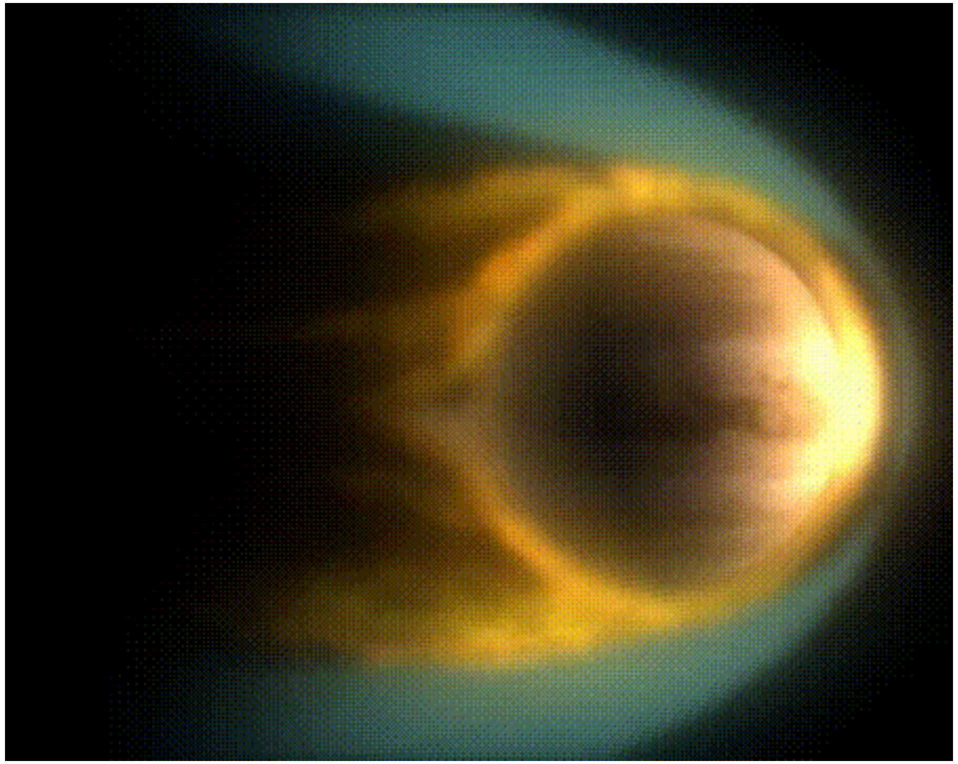
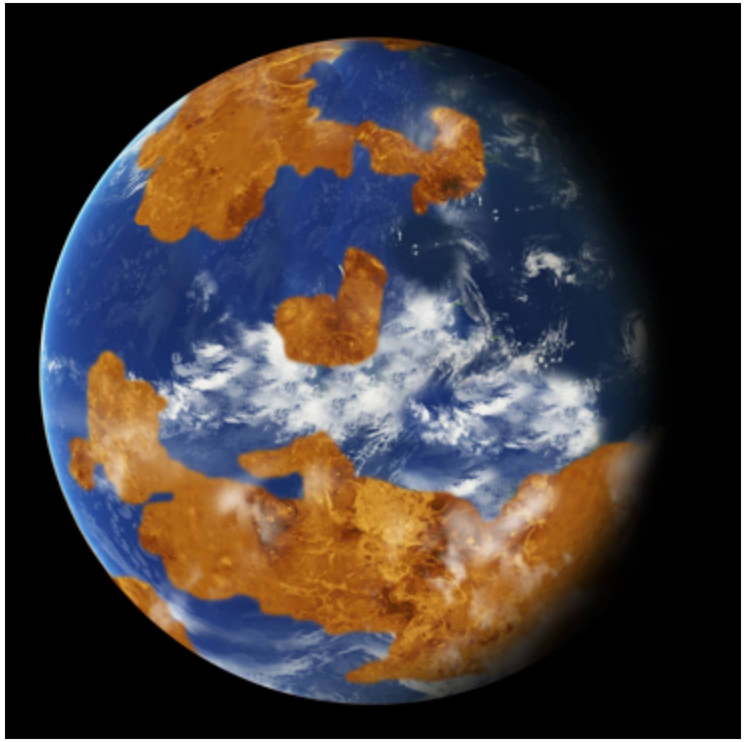
Venus' water

Venus once had water in its atmosphere, but today Venus is very arid [Donahue+97, Way+18]

How was the water lost?





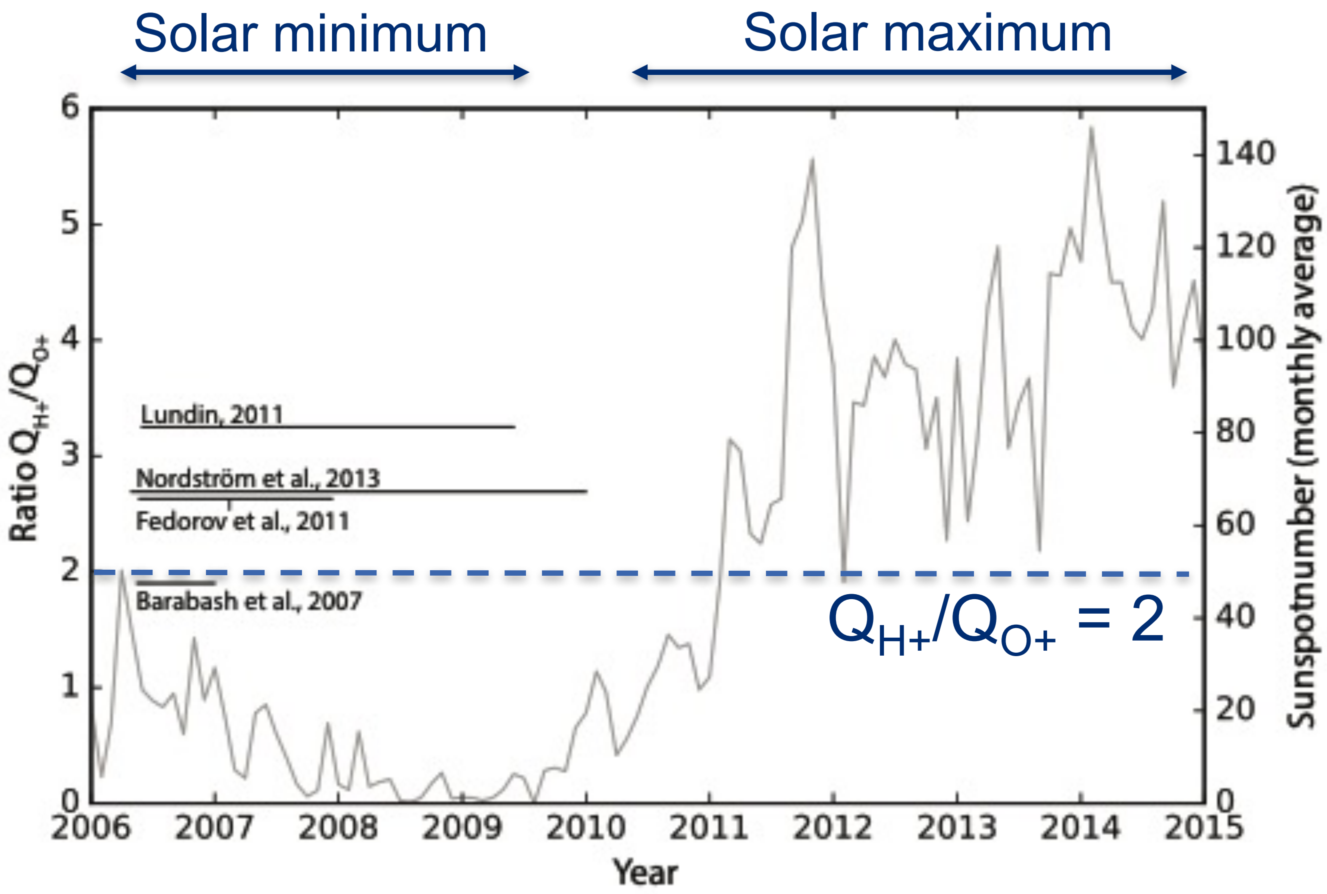
Escape of water as ions through space is one major mechanism

How is the H^+ and O^+ ion escape evolving over the solar conditions?

Q_{H+}/Q_{O+} escape rate ratio

- A ratio close to 2-3 was found for solar minimum:
  Stoichiometric ratio of water

- How much does the solar cycle variations influence the escape rate ratio Q_{H+}/Q_{O+}?

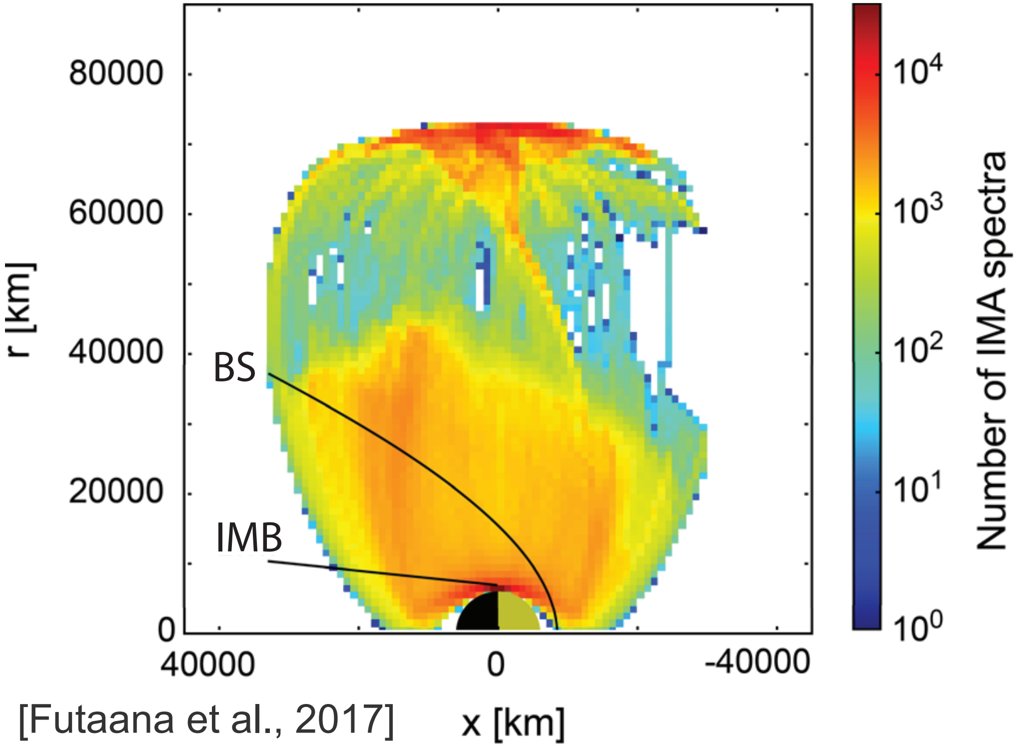


Instrumentation: VEX/ASPERA-4/IMA

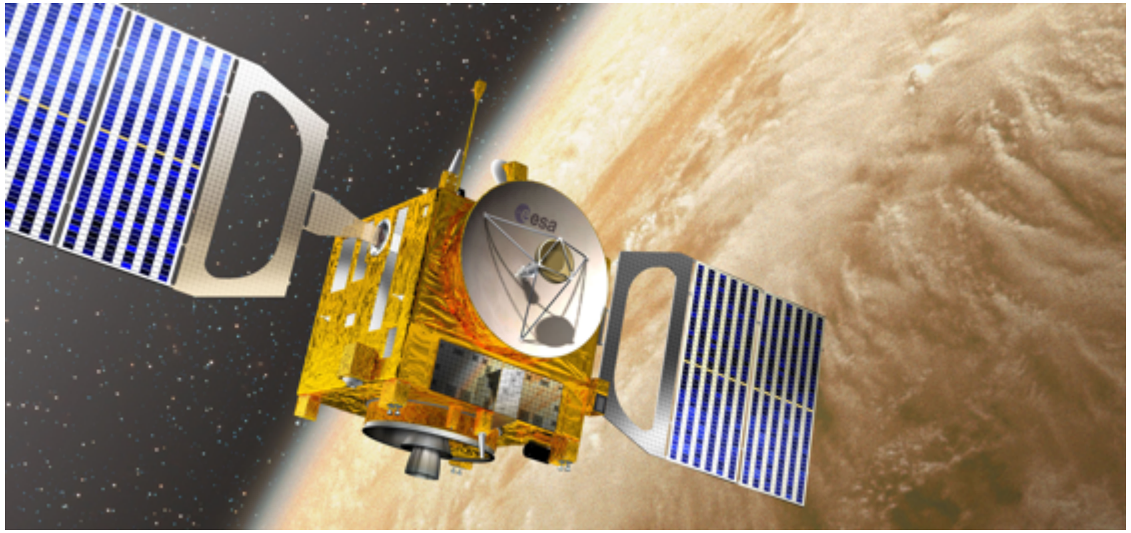
Venus Express

2006-2014

>3000 orbits



[Futaana et al., 2017]



ASPERA-4/IMA

FOV: 90x360°

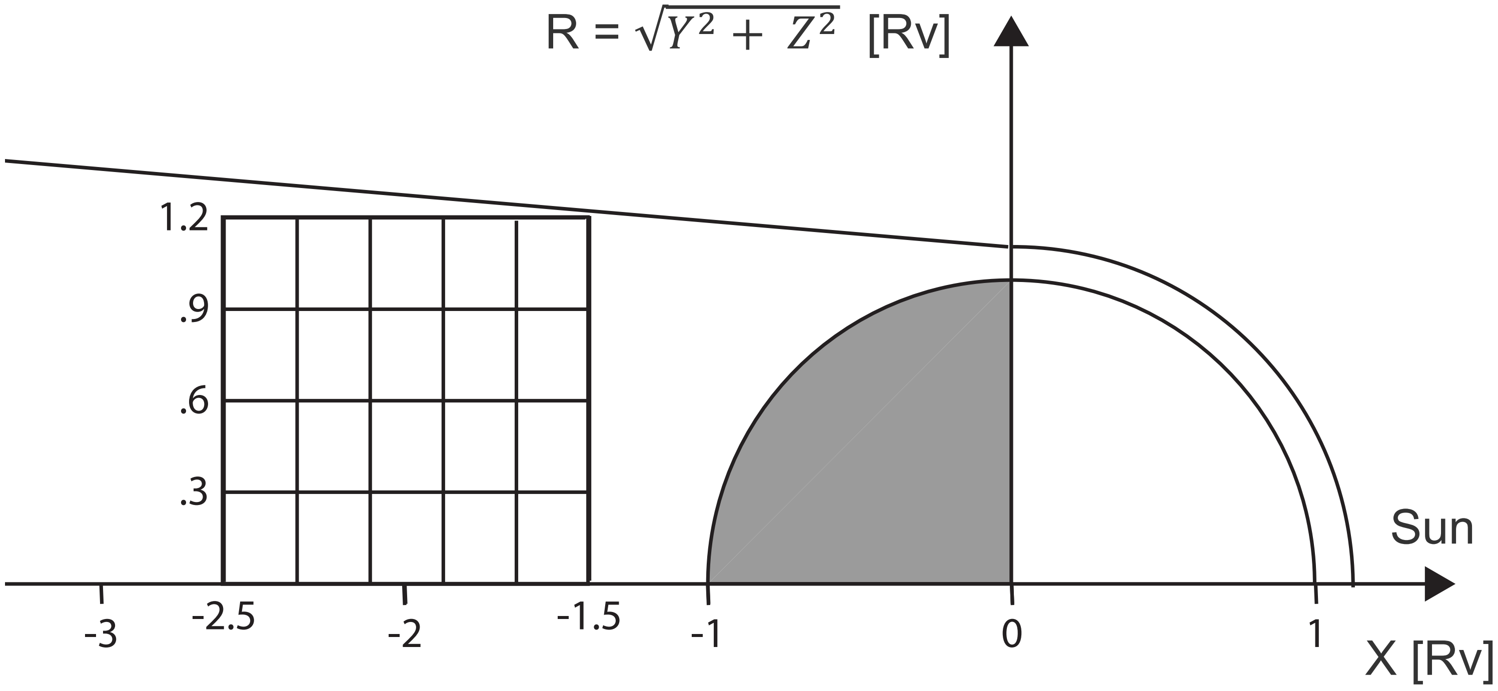
Energy range: 0.01-36 keV/q

M/q = 1, 2, 4, 8, 16, 32, >40

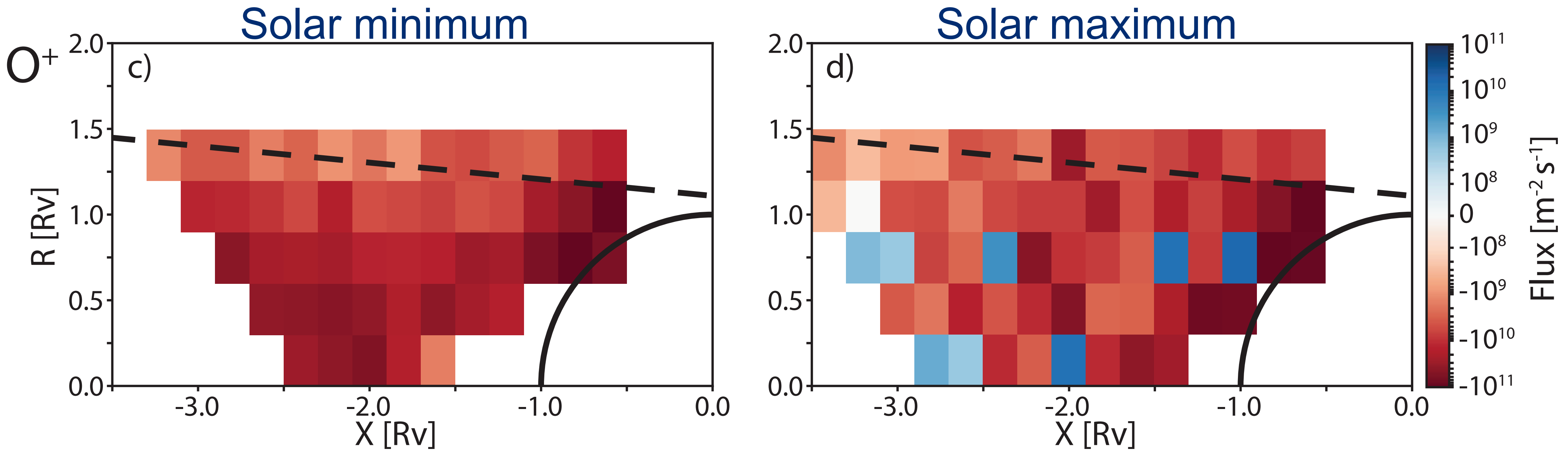
Time resolution: 192 s

Average velocity distribution functions

- Cylindrical Venus-Solar-Orbital (VSO) coordinate system
- Magnetotail divided into spatial grids
- Average distributions made for each spatial grid
- Average distributions used for calculating the average flux



O^+ Flux maps

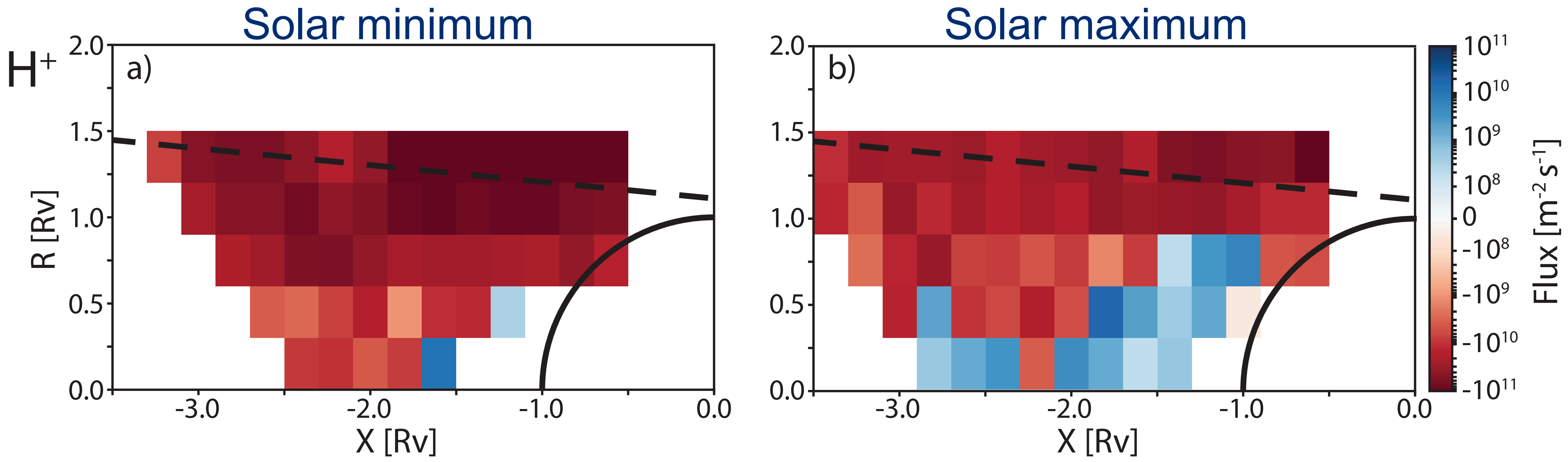


$$Q_{O+} = 2.9 \pm 1.1 \cdot 10^{24}$$

$$Q_{O+} = 2.0 \pm 1.1 \cdot 10^{24}$$

- The inflow increases from solar minimum to maximum
  → Small decrease in escape rate

H^+ Flux maps



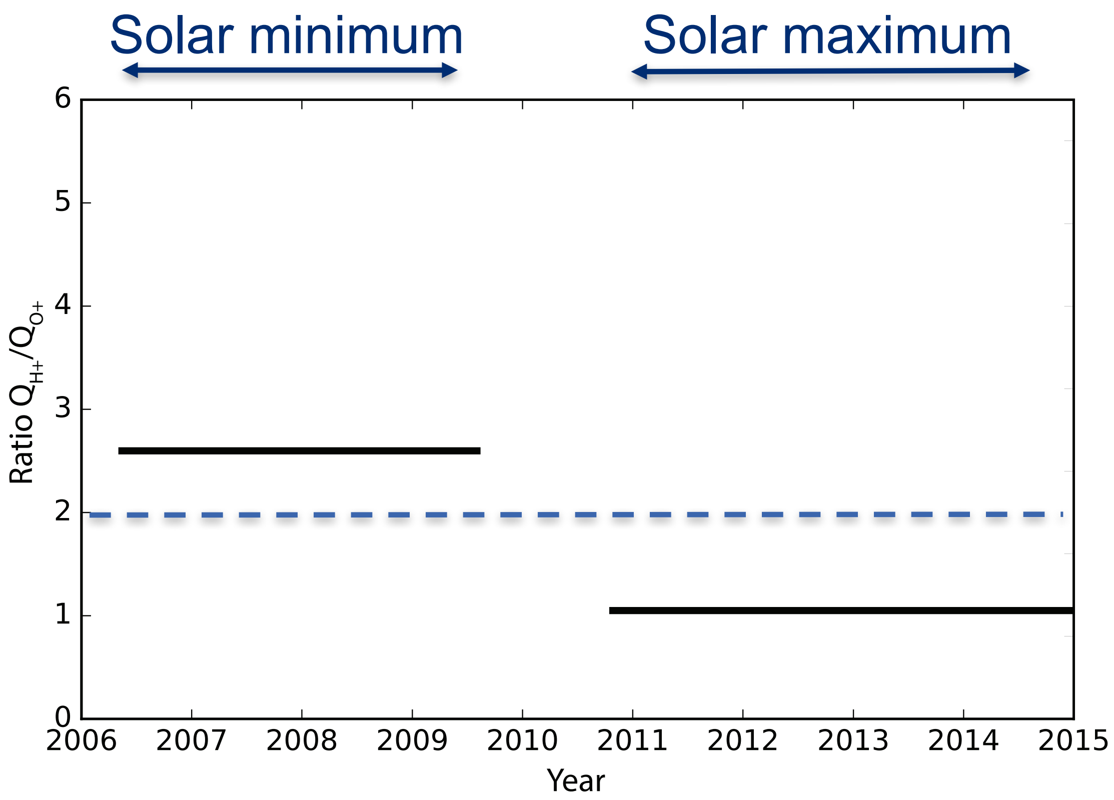
$$Q_{H+} = 7.6 \pm 2.9 \cdot 10^{24}$$

$$Q_{H+} = 2.1 \pm 1.2 \cdot 10^{24}$$

- Large increase in inflow from solar minimum to maximum
  → Escape rate decreases by a factor 3.6

Escape rates change over solar cycle

	Solar minimum 2006-2009	Solar maximum 2010-2014
Q_{H+} [s^{-1}]	$7.6 \cdot 10^{24}$	$2.1 \cdot 10^{24}$
Q_{O+} [s^{-1}]	$2.9 \cdot 10^{24}$	$2.0 \cdot 10^{24}$
Q_{H+}/Q_{O})	2.6	1.1



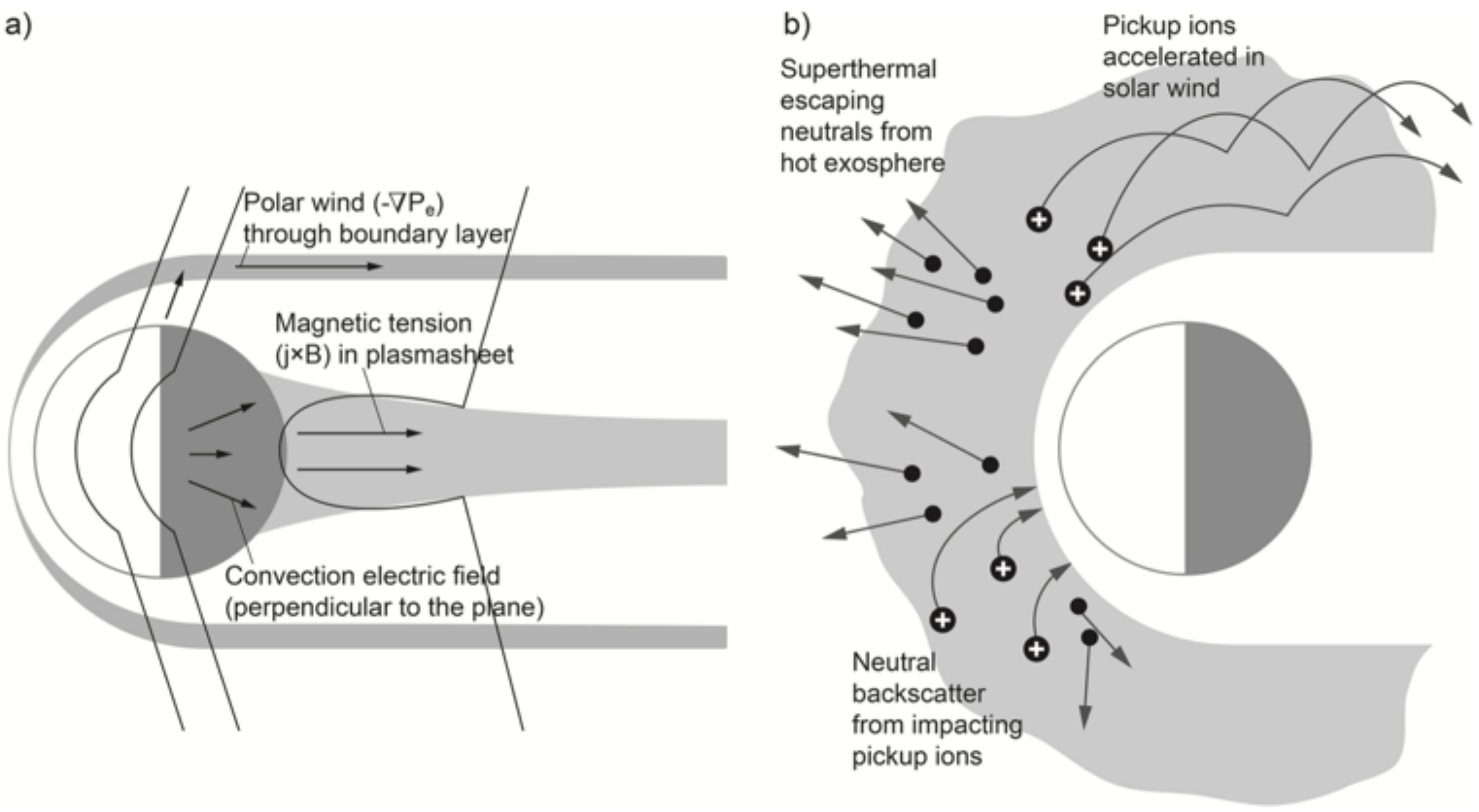
- The ratio decreases from solar minimum to maximum
- The decrease is mainly due to an increase in inflow, significantly decreasing the H^+ escape rate

Other escape channels' effect on total escape ratio

- Escape in magnetotail is not the only escape channel
  - Ion escape outside magnetotail
  - Neutral escape

- Ion escape
  - H^+ and O^+ escape mainly through magnetotail
    [e.g. Masunaga et al., 2018]

- Neutral escape
  - Sputtering gives Q_O ~25 % of Q_{O+}
  - Q_H ~50% of Q_{H+}
    [Lammer et al., 2006]

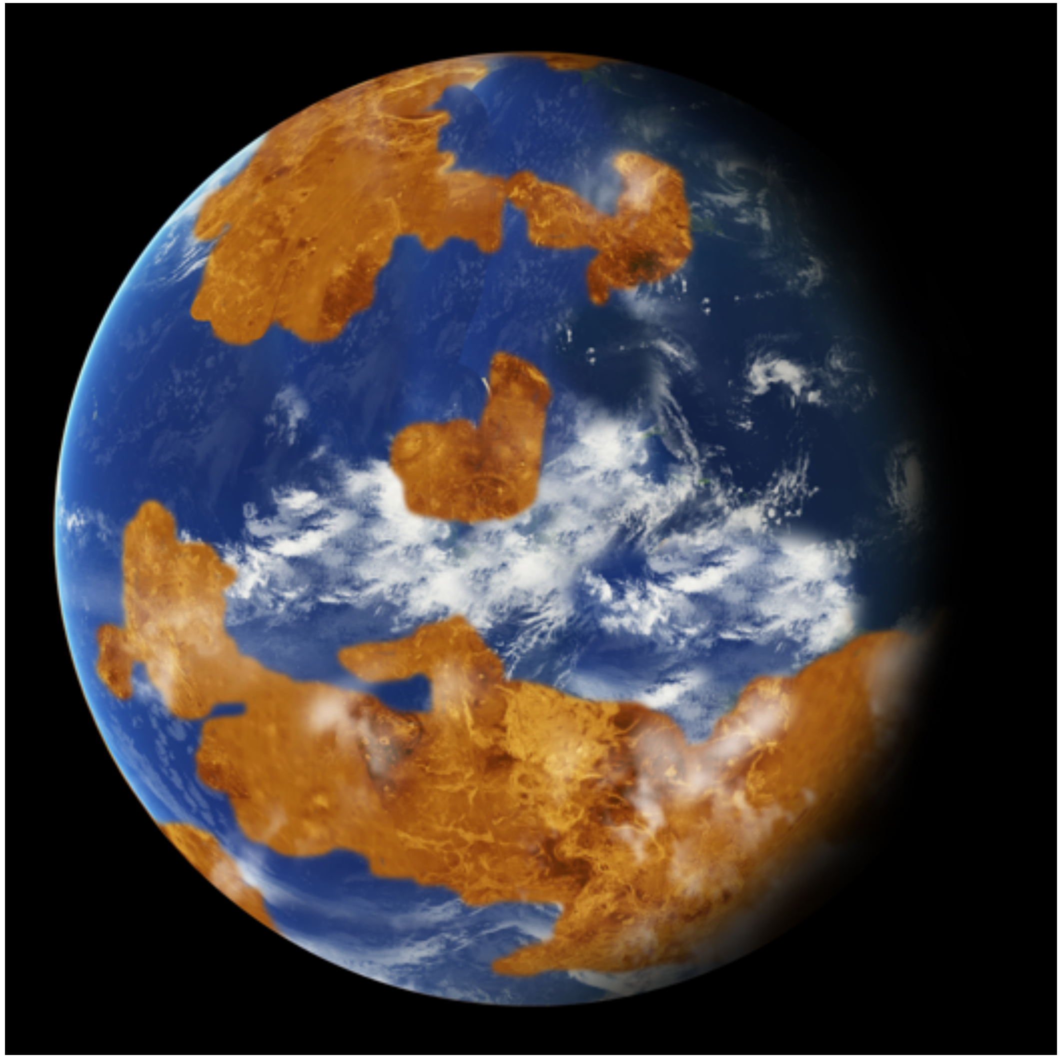


[Futaana et al., 2017]

Q_{H+}/Q_{O+} escape rate ratio

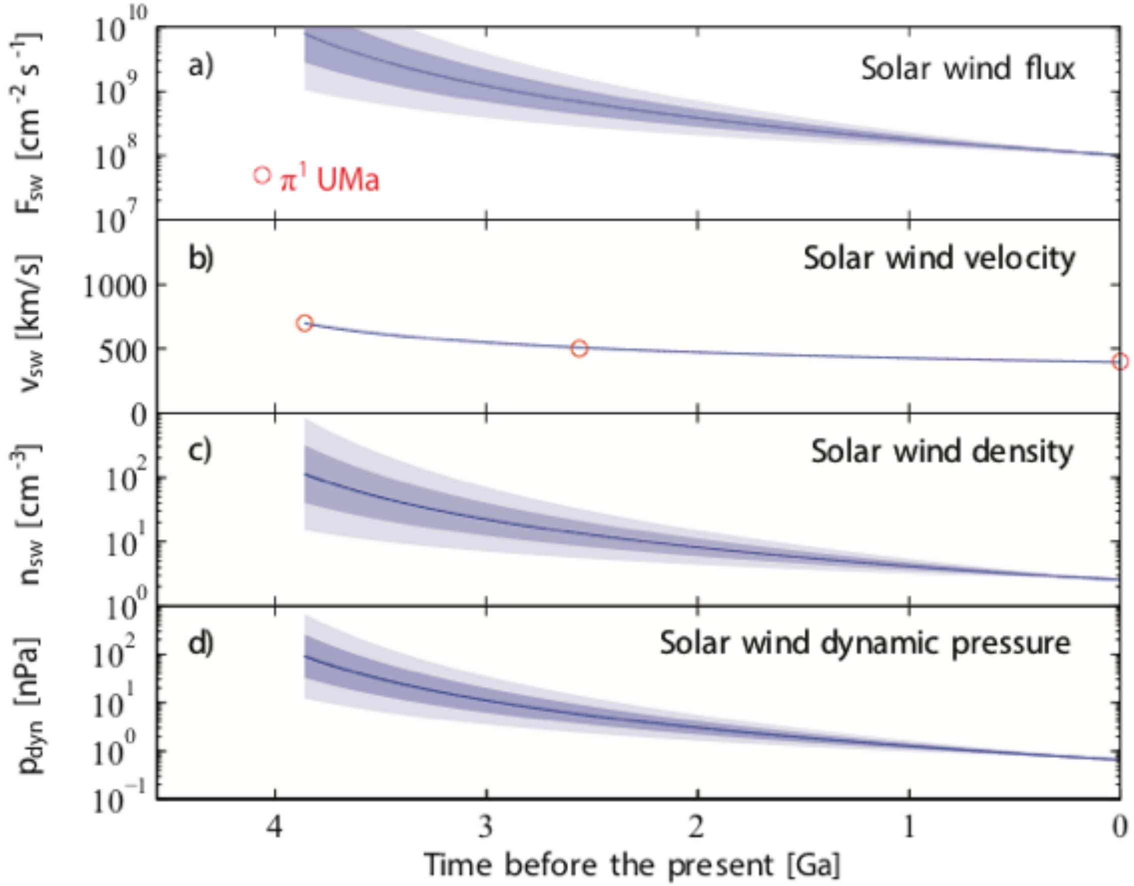
- O^+ escape rate average is steady over solar cycle
- H^+ escape rate decreases by a factor 3.6 from solar minimum to maximum
  - Mainly due to an increase in inflow
- H^+/O^+ escape rate ratio 2.6 ➔ 1.1
  - Average is ~2
- Indicate a historic escape rate below stoichiometric ratio of water: 2
  - As pre-historic solar conditions were more similar to solar maximum conditions

[Persson et al., GRL, 2018]



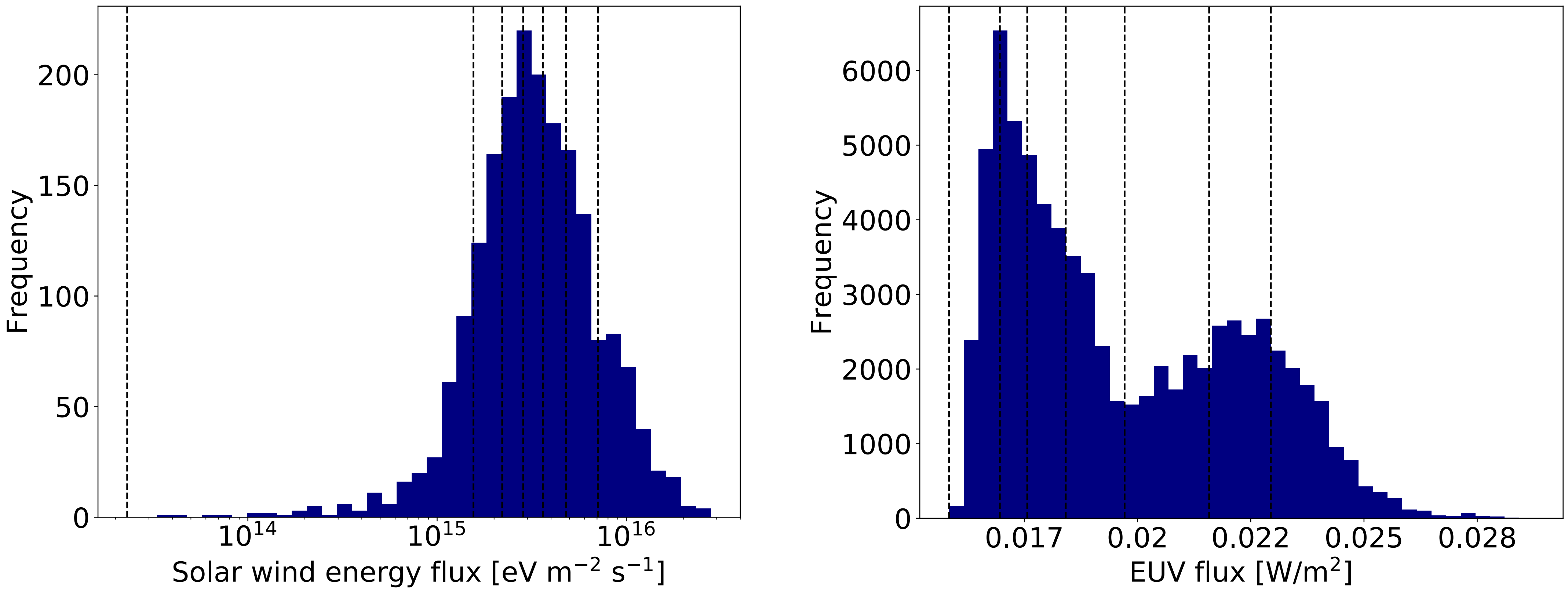
What is the escape rate dependence on upstream parameters?

- The upstream parameters have evolved over the solar system history
  - Extrapolation of escape rates require detailed knowledge of correlations
- The Martian heavy ion escape was recently found to be production-limited [Ramstad et al., 2017]
- **Is the Venusian heavy ion escape limited by the production of ions or by the amount of available energy?**



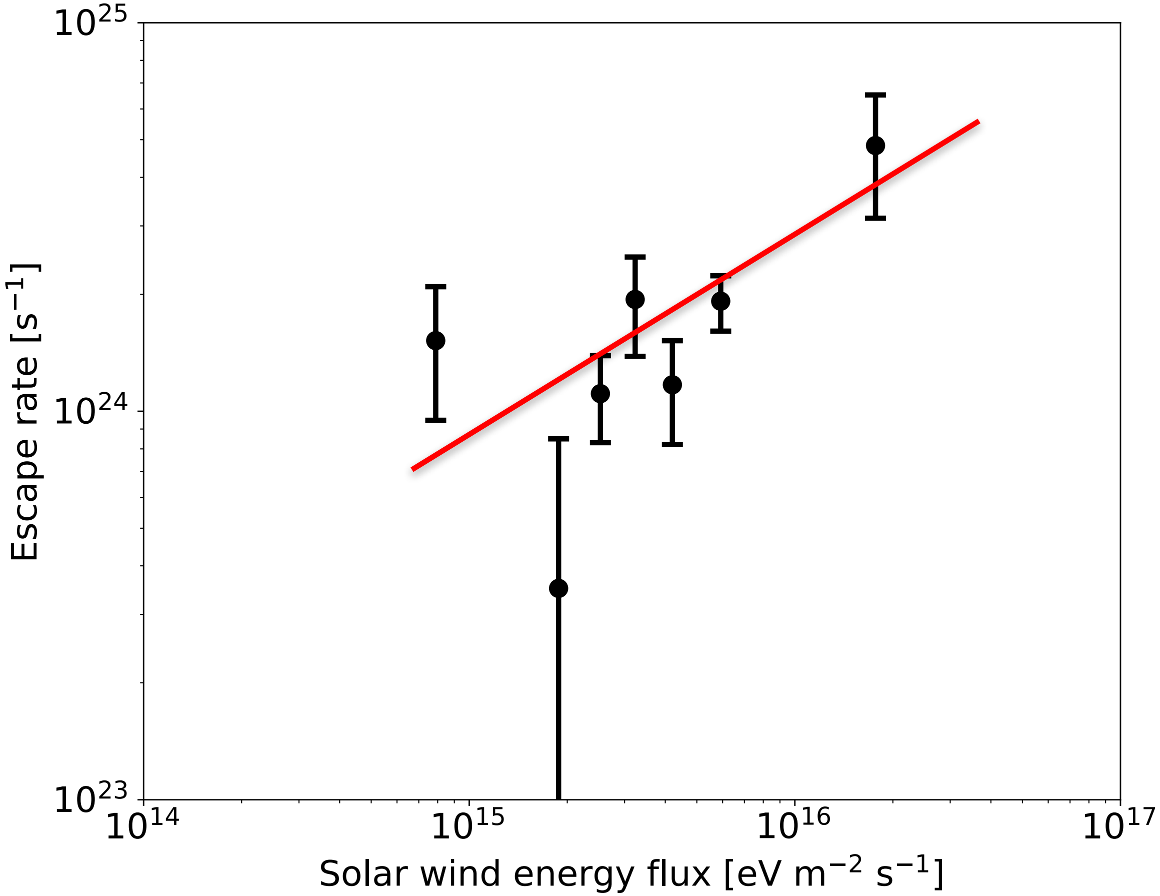
[Ramstad et al., 2017]

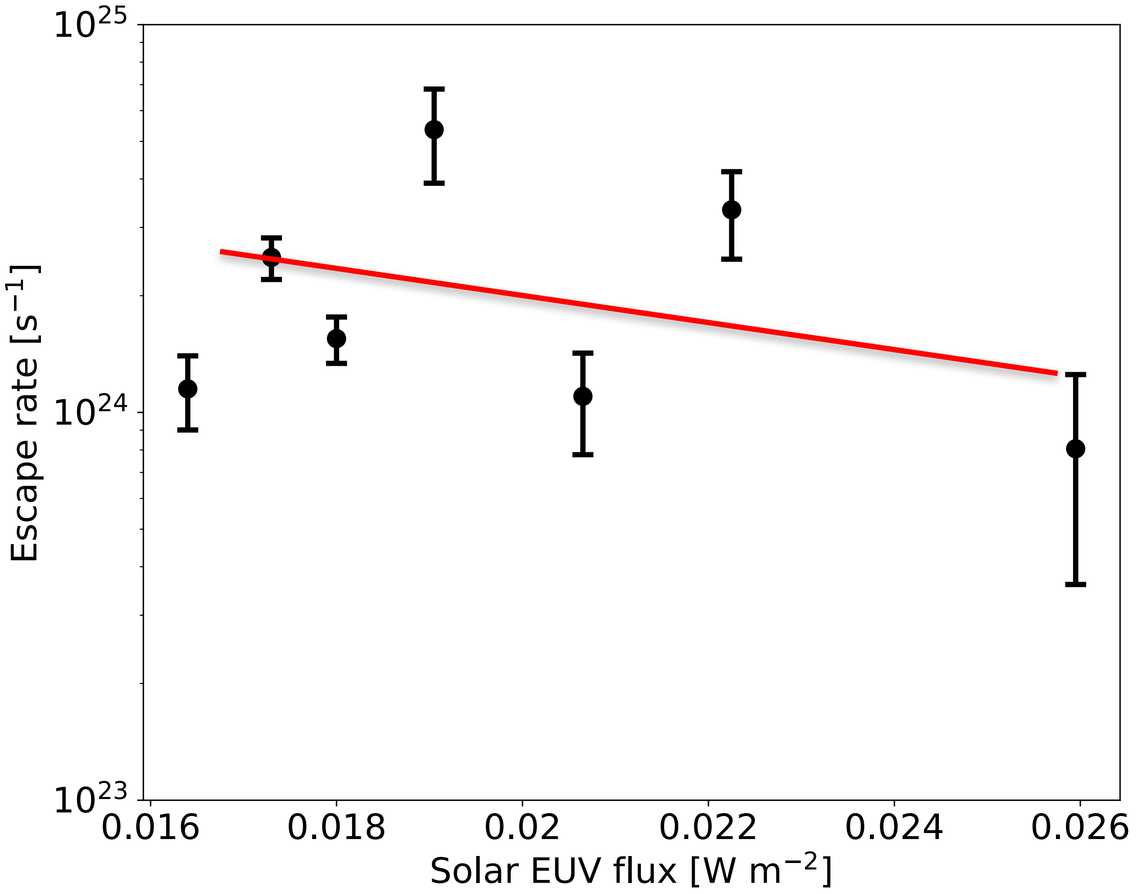
Method



- Constrained one upstream parameter at a time into 7 bins
- Average distribution functions for O^+ made in the magnetotail using the cylindrical VSO coordinate system

Preliminary results of O^+ escape rate





- O^+ escape rate dependent on the available energy in the solar wind
  → Energy-limited escape

Conclusions

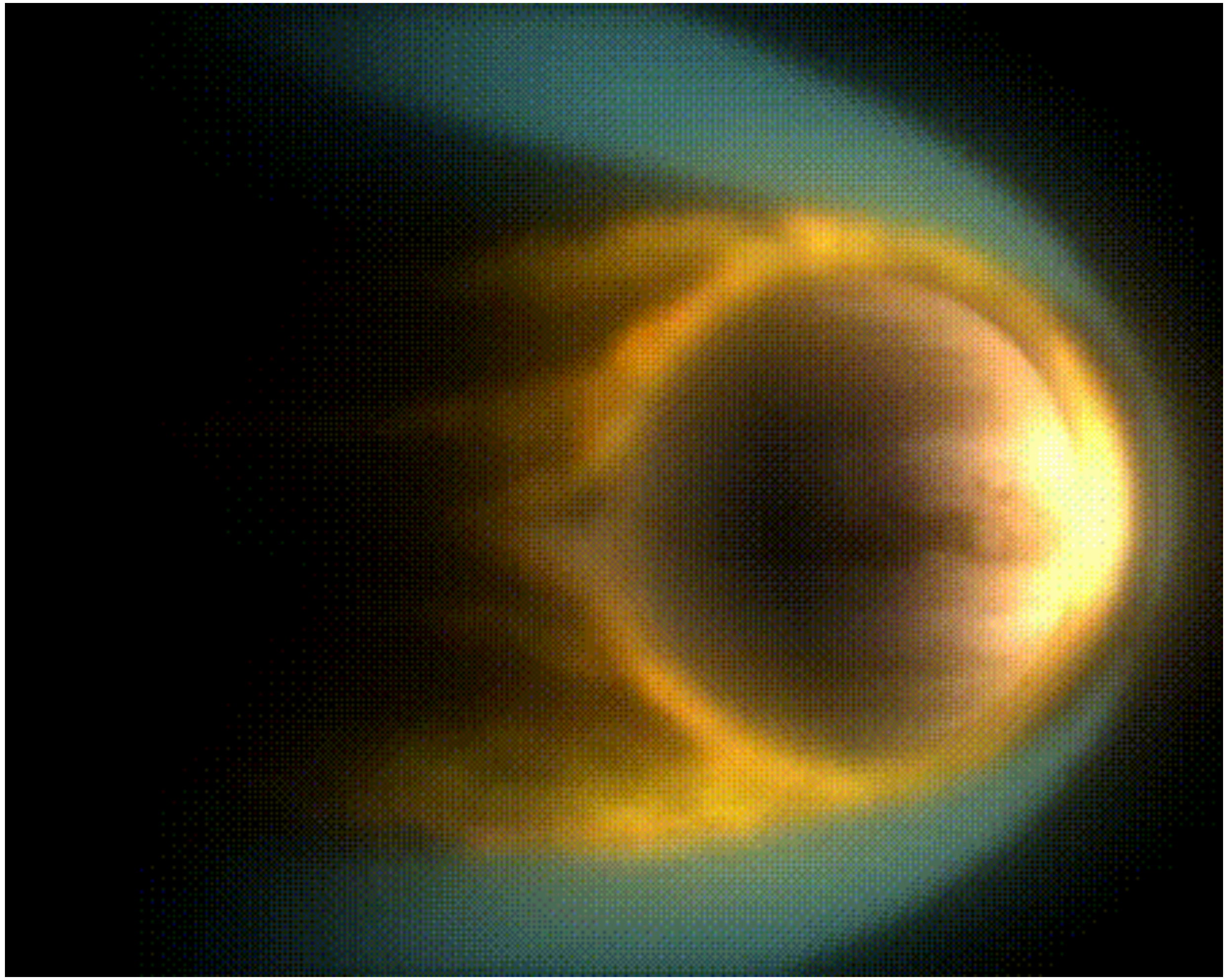
- H^+/O^+ escape rate ratio 2.6 ➔ 1.1

- Indicate a historic escape rate below stoichiometric ratio of water: 2

  [Persson et al., GRL, 2018]

- O^+ escape rate is energy-limited
  → Correlation between solar wind energy and escape rate

- Historically, more energy available in the solar wind
  → Higher O^+ escape rate?
  → How is the inflow affected?



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