The Venusian atmospheric oxygen ion escape and its effect on the atmospheric evolution

Moa Persson (1,2),
Y. Futaana (1), H. Nilsson (1),
R. Ramstad (3), A. Fedorov (4),
S. Barabash (1), and J. Luhmann (5)

(1) Swedish Institute of Space Physics, Kiruna, Sweden (moa.persson@irf.se),
(2) Department of Physics, Umeå University, Sweden,
(3) LASP, Uni. of Colorado Boulder, CO, USA,
(4) IRAP, CNRS, Toulouse, France,
(5) SSL, UC, Berkeley, CA, USA

Venus Science Today,
Zoom meeting, 2020-08-31

[Image: JAXA/ISAS/DARTS/Damia Bouic]

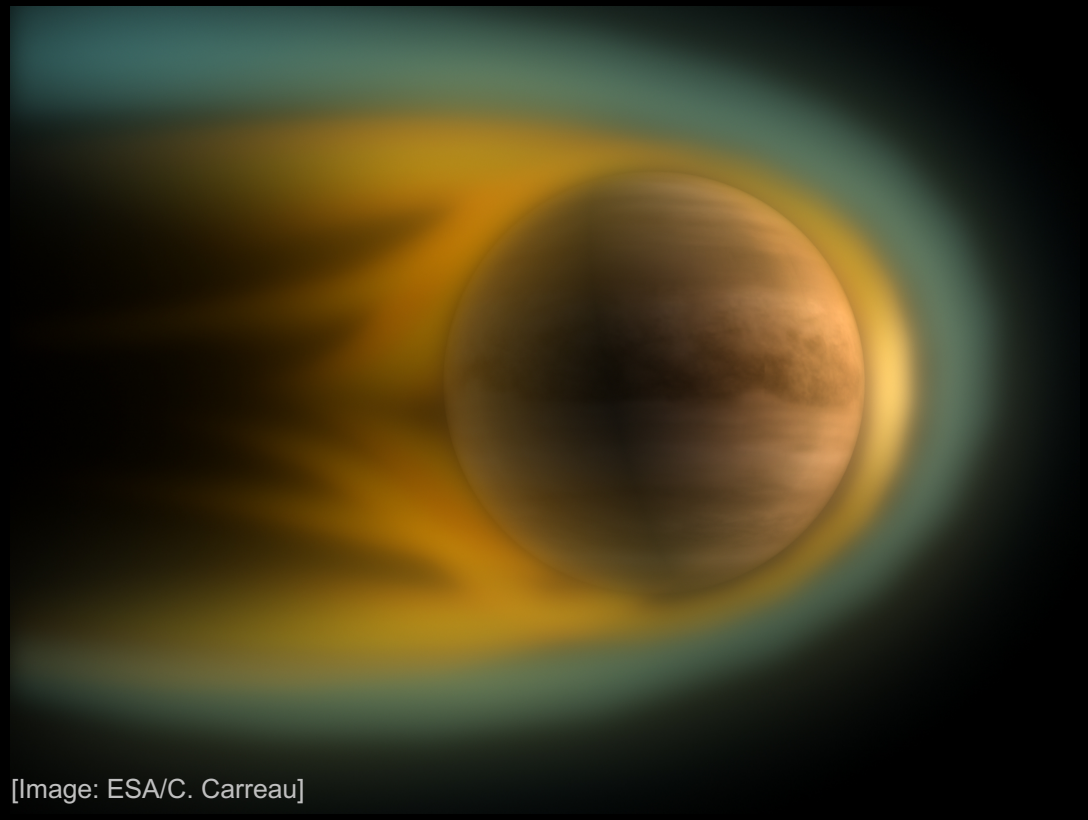
CC BY

INSTITUTET FÖR RYMDFYSIK
Swedish Institute of Space Physics

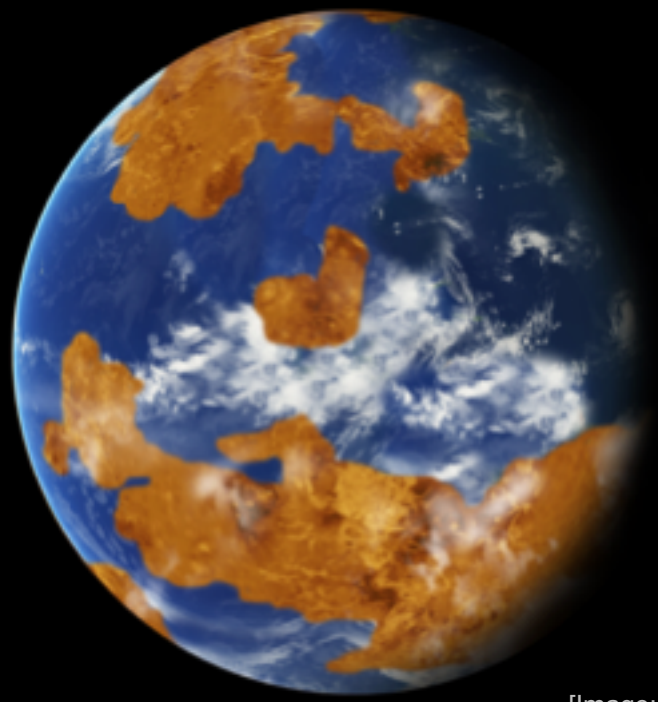
Evolution of the Venusian atmosphere

Venus once had water in its atmosphere,
but today Venus is arid
[Donahue et al., 1997, Way et al., 2018]

How has the atmosphere evolved?



[Image: ESA/C. Carreau]



[Image: NASA]

Water loss mechanisms:

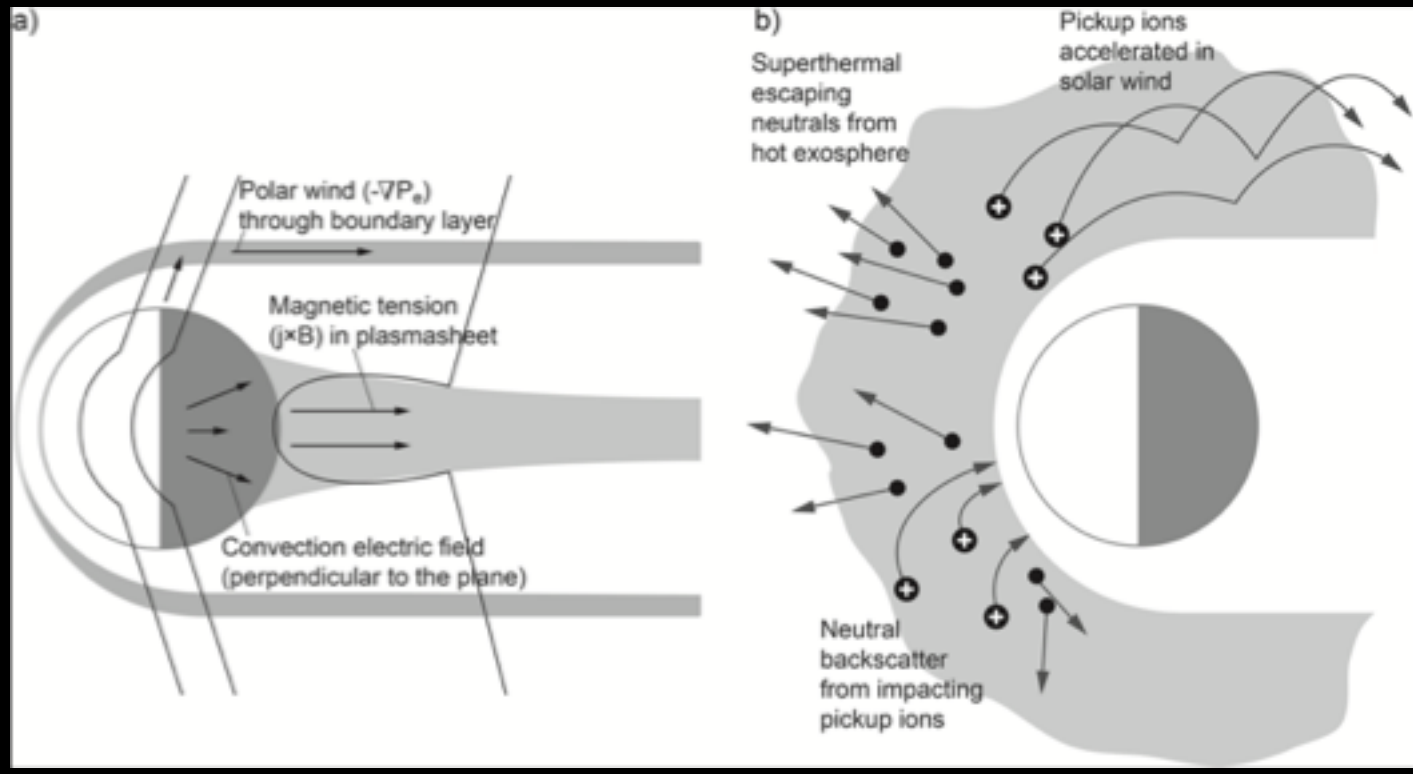
1. Interaction between surface and atmosphere
2. Escape of atmospheric constituents to space

→ Here we focus on escape to space

CC BY

O^+ escape to space from the Venusian atmosphere

- Neutral escape
  - Thermal and hydrodynamical escape (insignificant)
  - Photochemical escape (insignificant)
  - Sputtering (<25 % of total ion escape) [Lammer et al., 2006]
- Ion escape
  - Magnetosheath (~30 %) [Masunaga et al., 2018]
  - **Induced Magnetotail (~70 %)**



[Futaana et al., 2017]

What is the ion escape in the magnetotail today and how has it evolved over the past 3.9 Gyrs?

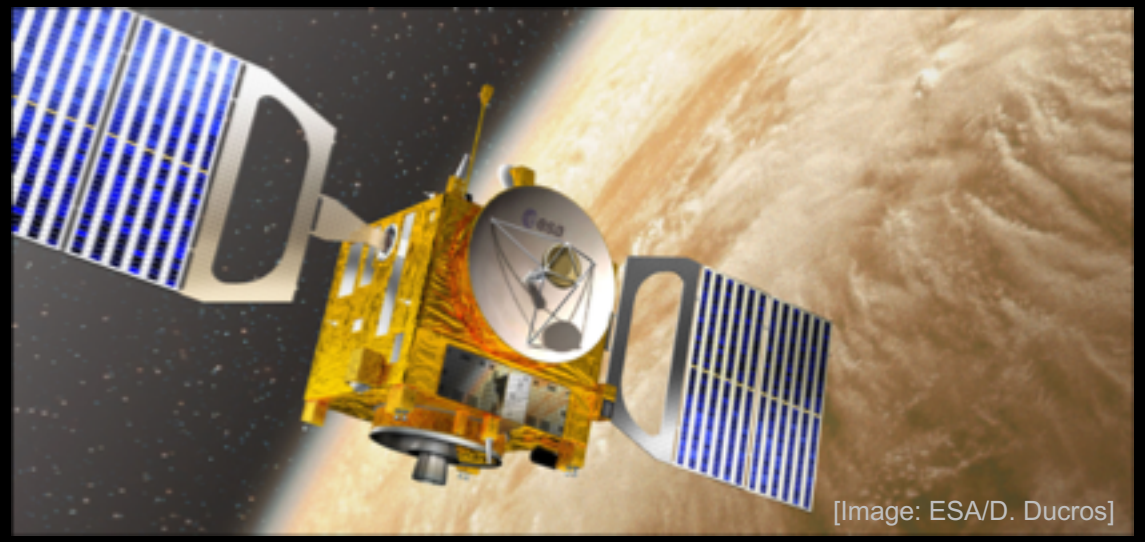
CC BY

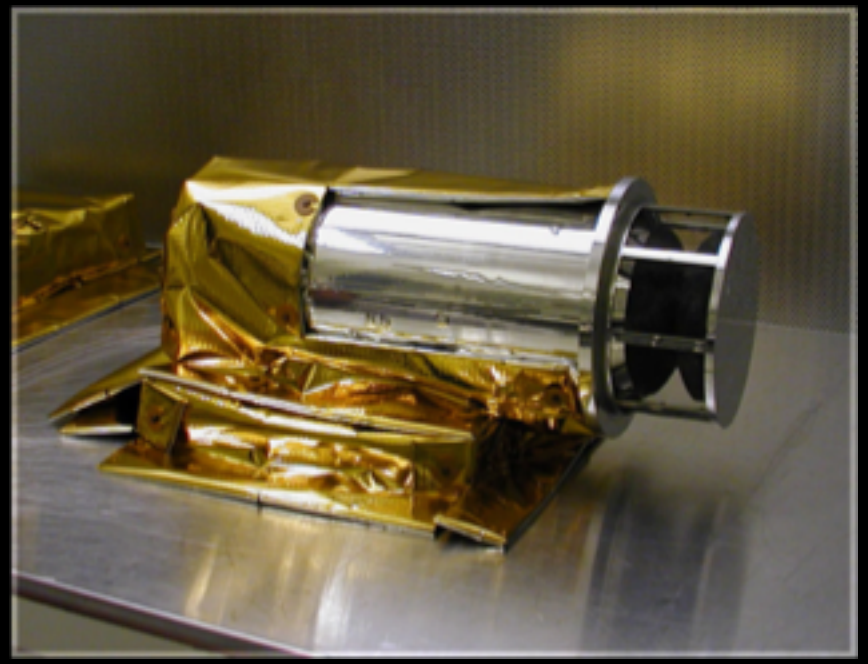
Instrumentation: VEX/ASPERA-4/IMA

Venus Express

2006-2014

>3000 orbits


[Image: ESA/D. Ducros]



ASPERA-4/Ion Mass Analyser

FOV: 90x360°

Energy range: 0.01-36 keV/q

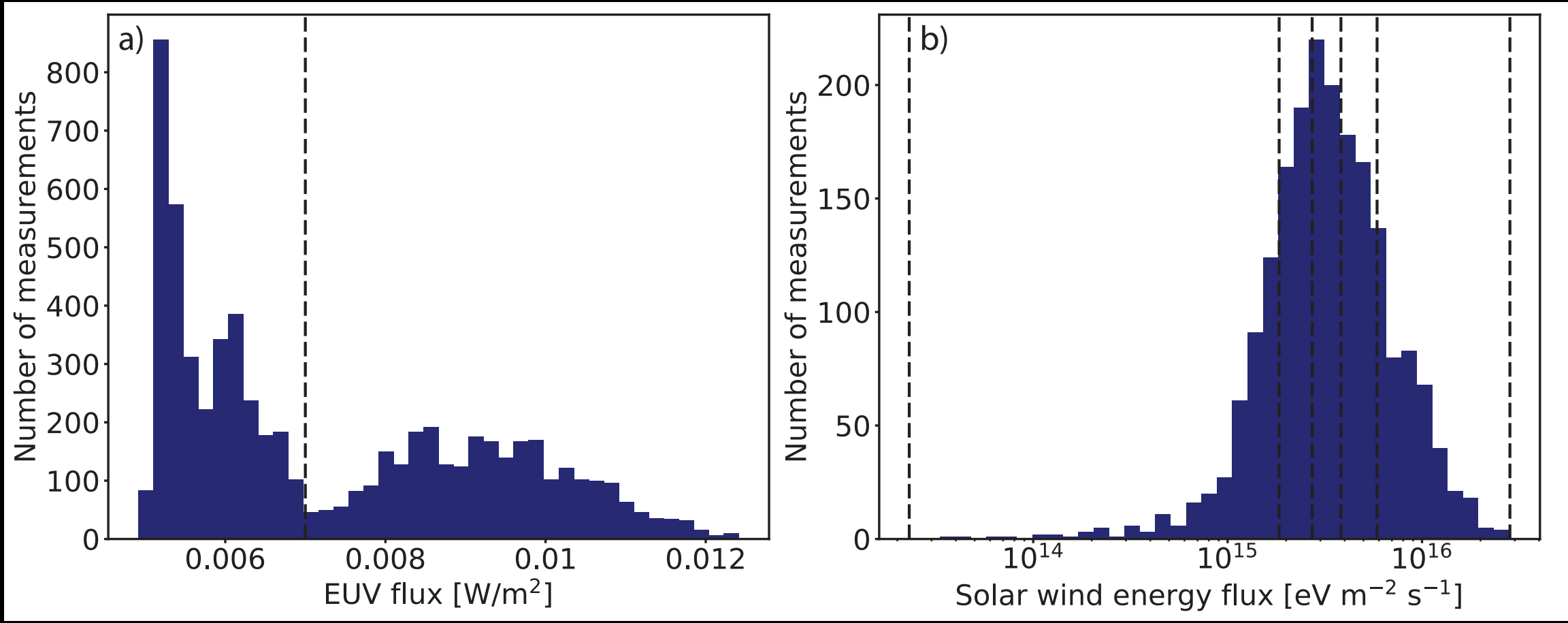
M/q = 1 - >40

Time resolution: 192 s

[Barabash et al., 2007]

CC BY

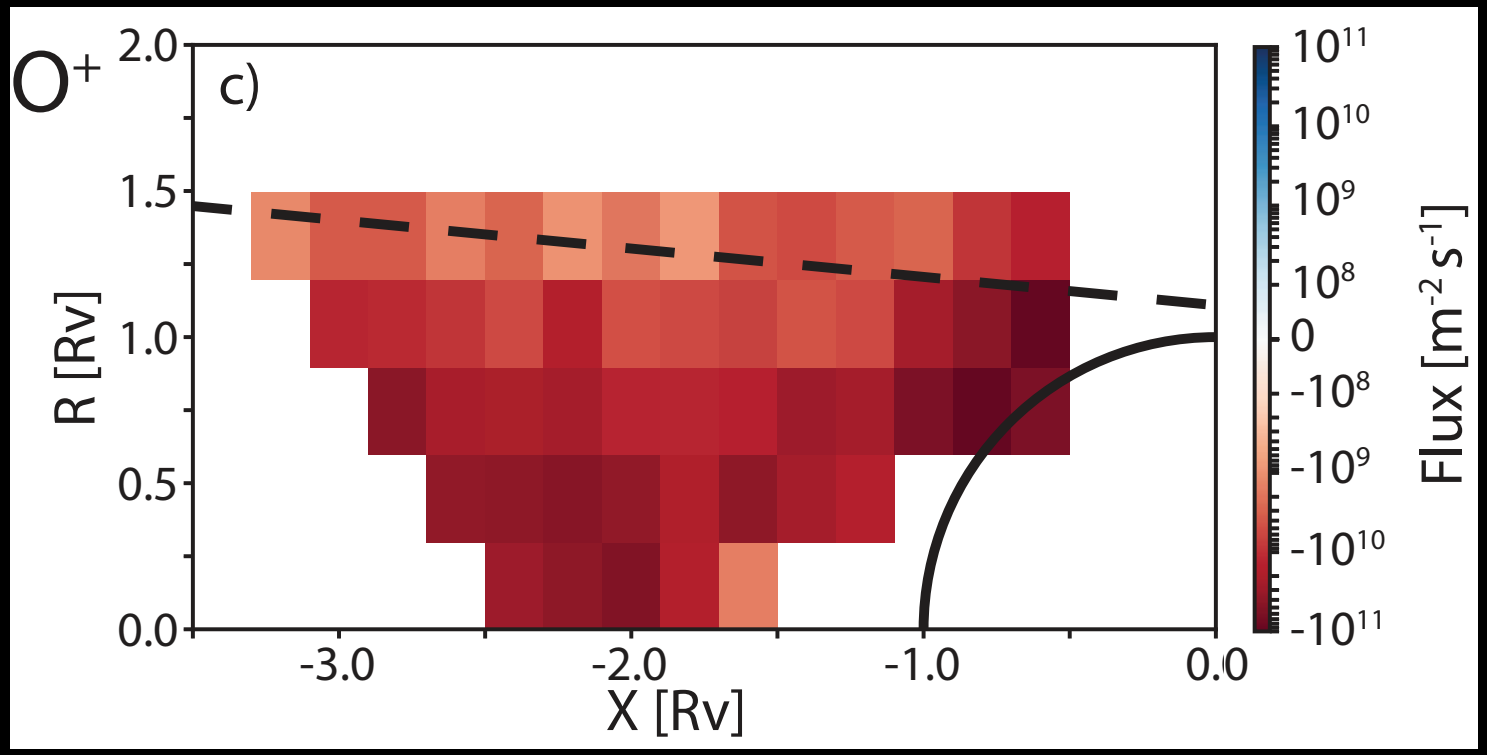
Divide measurements by upstream parameters



Low vs. High EUV flux bin x 5 SW energy flux bins = 10 bins

CC BY

Create average O^+ ion distributions and flux maps



[Persson et al., 2018]

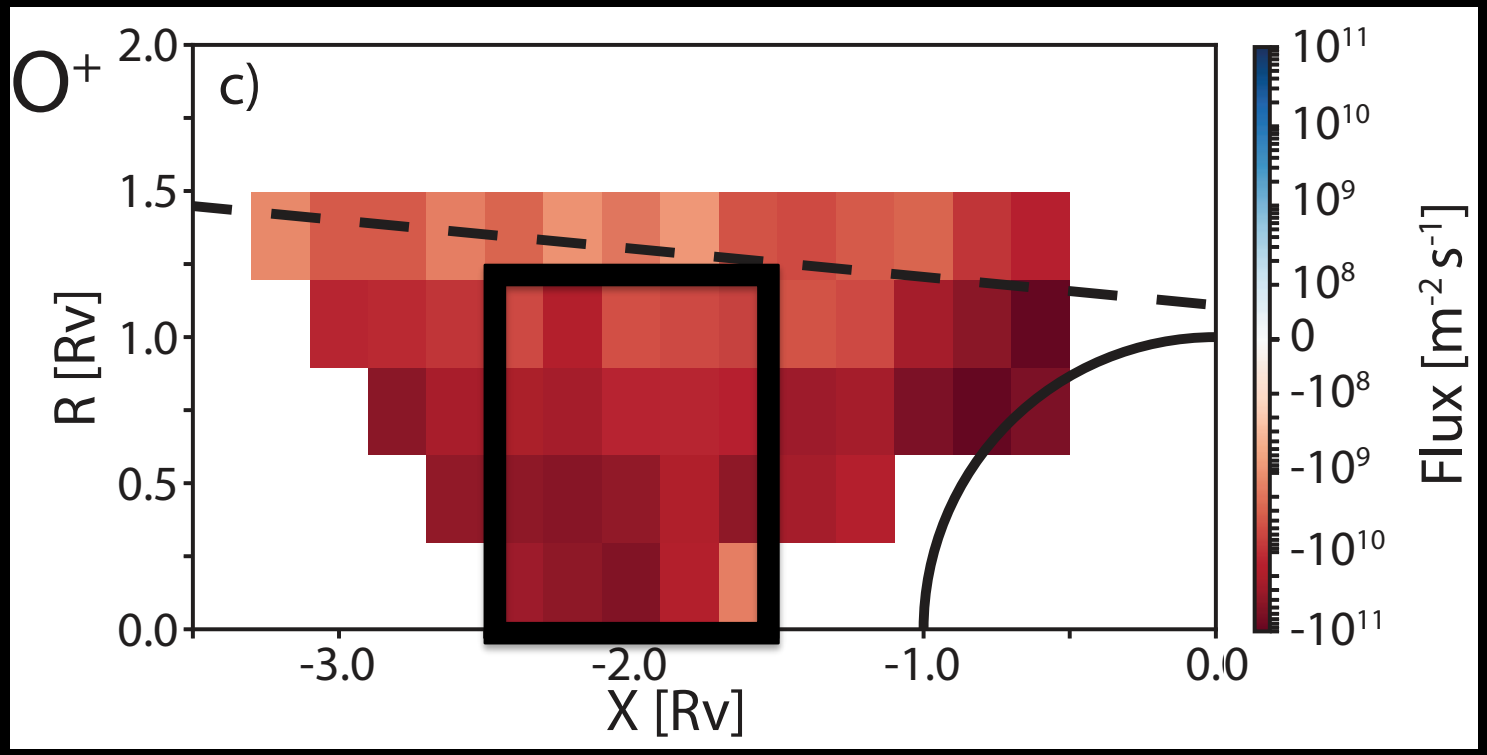
Combine measurements with spatial bins and upstream conditions

→ Create average ion distributions

→ Calculate ion flux in each spatial bin

CC BY

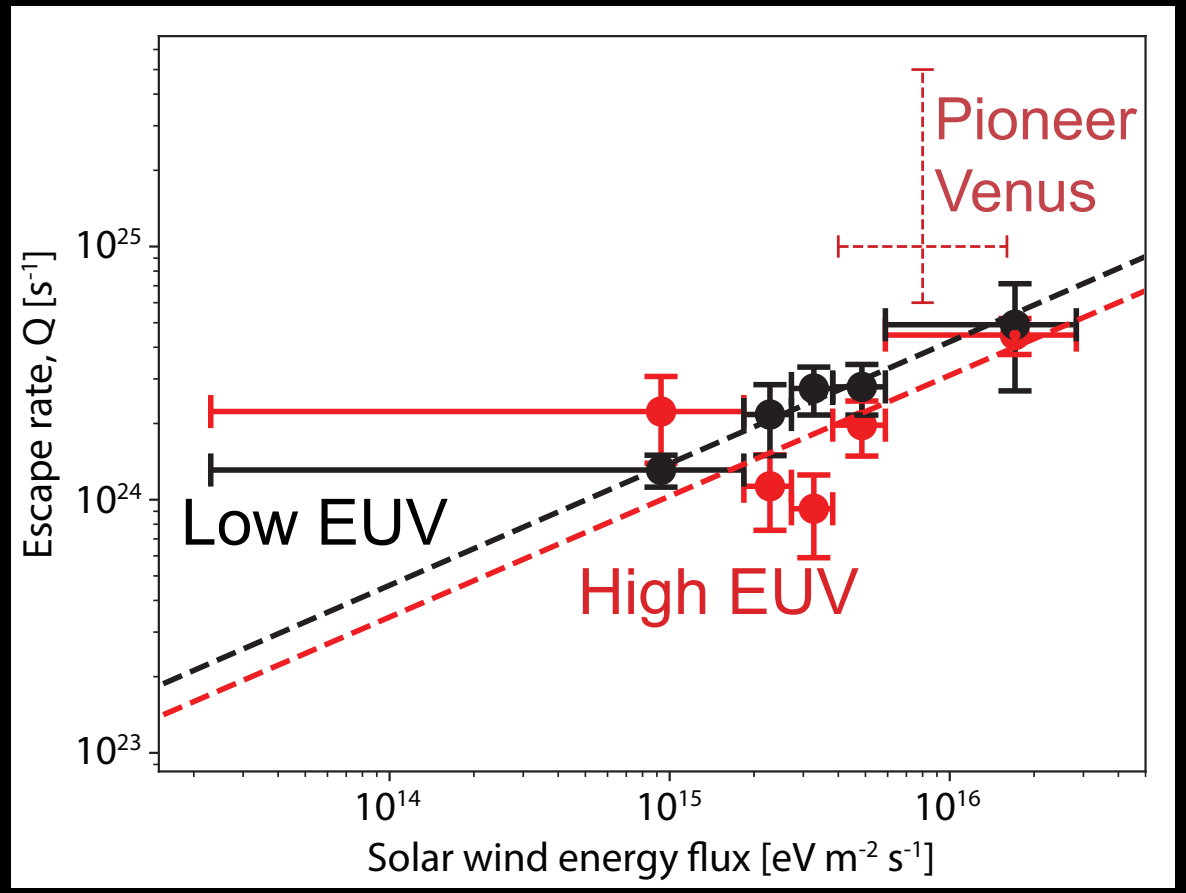
Calculate average escape rates



[Persson et al., 2018]

→ Calculate the total average escape rates by integrating the average flux multiplied with area over the magnetotail

Average O^+ escape rates



- Escape rate increases with available energy in the solar wind
- Escape rate does not increase with EUV flux
  → Decreases slightly due to increase in return flows
- Escape rates from Pioneer Venus measurements are higher
  → Solar wind energy flux was higher

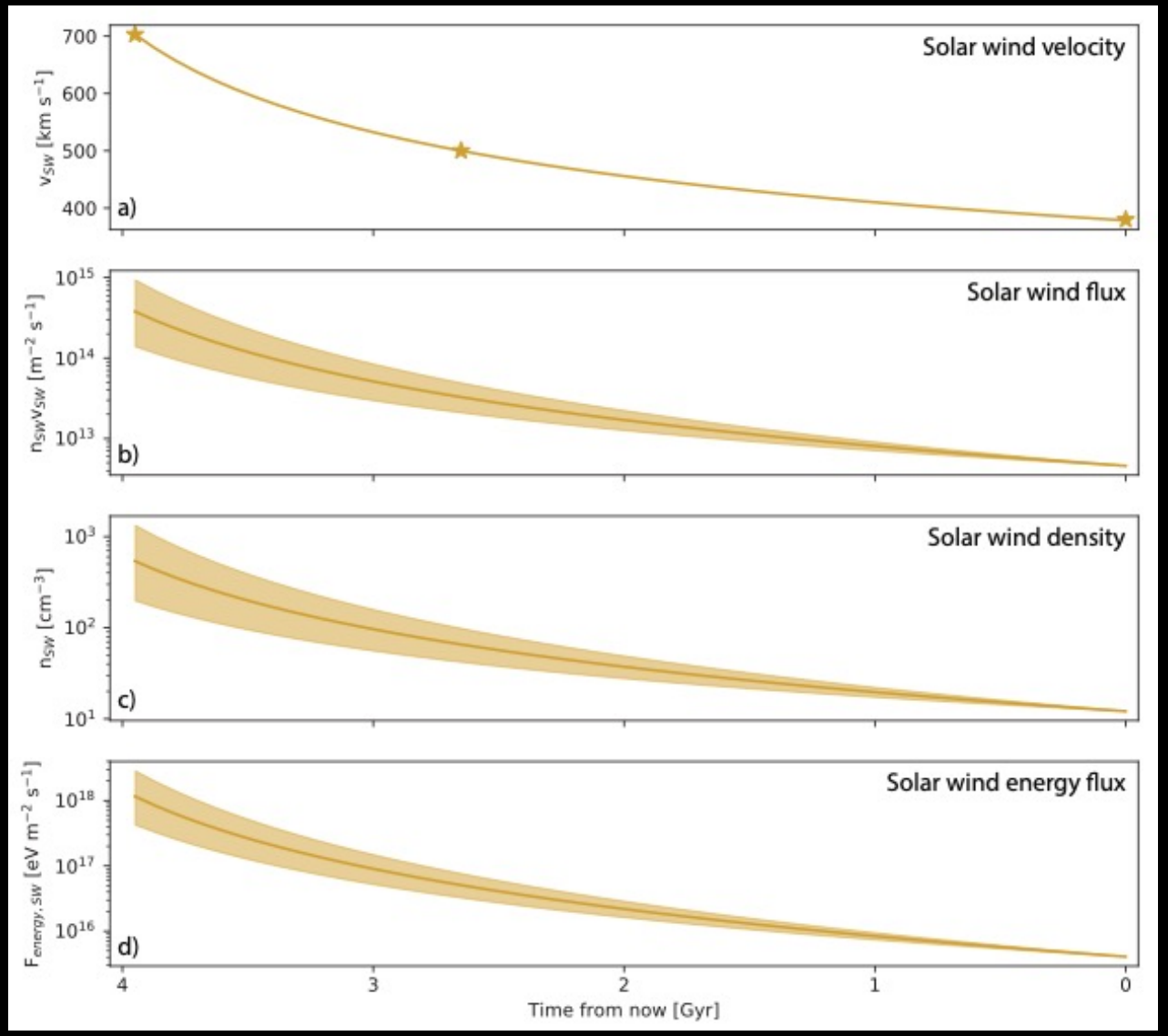
[Persson et al., 2020]

CC BY

Extrapolation of the O^+ escape rates to 3.9 Ga

- We may extrapolate to understand evolution of atmosphere
- Assume current interaction was the same over the past 3.9 Ga
- Get upstream parameters evolution from modelling and observations of Sun-type stars

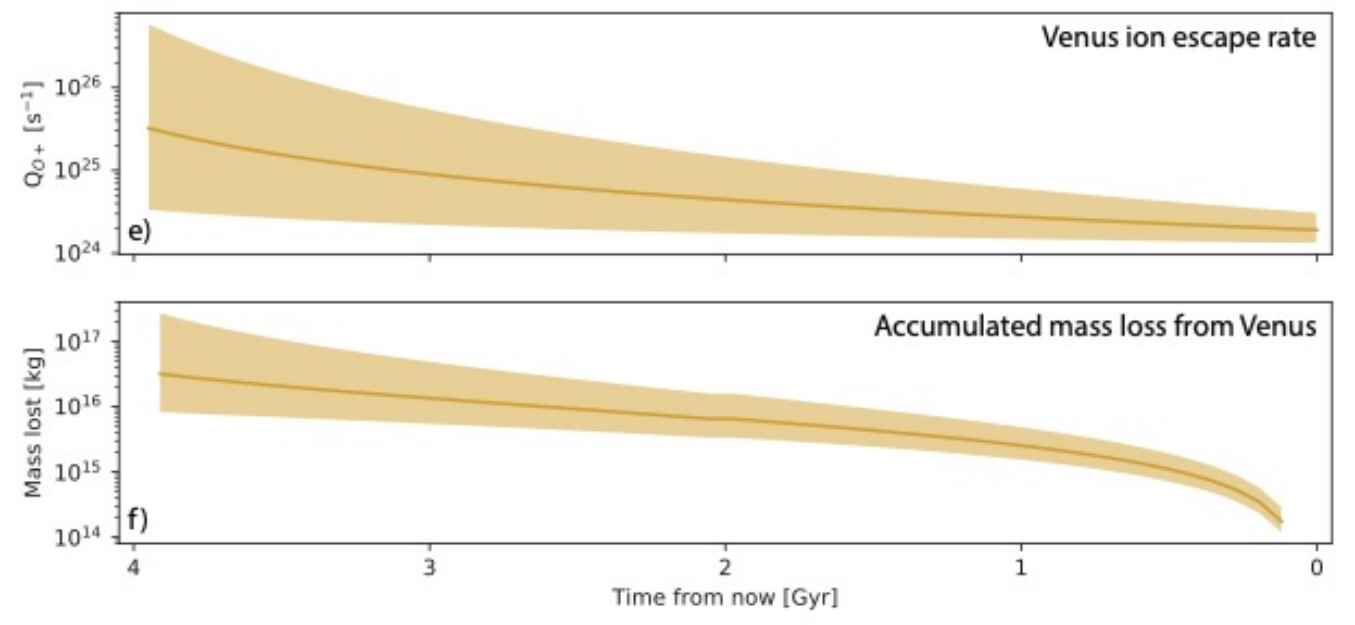
[Wood, 2006; Airapetian et al., 2016]



CC BY

Extrapolation of the O^+ escape rates to 3.9 Ga

- Extrapolation of O^+ escape rate
  - $Q_{3.9Ga} \sim 3.2 \cdot 10^{25}\ s^{-1}$
- Total accumulated mass lost
  - $\sim 10^{16}$ kg
  - Global water depth: **0.02-0.6 m**



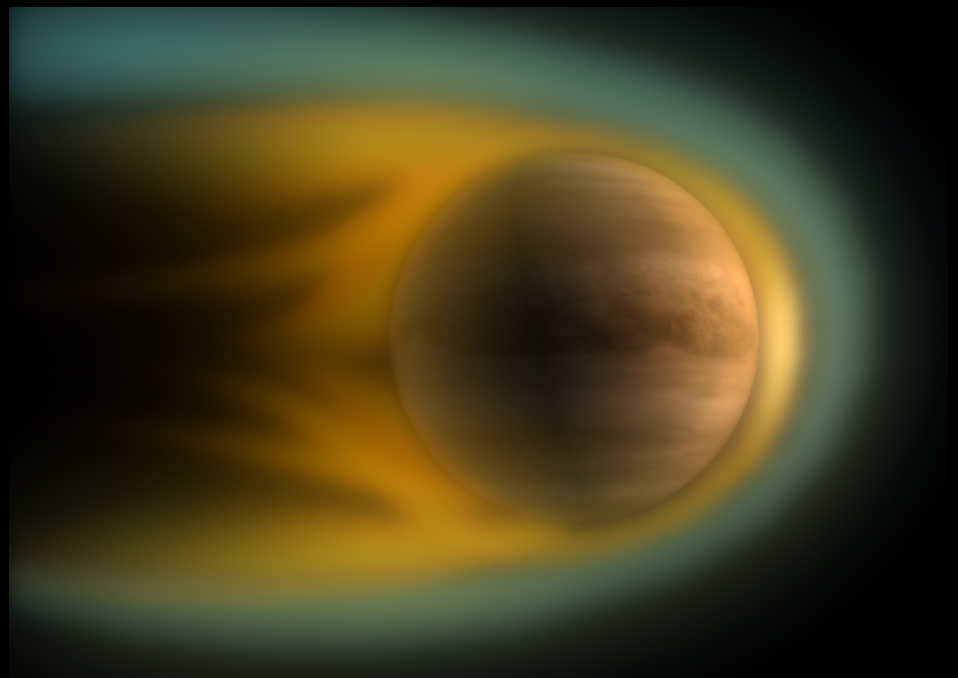
The loss of Venus' historical water content cannot be fully explained by the ion escape to space

[Persson et al., 2020]

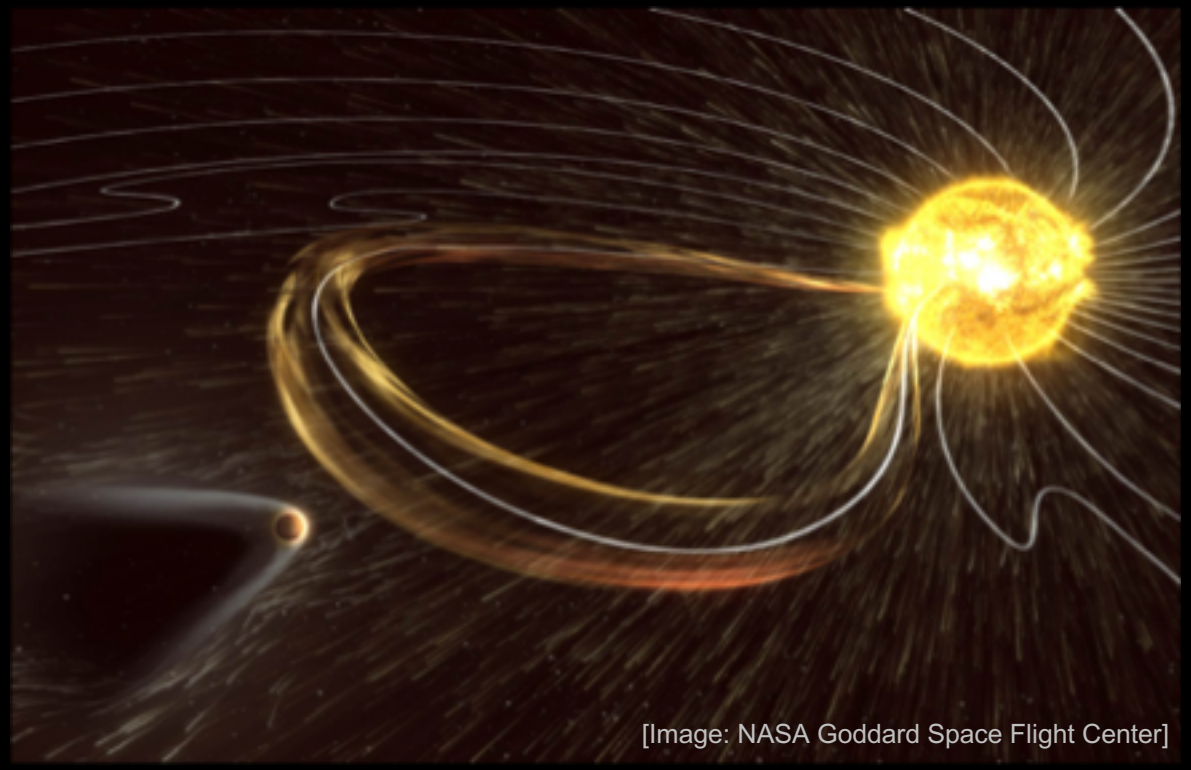
CC BY

Additional processes affecting the evolution

- CMEs can enhance the outflow from the Venusian atmosphere by between 2-100 times
- Depending on the CME frequency and how it hits Venus, CMEs may have contributed largely to the escape of atmospheric constituents



[Image: ESA/C. Carreau]



[Image: NASA Goddard Space Flight Center]

- The return flows in the Venusian magnetotail decrease the net escape
- The effect is largest during solar maximum

CC BY

Conclusions

- The average O^+ escape rates from the current Venusian atmosphere cannot explain the historical water loss from Venus
- Extreme space weather events may help explain the water loss but more studies needed
- Return flows are important for the Venusian net escape rates

[Image: JAXA/ISAS/DARTS/Damia Bouic]

CC BY