Global Venus-solar wind coupling and oxygen ion escape

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Key points

- The average O^+ ion escape to space cannot explain the loss of an ocean of water on Venus
- An increase of the energy in the upstream solar wind leads to an increase in the net O^+ escape rates
- However, the fraction of energy transferred (coupling) from the solar wind to the escaping ions decreases as the energy of the upstream solar wind increases
- The coupling is similar to what is observed at Mars, but is different from that found at Earth

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

EPSC 2020 September,
Virtual meeting poster

IRF INSTITUTET FÖR RYMDFYSIK
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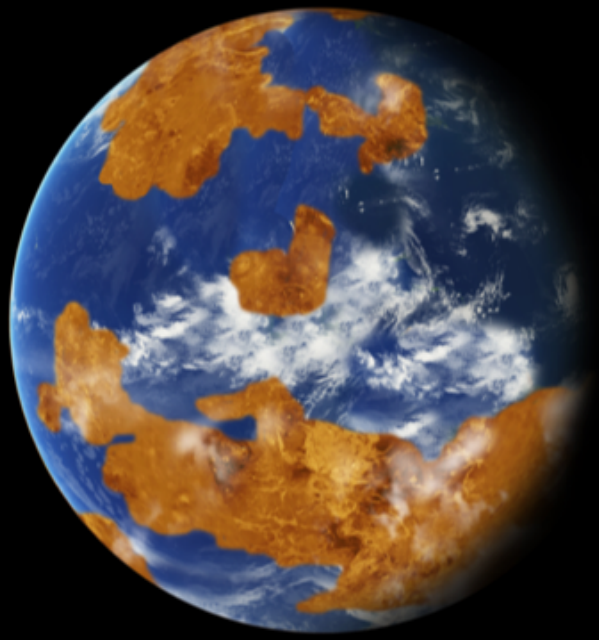
Evolution of the Venusian atmosphere



[Image: NASA]

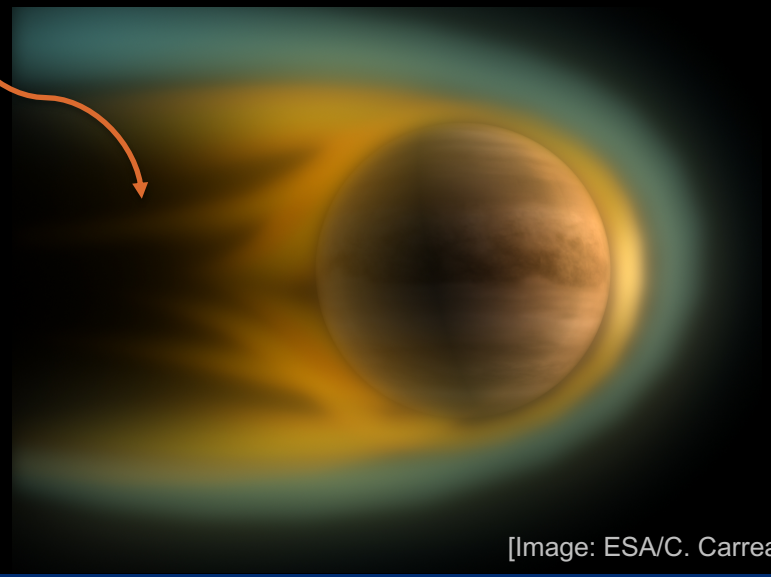
Venus once had water in its atmosphere, but today Venus is very arid.
How has the atmosphere evolved? [Donahue et al., 1997, Way et al. 2020]

Main categories of water loss:

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

→ Here we focus on escape to space

The largest component of oxygen escape today is through non-thermal ion escape in the Venusian magnetotail



[Image: ESA/C. Carreau]

We use Venus Express/ASPERA-4/Ion Mass Analyser measurements to calculate the average ion escape in the Venusian magnetotail and its coupling with the upstream solar wind.

Venus Express orbited Venus 2006-2014, and had >3000 orbits.
IMA properties: 90x360˚ field of view, 0.01-36 keV/q, M/q = 1->40,192 s

[Barabash et al., 2007]

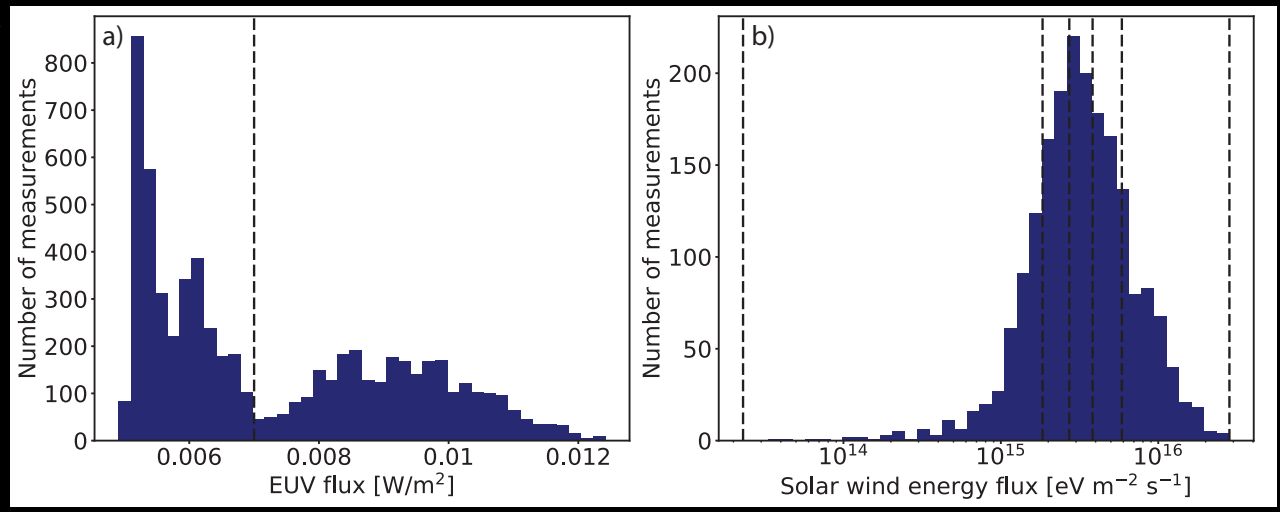
Average O^+ escape rates

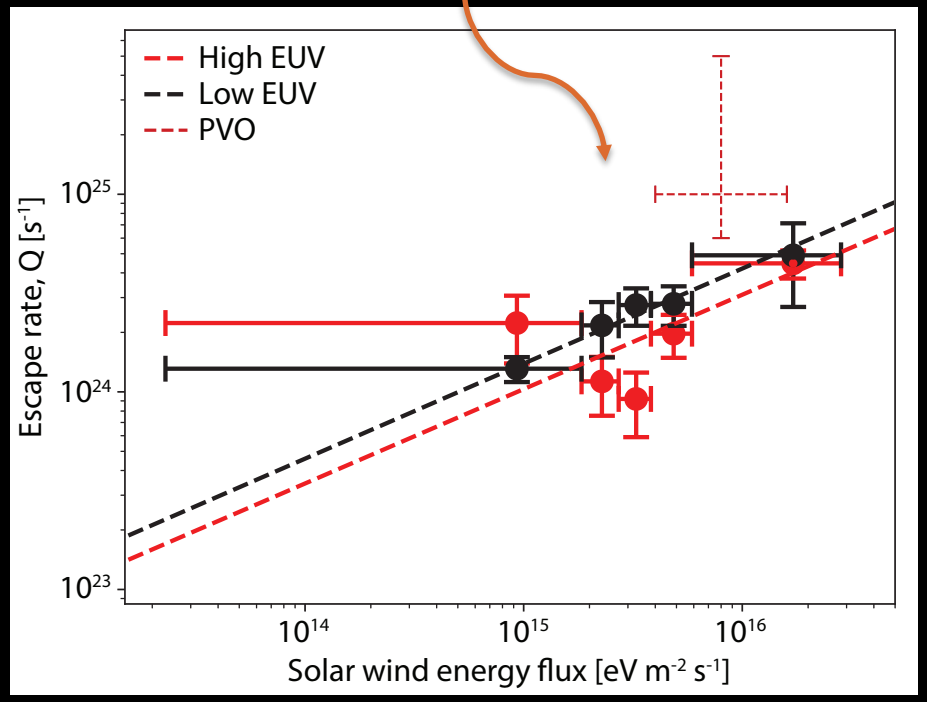
Upstream solar wind parameters divided into:

→ 5 solar wind energy flux x 2 EUV flux = 10 bins

The average ion flux, and subsequently, the average O^+ ion escape is calculated from average ion distributions made in the magnetotail for each upstream parameter bin

→ 10 escape rates calculated





Results

- Escape rate (Q) 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

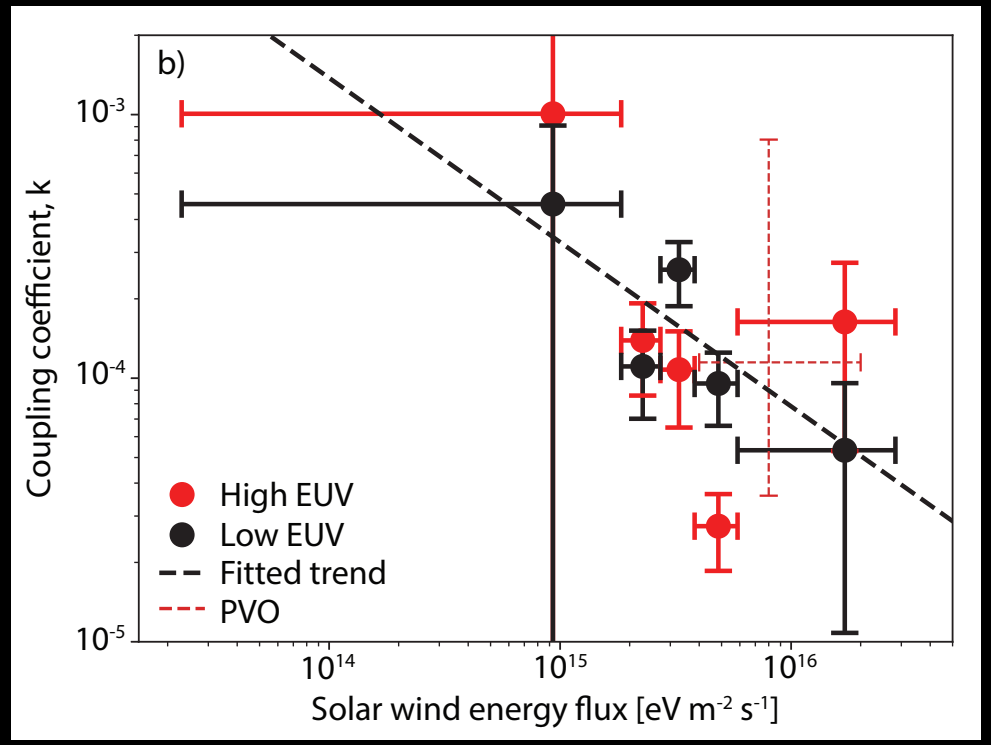
[Persson et al., 2020]

Venus-solar wind coupling

The coupling between the available energy to enter the system and the energy leaving the system tells us about the efficiency of the energy transfer from the solar wind to the Venusian atmosphere.

Coupling between power into and out from the system

$$k = \frac{P_{escape}}{P_{SW}} = \frac{\sum Q(E) \cdot E \cdot \Delta E}{F_{SW,energy} \cdot A}$$



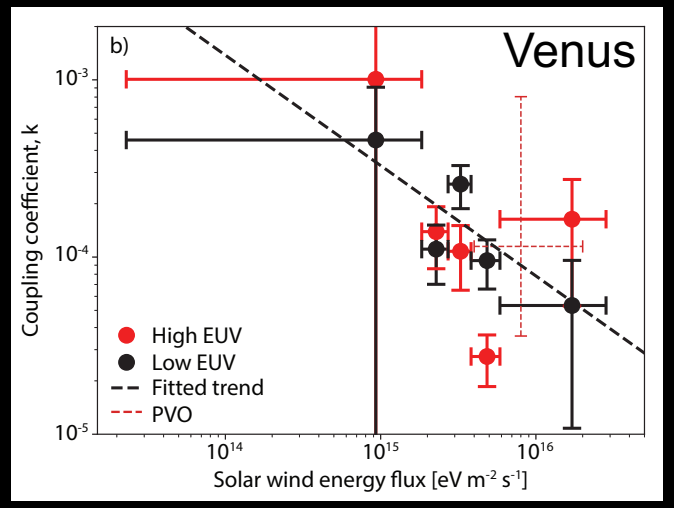
Results

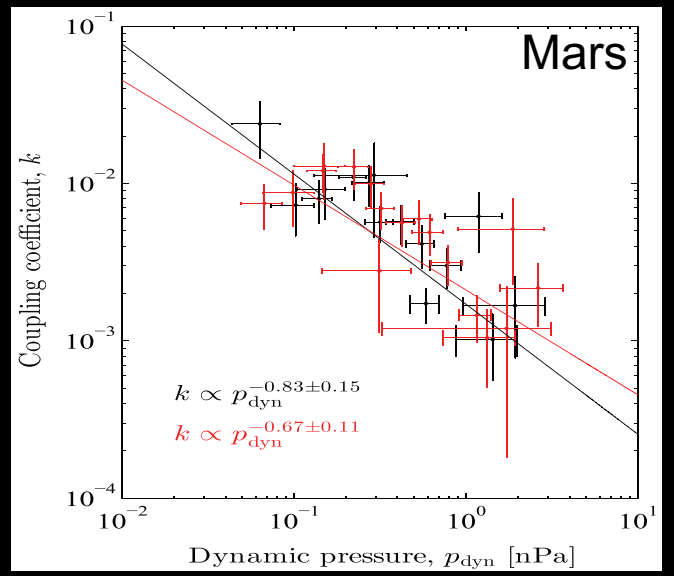
- We find that the coupling decreases with increased energy available in the upstream solar wind
  - → Energy transfer becomes less efficient

[Persson et al., in prep.]

Comparison between Venus, Mars and Earth

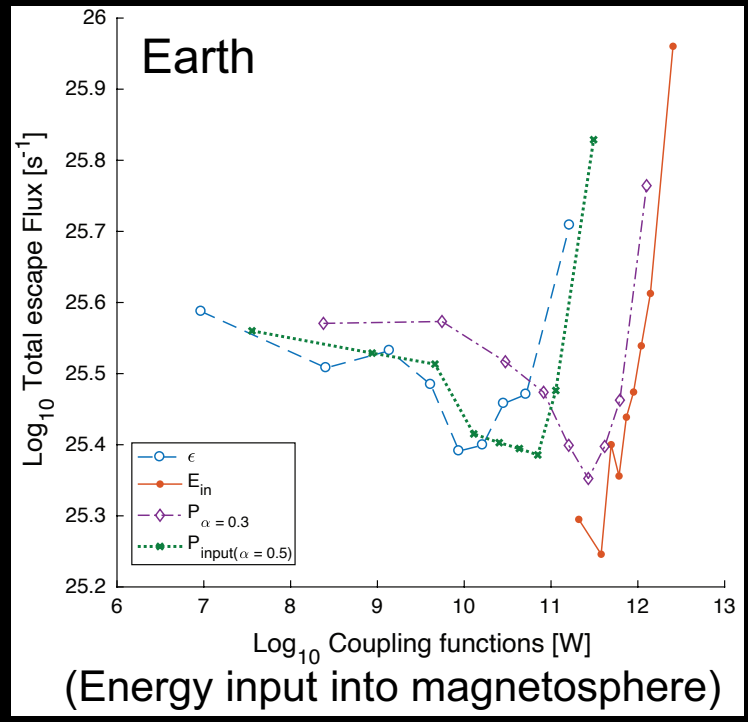
[Persson et al., in prep.]





[Ramstad et al., 2017]

- The coupling behaves similarly at Venus and Mars, which both have induced magnetospheres
- However, the fraction of energy transmitted to Venus from the solar wind is smaller than for Mars
- For Earth the coupling behaves differently
  - → The escape only increases after a threshold is reached
  - → Different because of the intrinsic magnetic field?



[Schillings et al., 2019]

Conclusions

- The escape rates increase with an increase in upstream solar wind energy flux
- However, the coupling between the solar wind and the ion escape decreases as energy increases in the upstream solar wind
- The coupling trends are similar to that at Mars, but a smaller fraction of energy is transferred from the solar wind to Venus than to Mars
- As only a small fraction of energy is transferred, Venus efficiently screens itself from the solar wind

References & Acknowledgements

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- The Swedish contribution to the ASPERA-4 experiment on board Venus Express was supported by the Swedish National Space Agency (SNSA). We acknowledge the European Space Agency (ESA) for supporting the successful Venus Express mission.
- M. Persson acknowledges support to her graduate studies from SNSA (Dnr: 129/14).

- ASPERA-4/IMA data used in this study are publicly available via the ESA Planetary Science Archive (PSA; https://www.cosmos.esa.int/web/psa/ venus-express).