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Does Earth's Intrinsic Magnetosphere Protect our Atmosphere from the Solar Wind?

- Comparative Measurements of Atmospheric Ion Escape at Earth, Venus, and Mars

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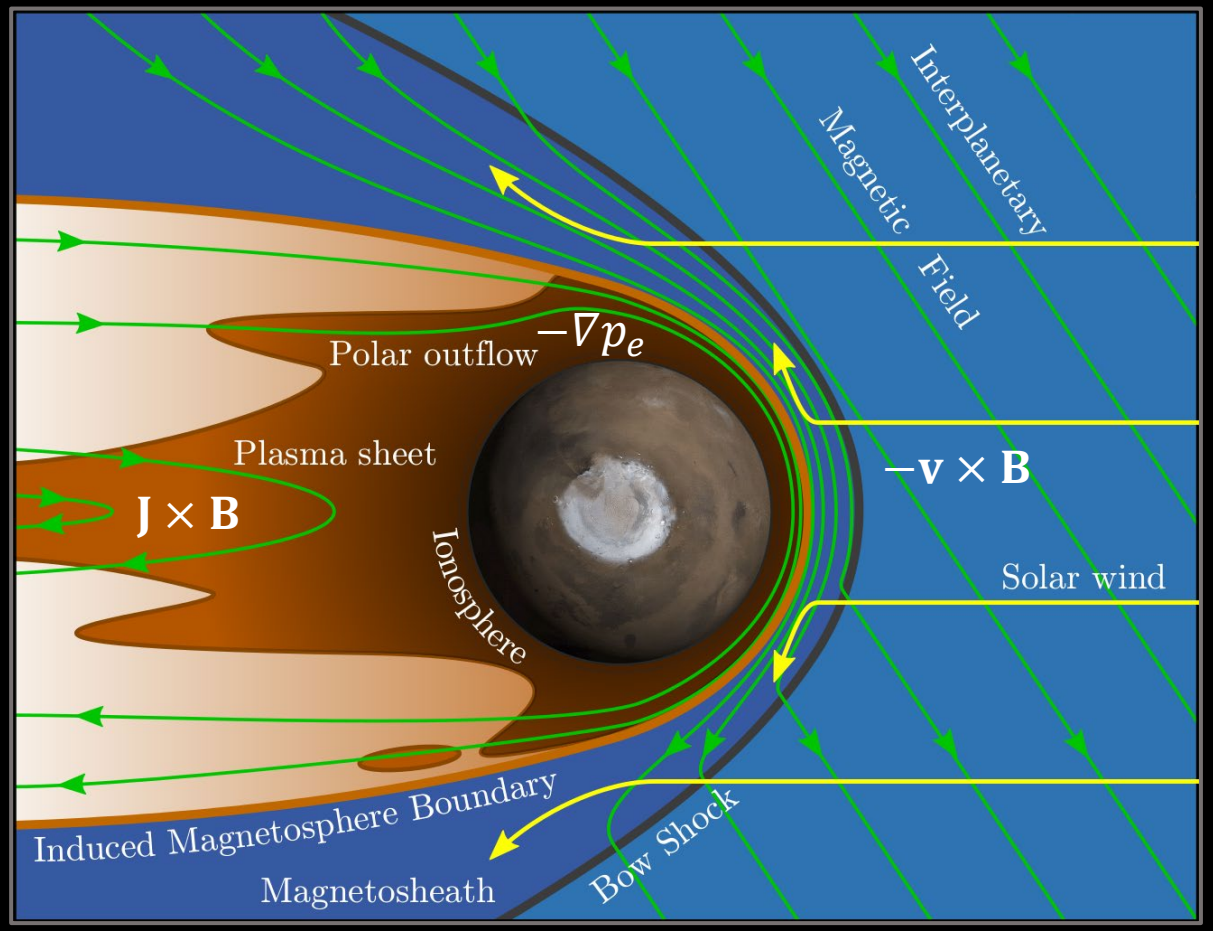
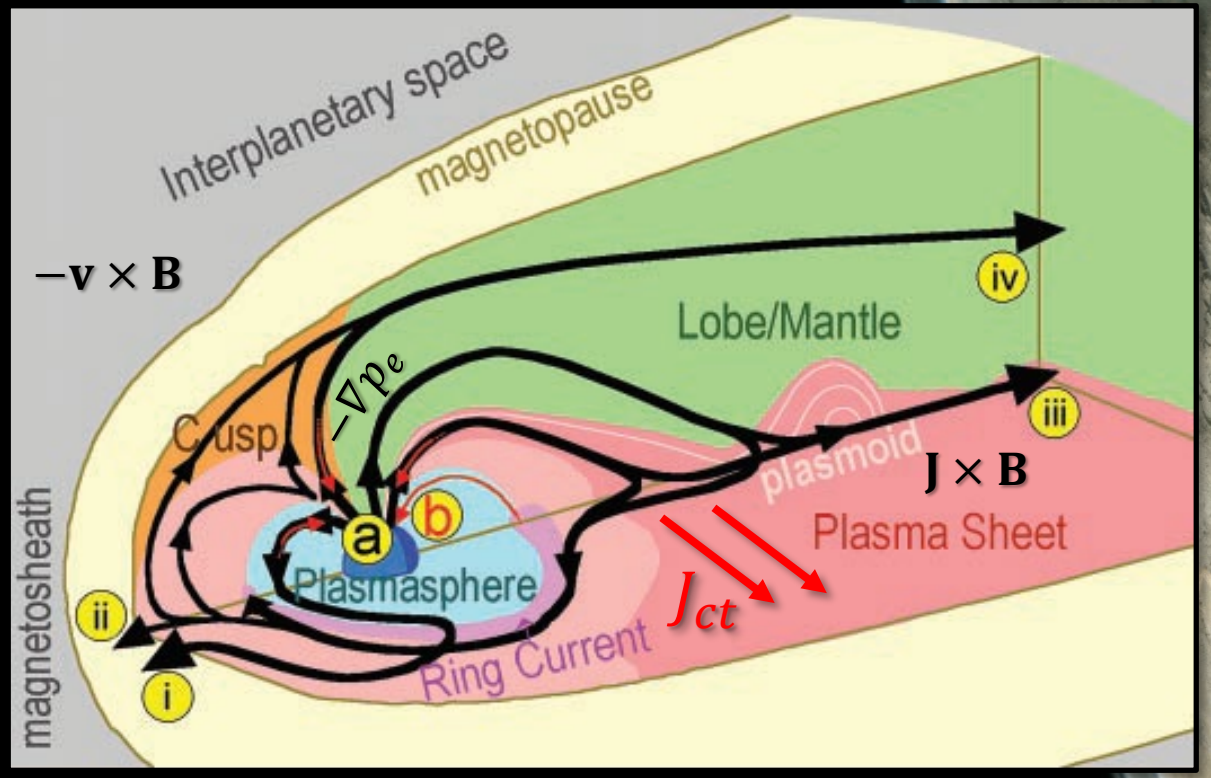
Ion escape in induced/intrinsic magnetospheres



[*Ramstad et al.* 2017c]



[*Seki et al.* 2001]

Motional Hall Ambipolar Resistive

$$\mathbf{E} = -\mathbf{v} \times \mathbf{B} + \frac{1}{n_e e}\mathbf{J} \times \mathbf{B} - \frac{1}{n_e e}\nabla p_e + \mathbf{J}/\sigma$$

Gravity and escape

Escape velocity

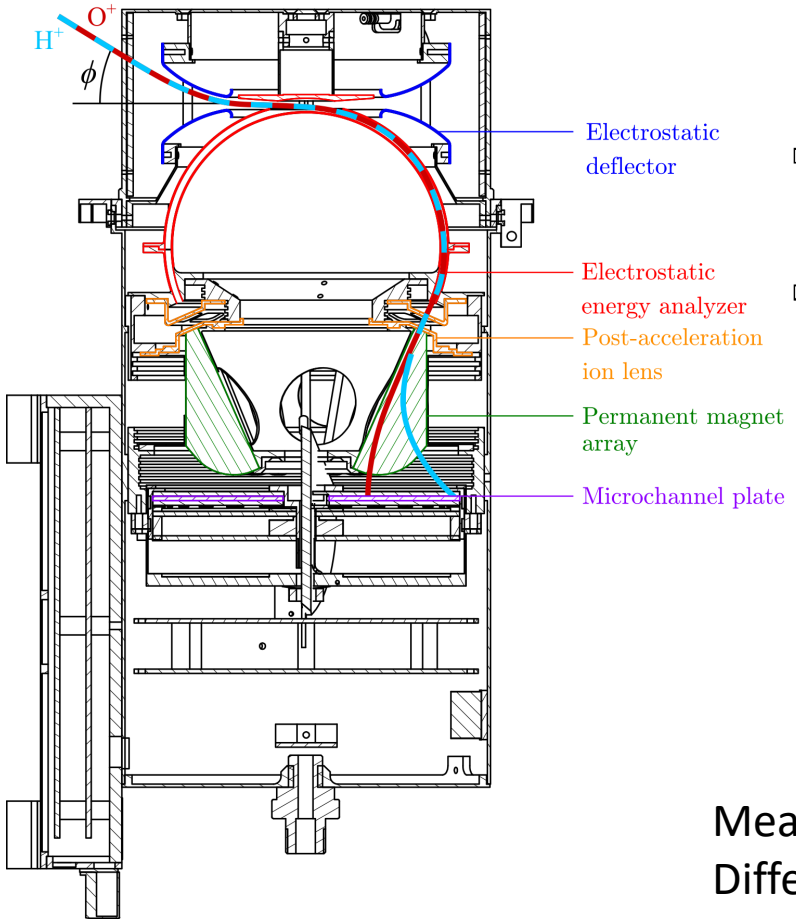
Venus	Earth	Mars
10.4 km/s	11.2 km/s	4.9 km/s

Escape energy

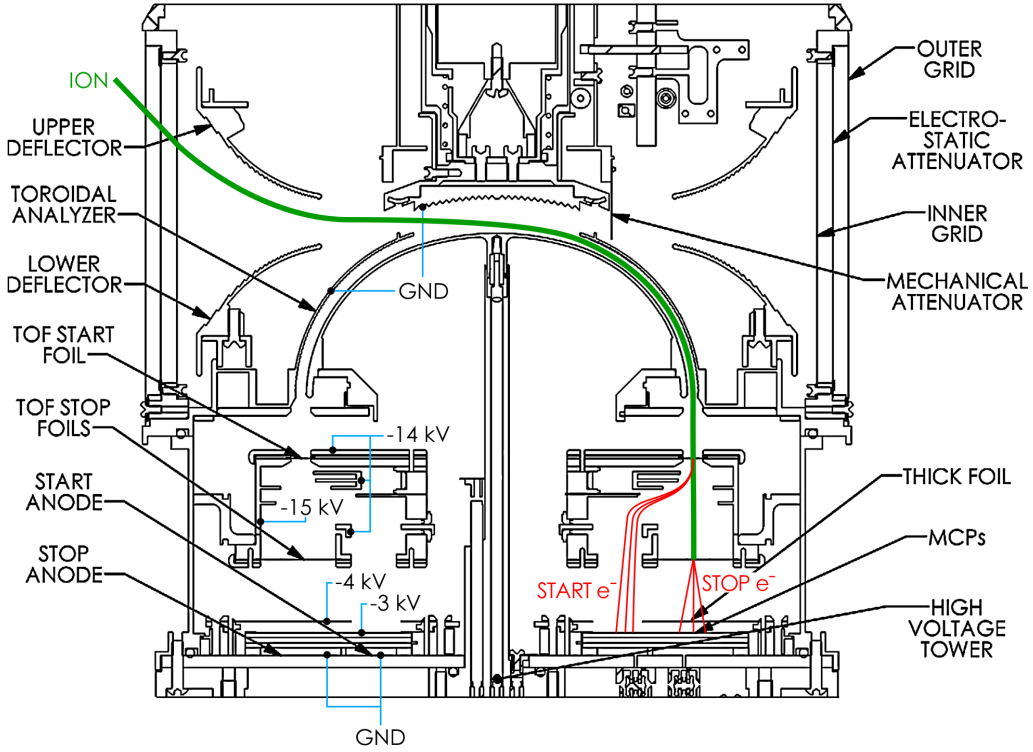
H	0.6 eV	0.7 eV	0.14 eV
O	8.9 eV	10.3 eV	2.1 eV
O_2	17.8 eV	20.6 eV	4.2 eV

Energy-mass spectrometers

Mars Express ASPERA-3/IMA
Venus Express ASPERA-4/IMA

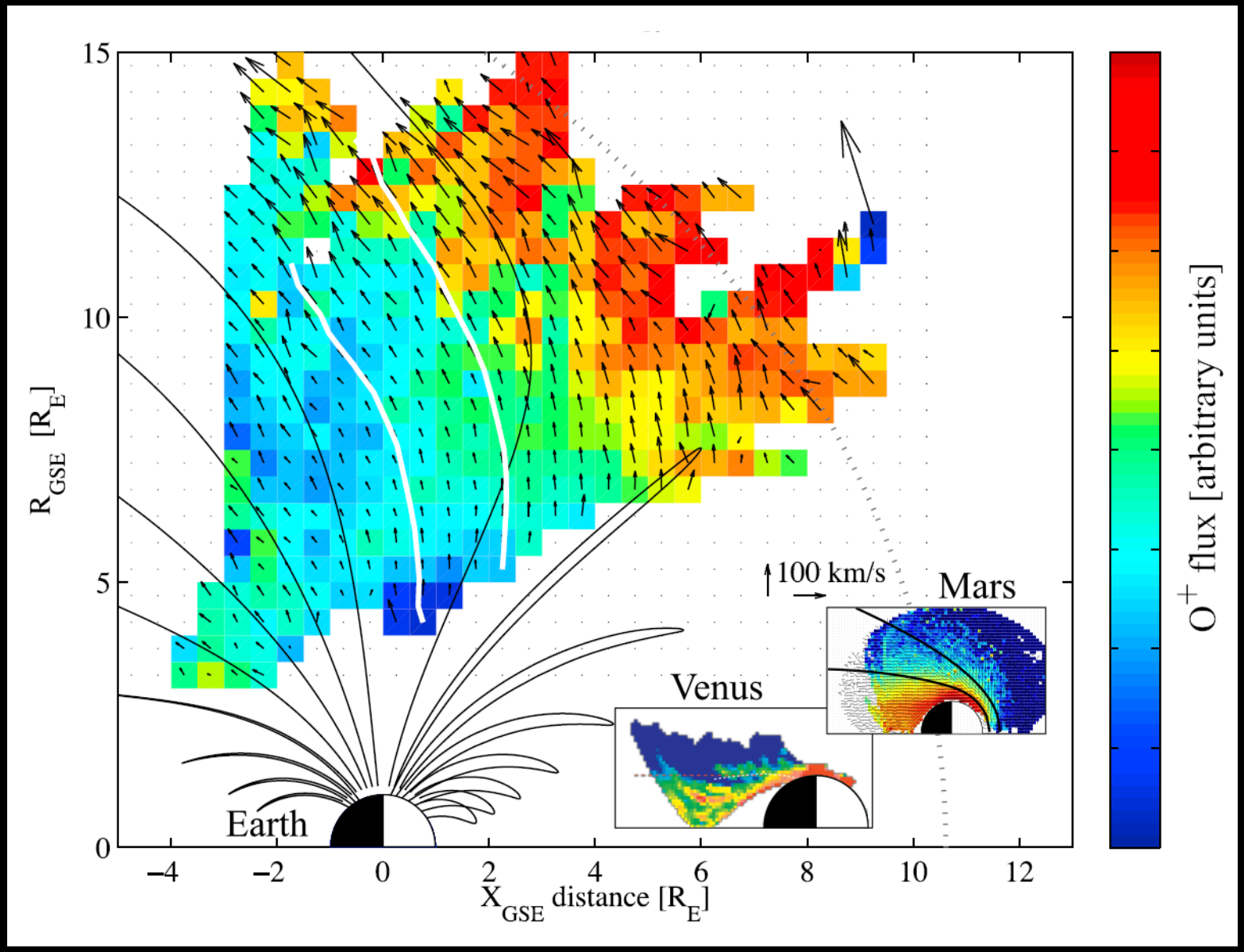


MAVEN STATIC



Measurement:
Differential flux $j(\theta, \phi, E, m)$ [$\mathrm{cm^{-2}\ s^{-1}\ sr^{-1}\ eV^{-1}}$]

Atmospheric ion escape at Venus, Earth, Mars

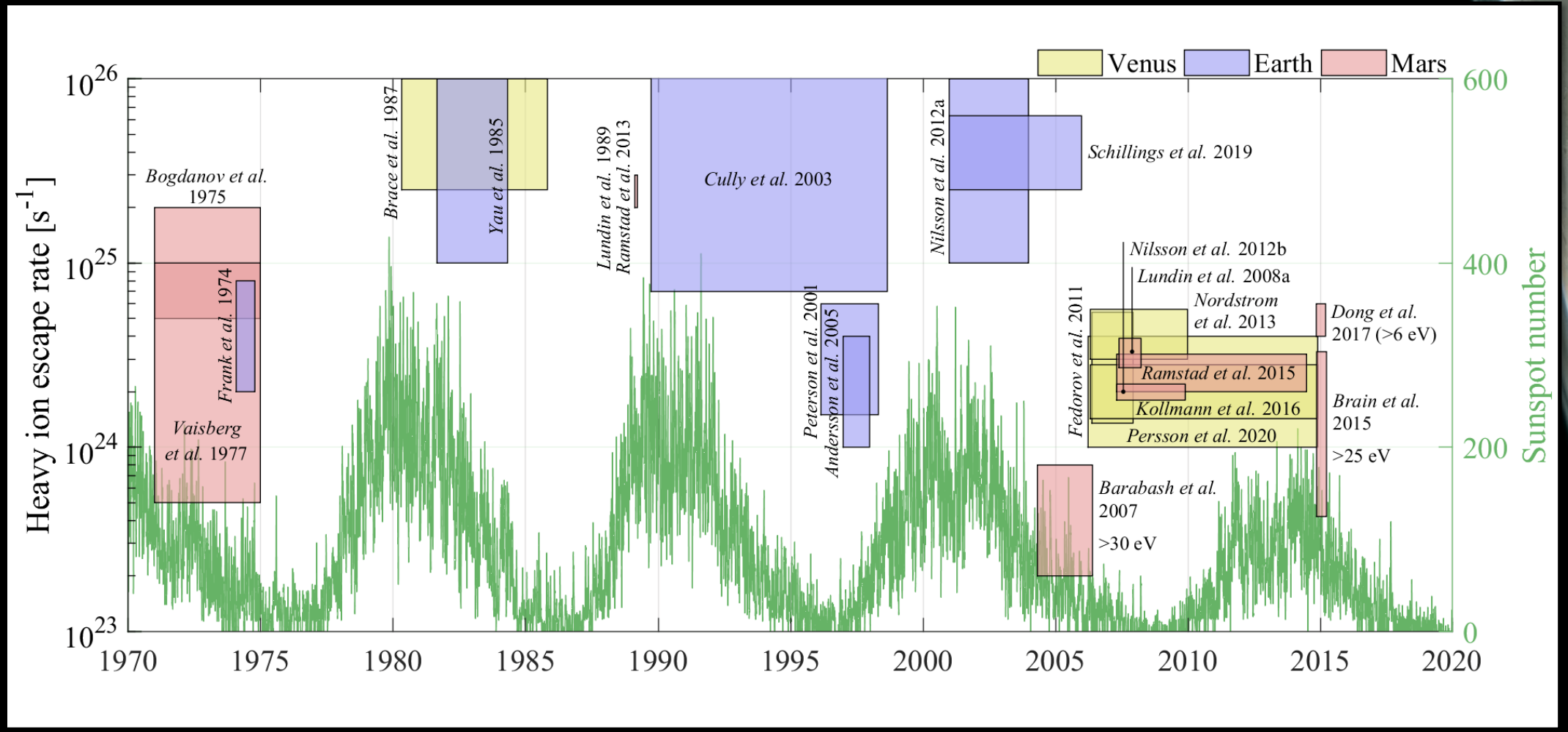


Fluxes of escaping O+ ions from Venus, Earth and Mars in cylindrical coordinates.

Shown to scale!

Adapted from:
Fedorov et al. [2008]
Nilsson et al. [2012]
Ramstad et al. [2017d; 2021]

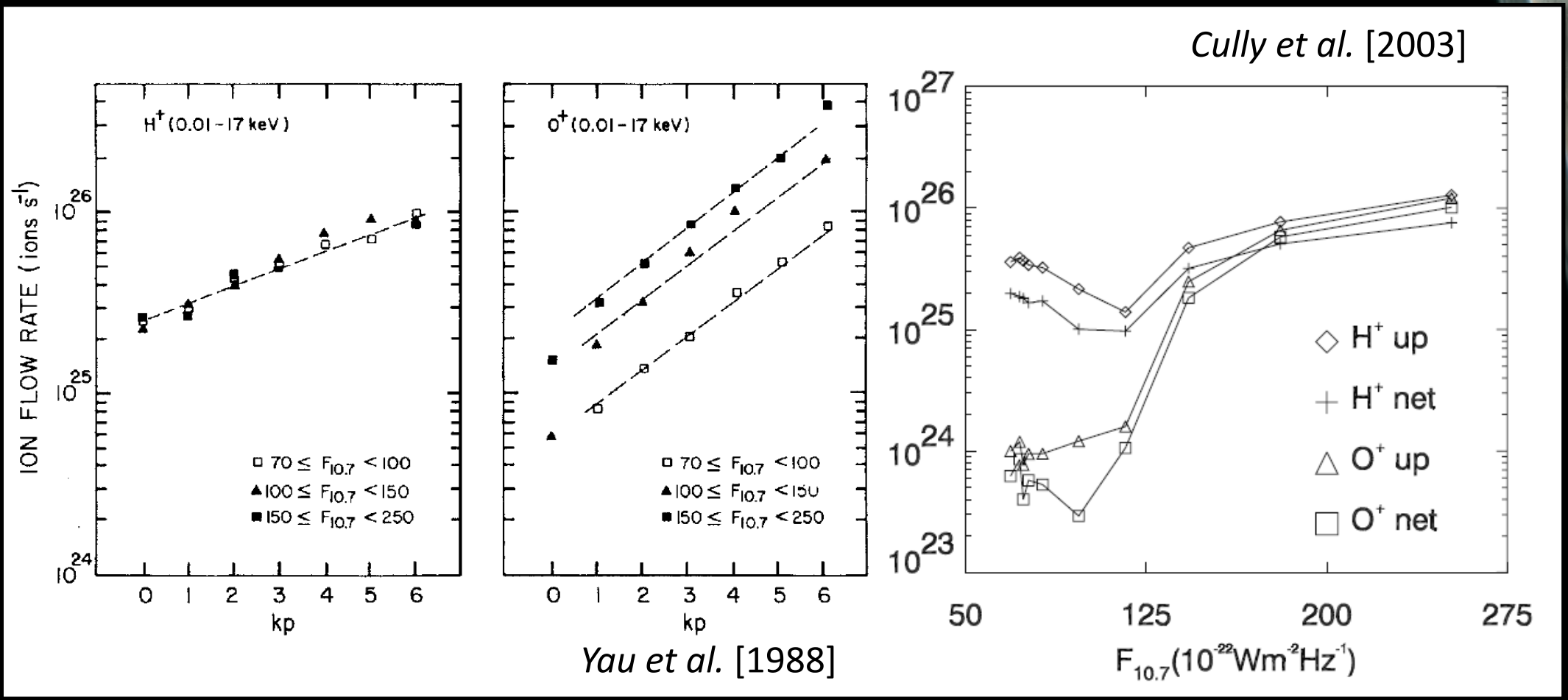
Ion escape rates at Venus, Earth, Mars



Ramstad & Barabash [2021]

Earth ion escape drivers

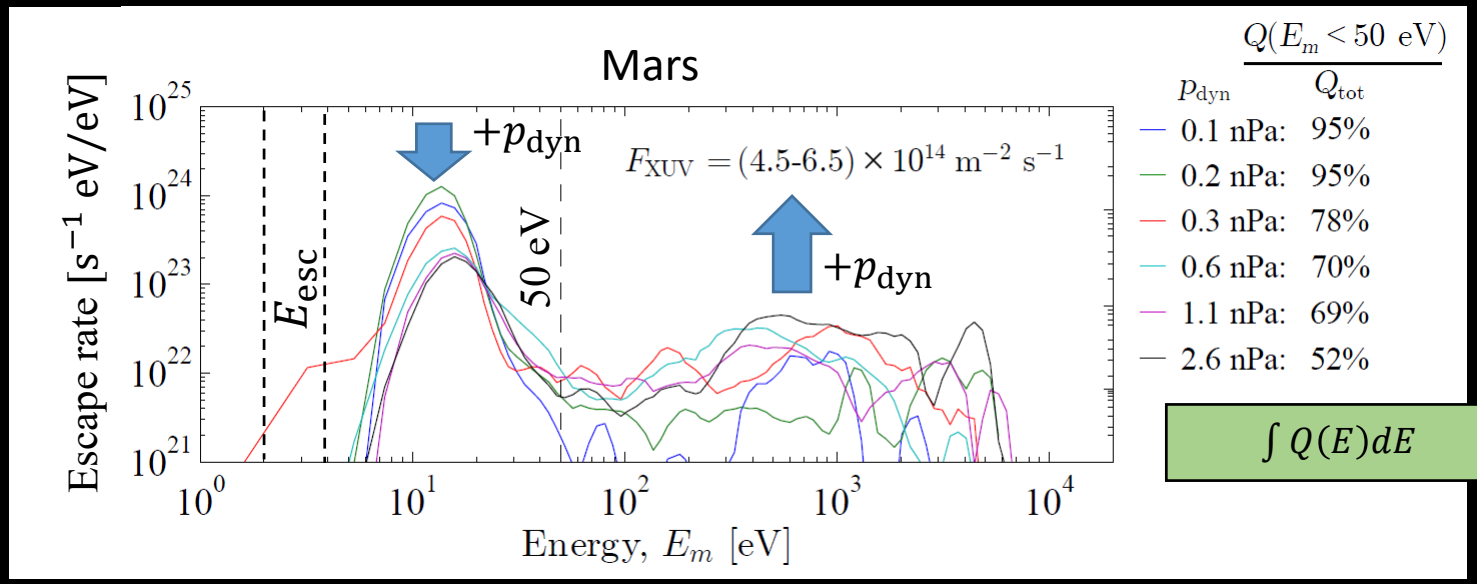
- Both solar EUV and solar wind are strong drivers of escape from Earth's atmosphere



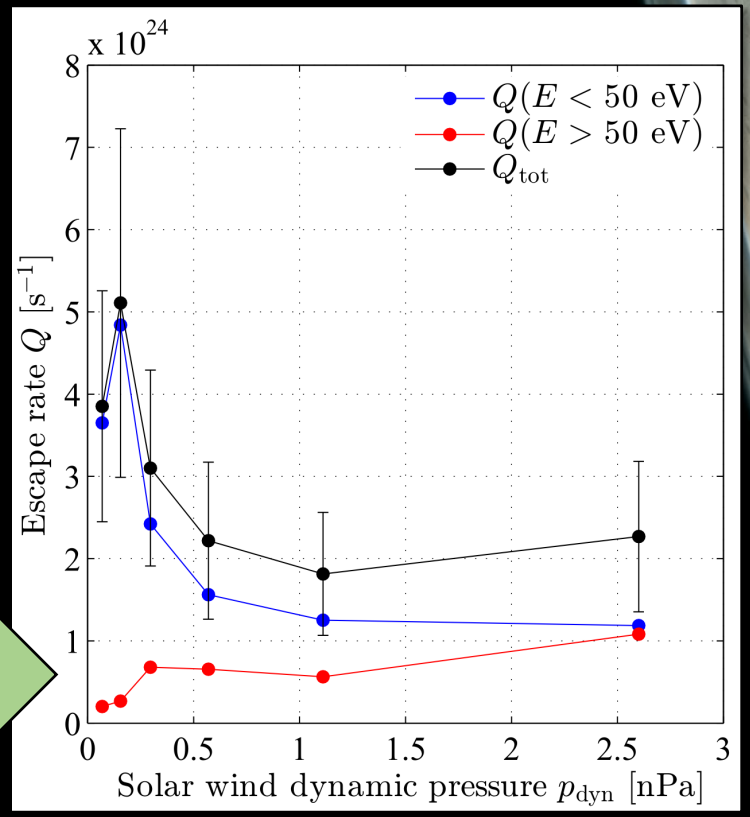
Energy range (and location) matters

A high energy cut-off can leave out cold plasma populations

- Increase in energization conflates increase in escape rate

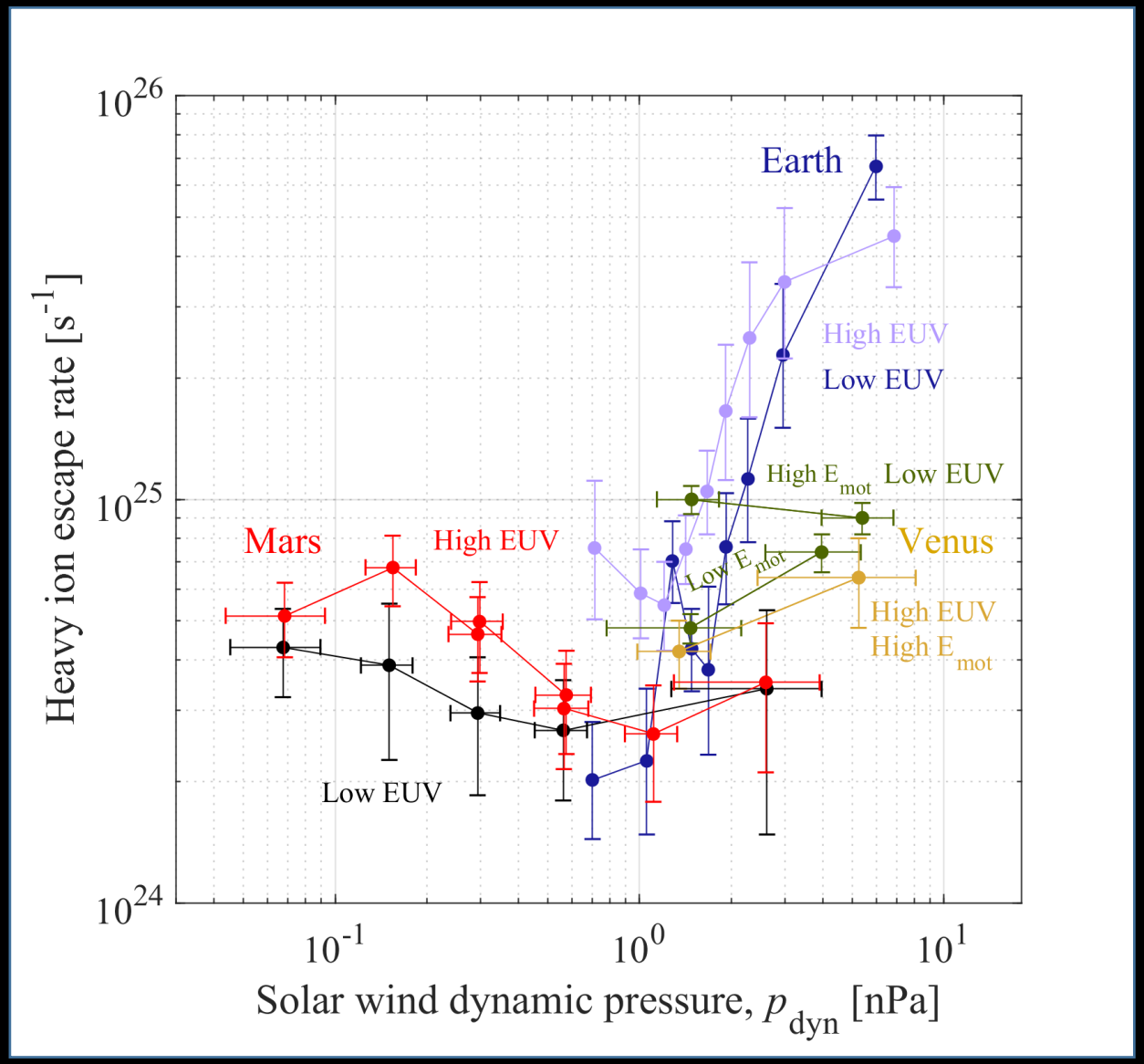


$\int Q(E)dE$



Ramstad [2017]

Solar wind dependence



Ion escape dependence on solar wind dynamic pressure.

Mars – Negligible dependence.

Venus – Weak positive dependence.

Earth – Strong positive dependence.

Ramstad and Barabash [2021], based on:
Masunaga et al. [2019]
Ramstad et al. [2018]
Schillings et al. [2019]

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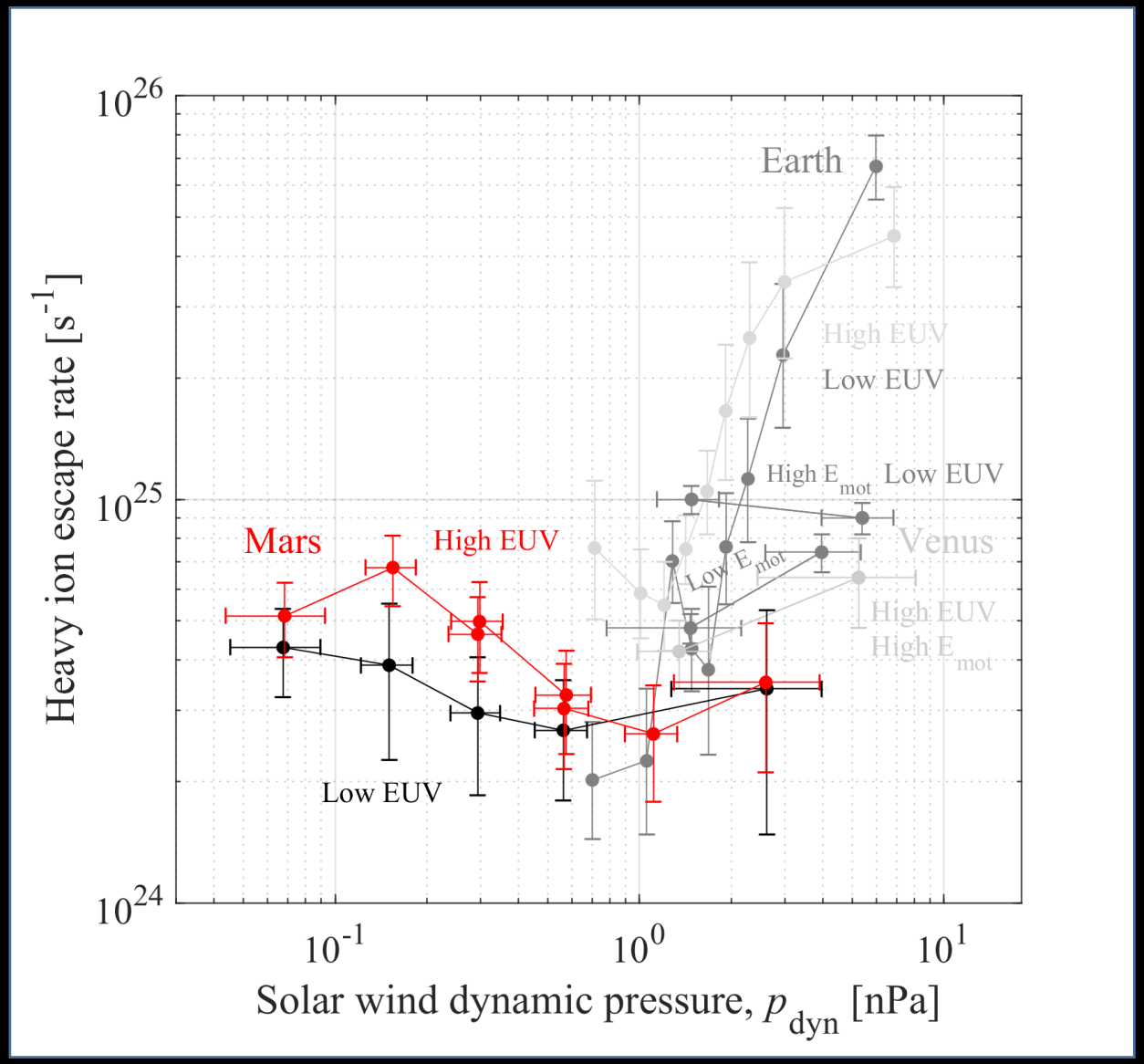

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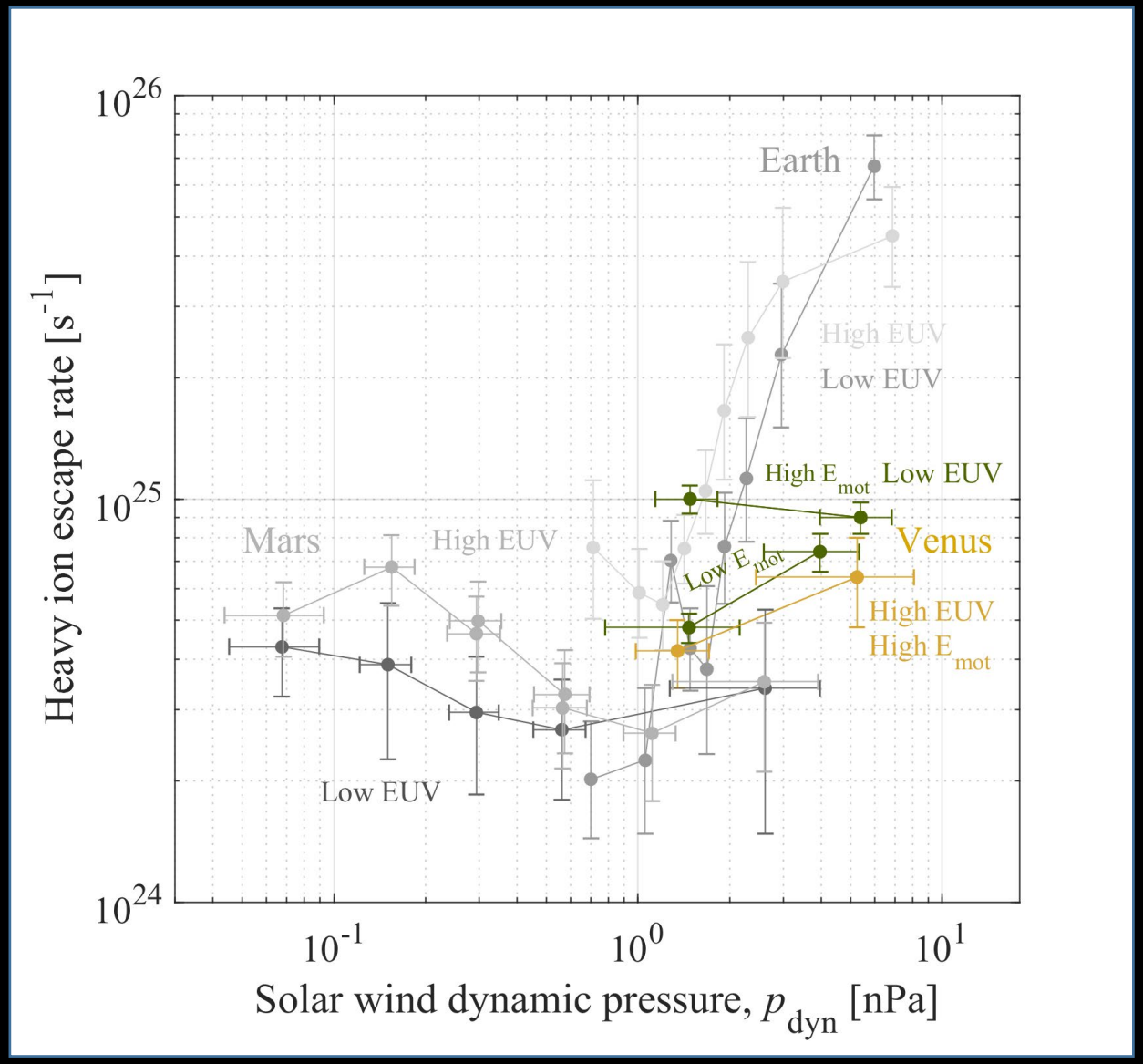

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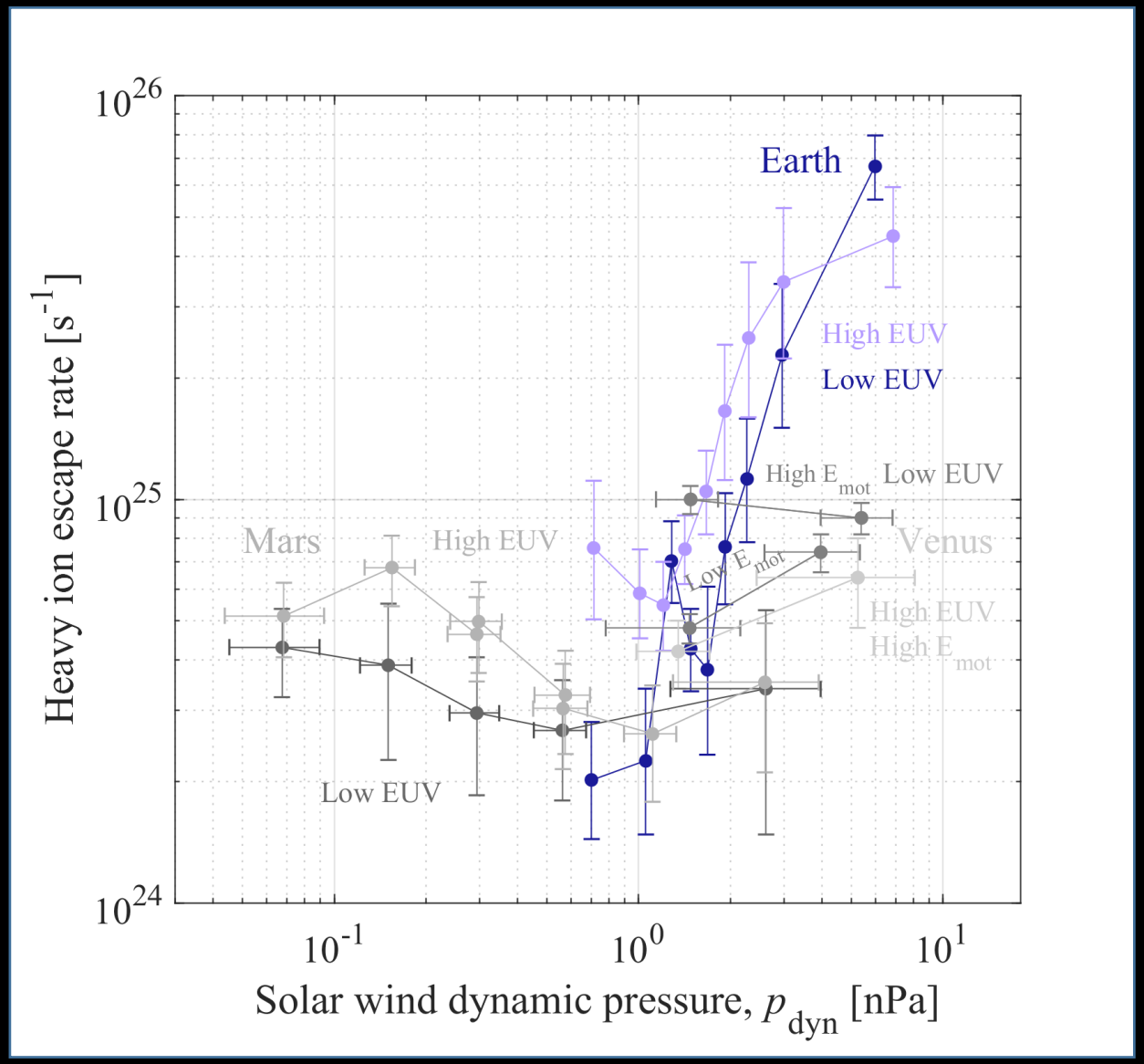

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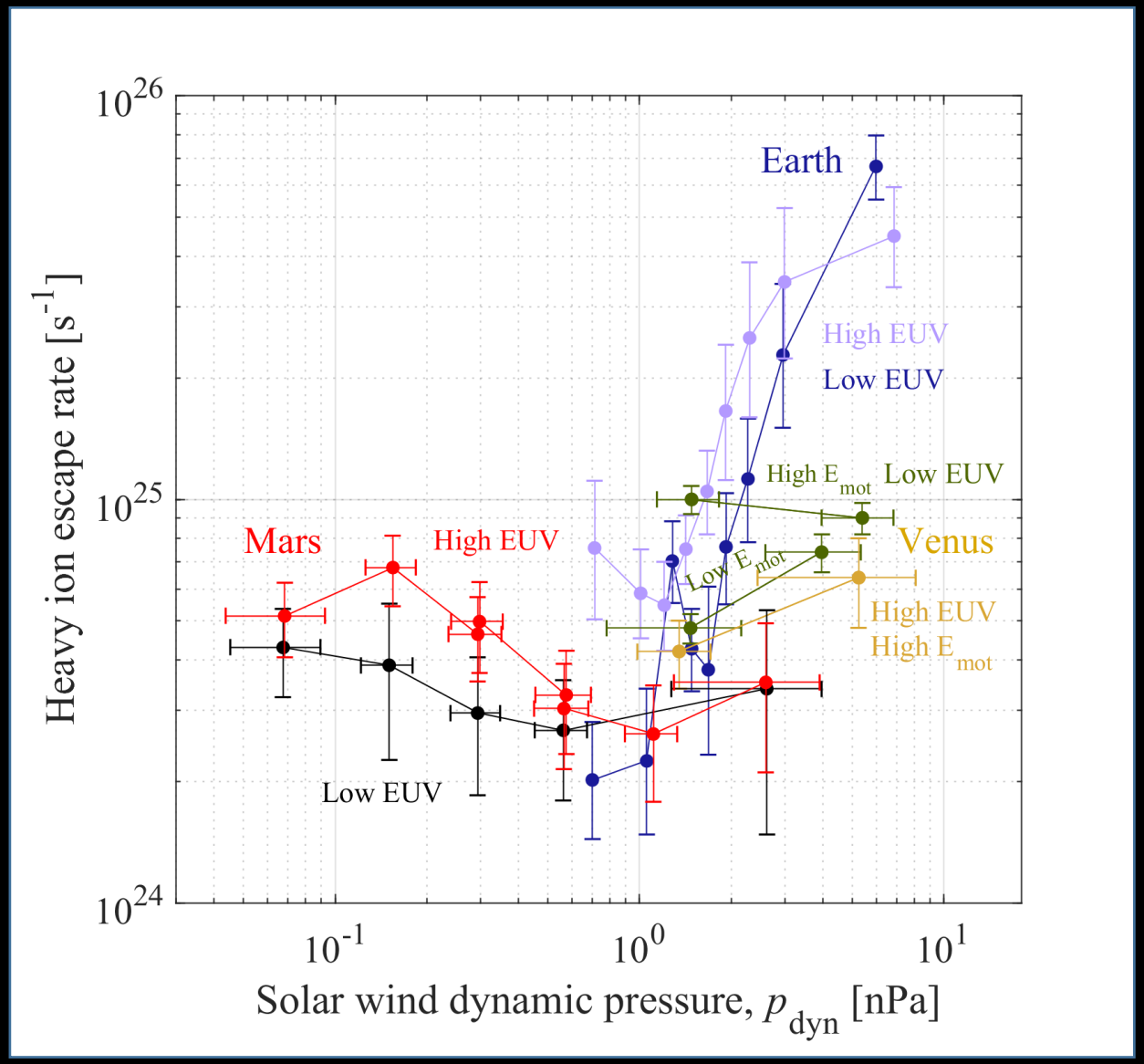

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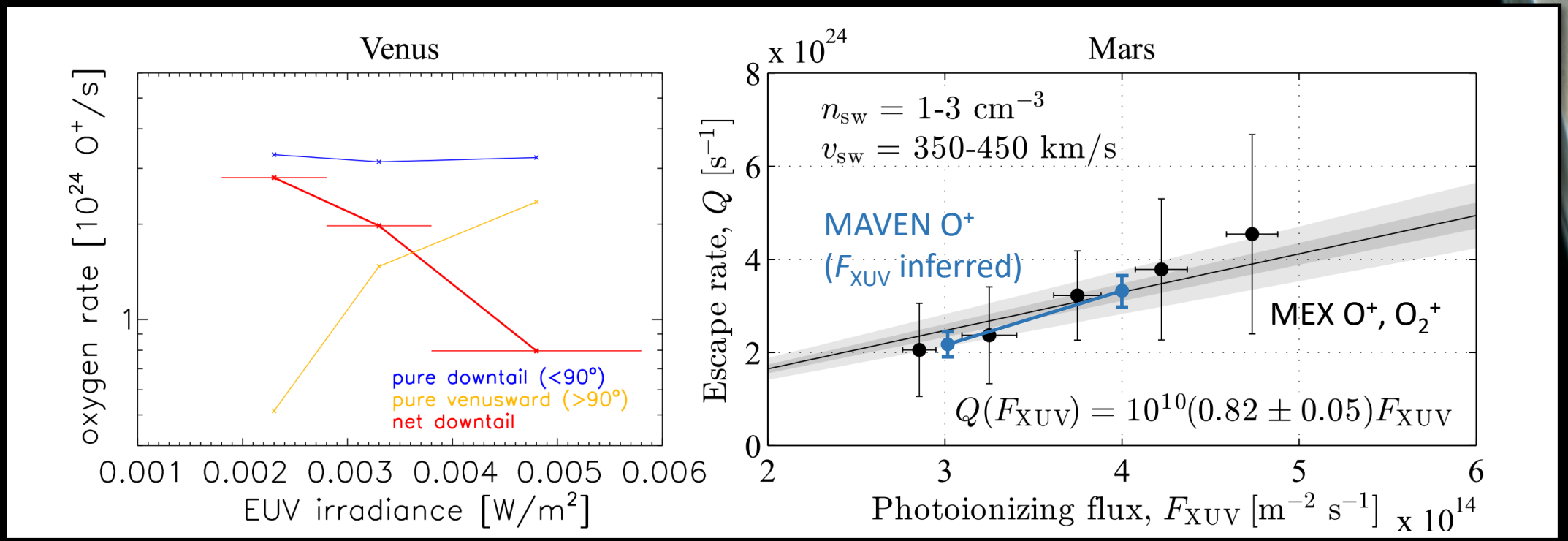
Schillings et al. [2019]

Solar EUV dependence

Ion escape from Venus and Mars displays opposite dependences on solar EUV/XUV, despite both interacting with the solar wind similarly.

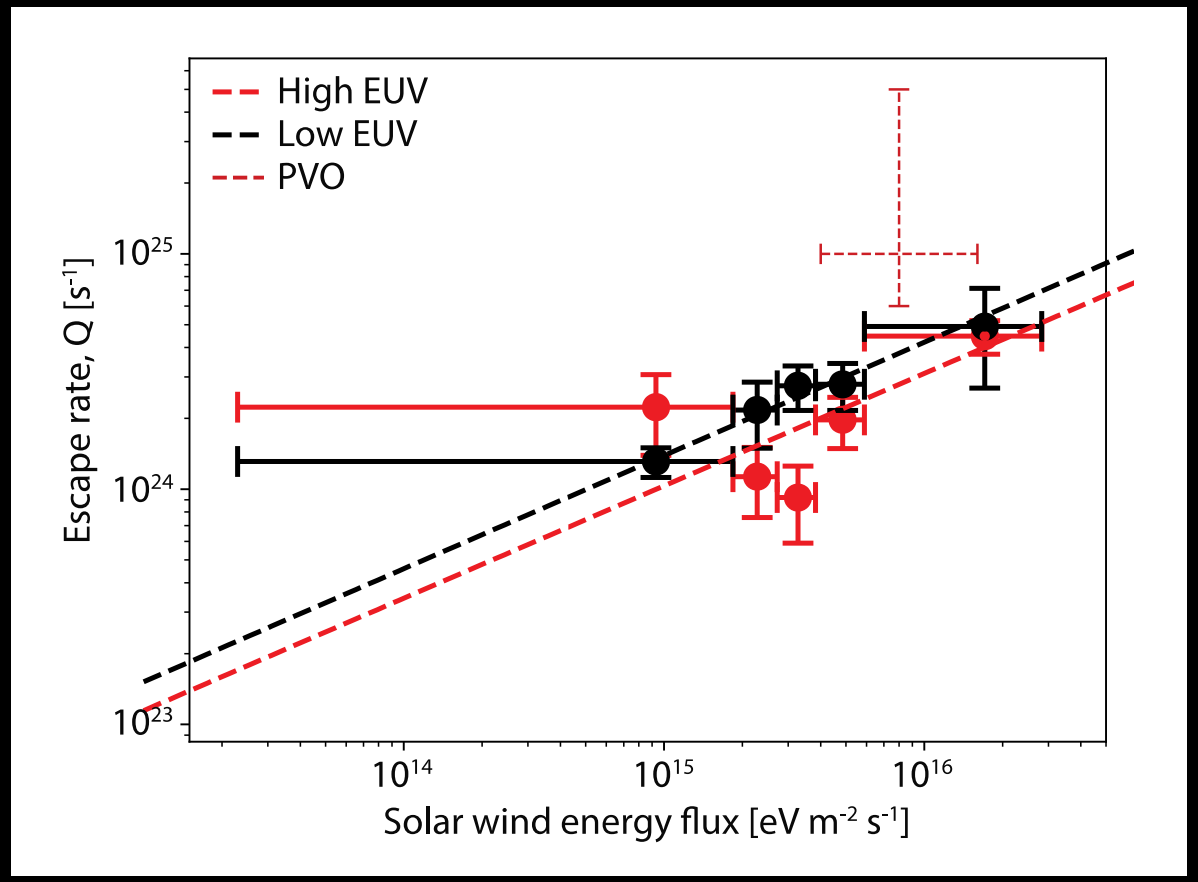


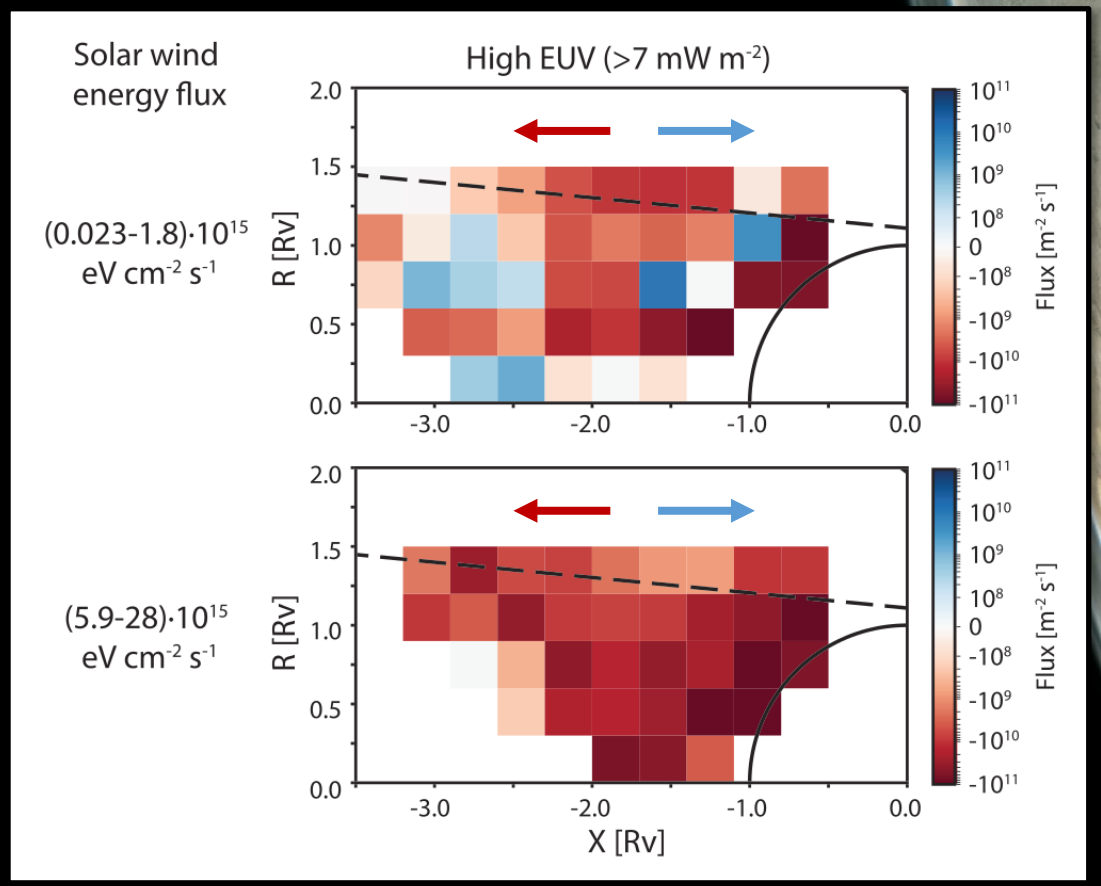
Kollmann et al. [2016]

Ramstad et al. [2017b]
Dong et al. [2017]

Venus ion escape is energy-limited

Increasing solar wind power reduces O^+ return flows, increasing the escape rate

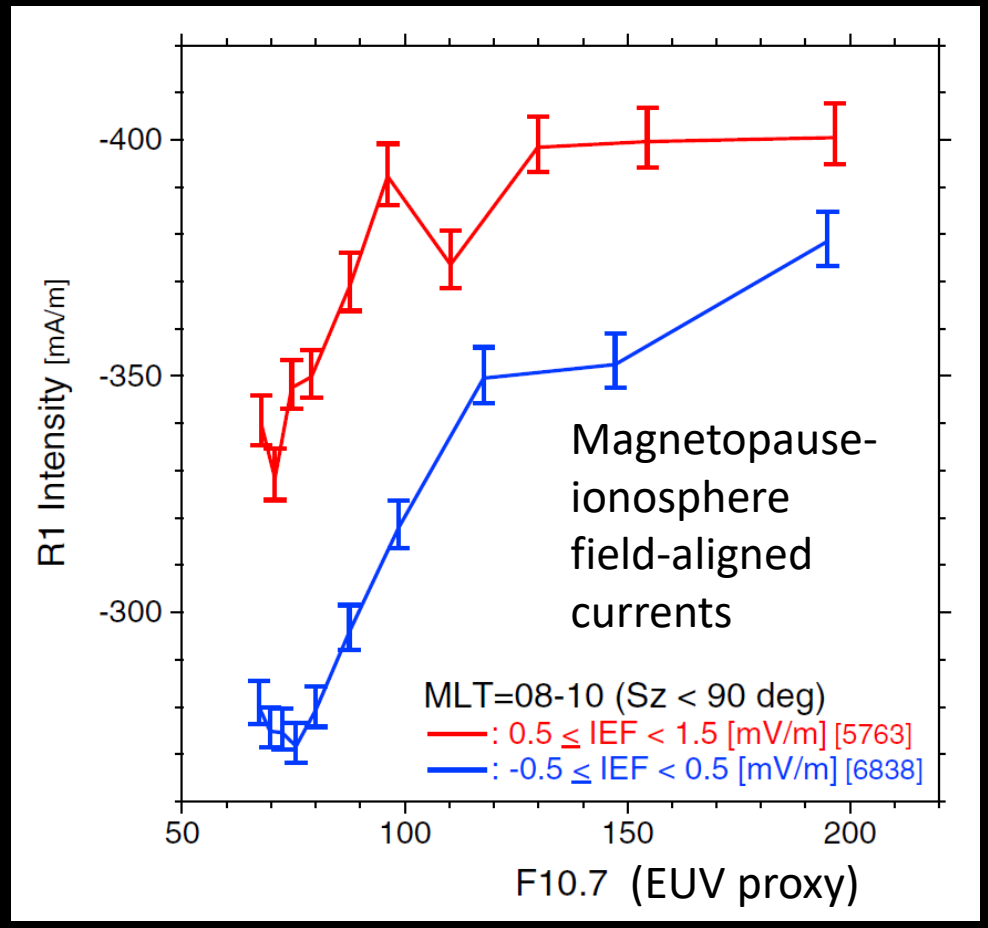




Persson et al. [2020]

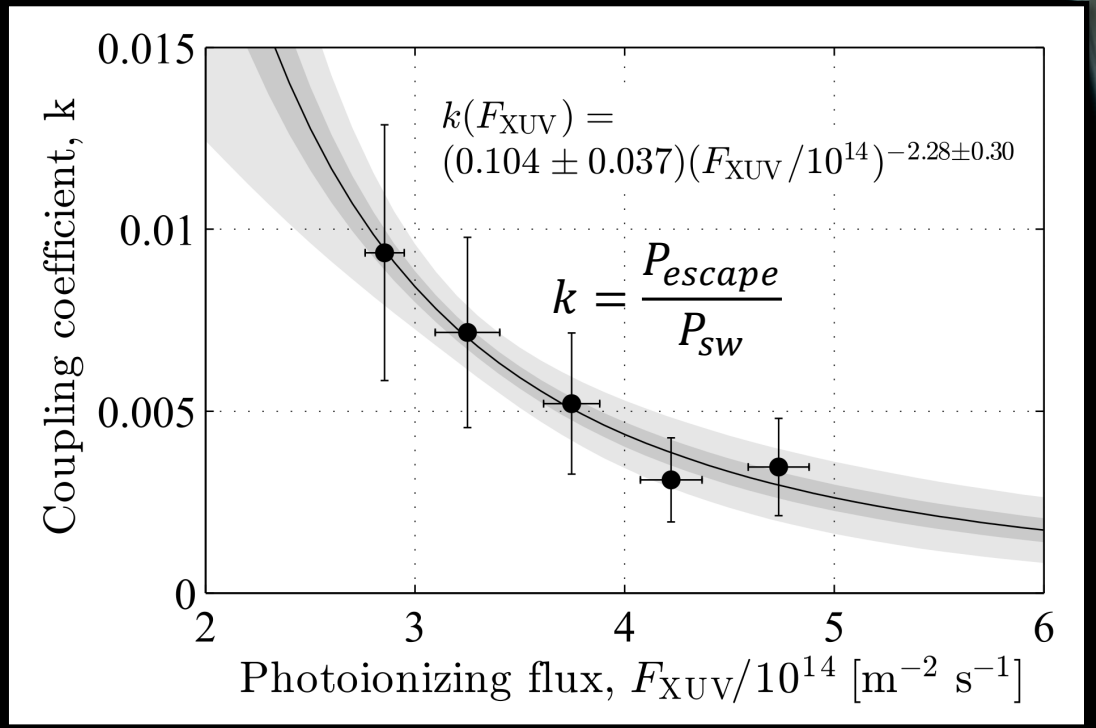
Coupling dependence on solar EUV

Intrinsic magnetosphere (Earth)



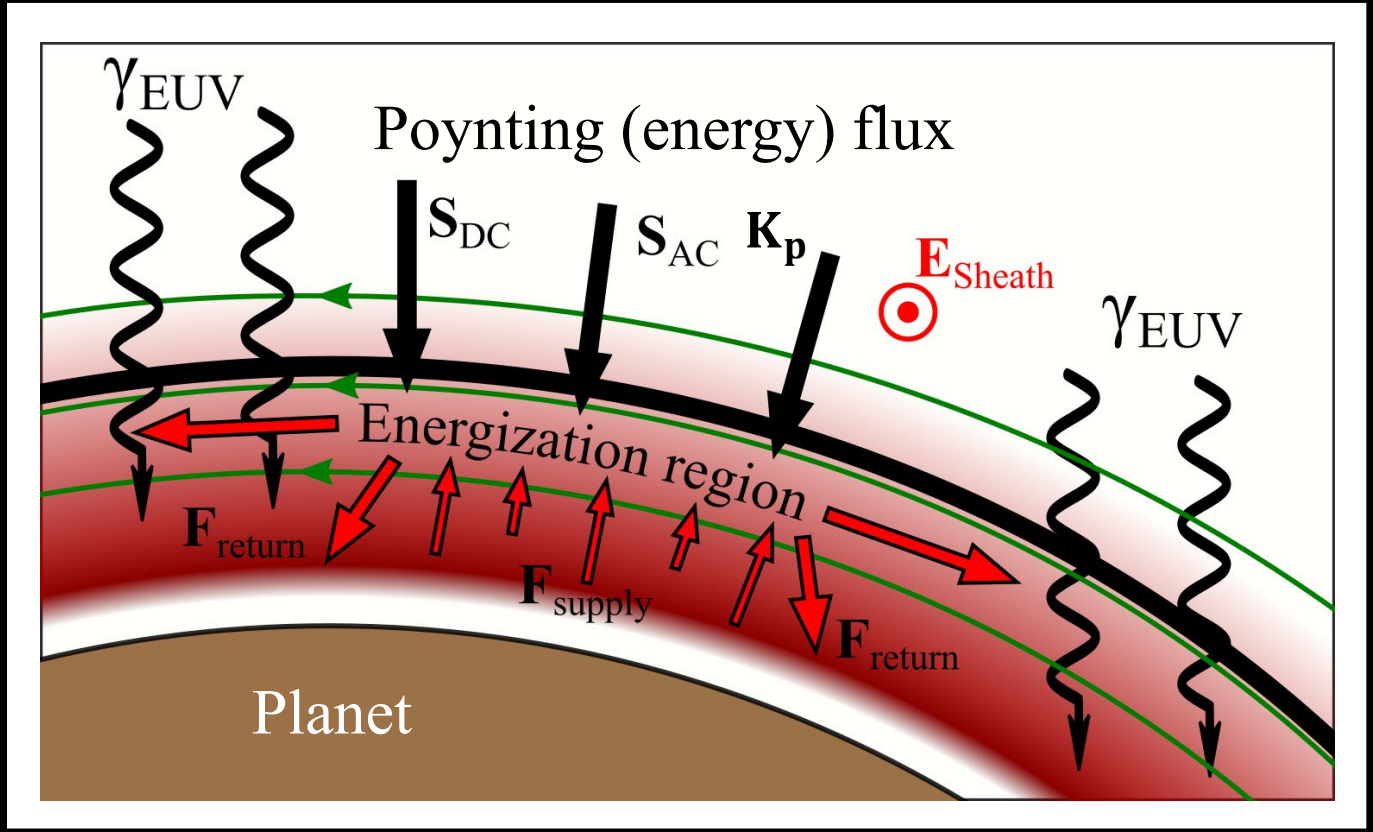
Ohtani et al. [2014]

Induced magnetosphere (Mars)



Ramstad et al. [2017b]

Pathway to atmospheric ion escape

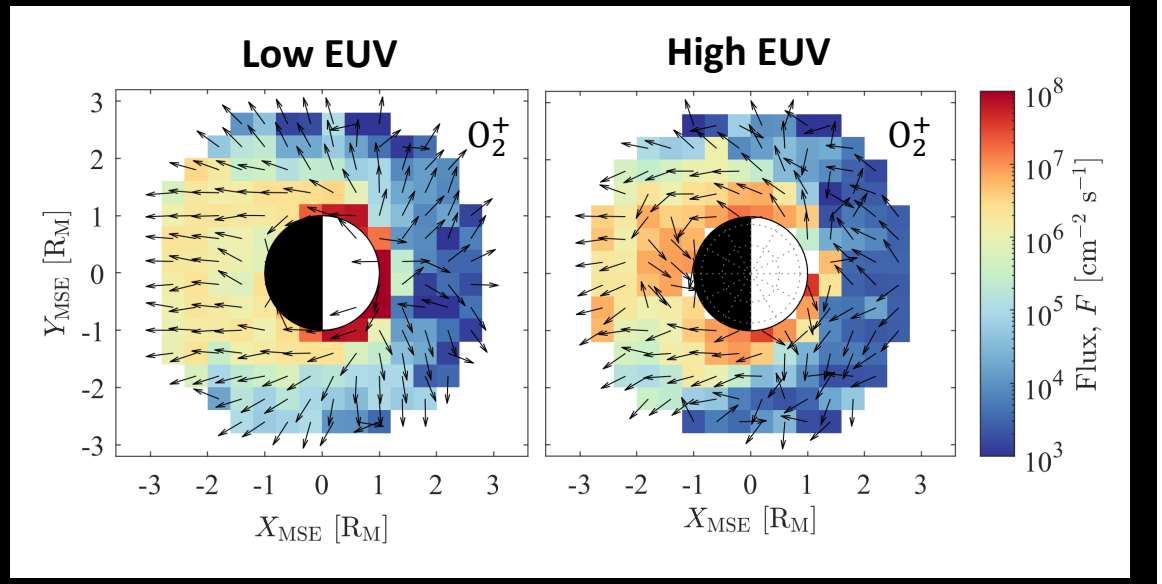


Ion escape requires

- Ionization of neutrals
- Energization of ions
- Transport path out of the gravity well

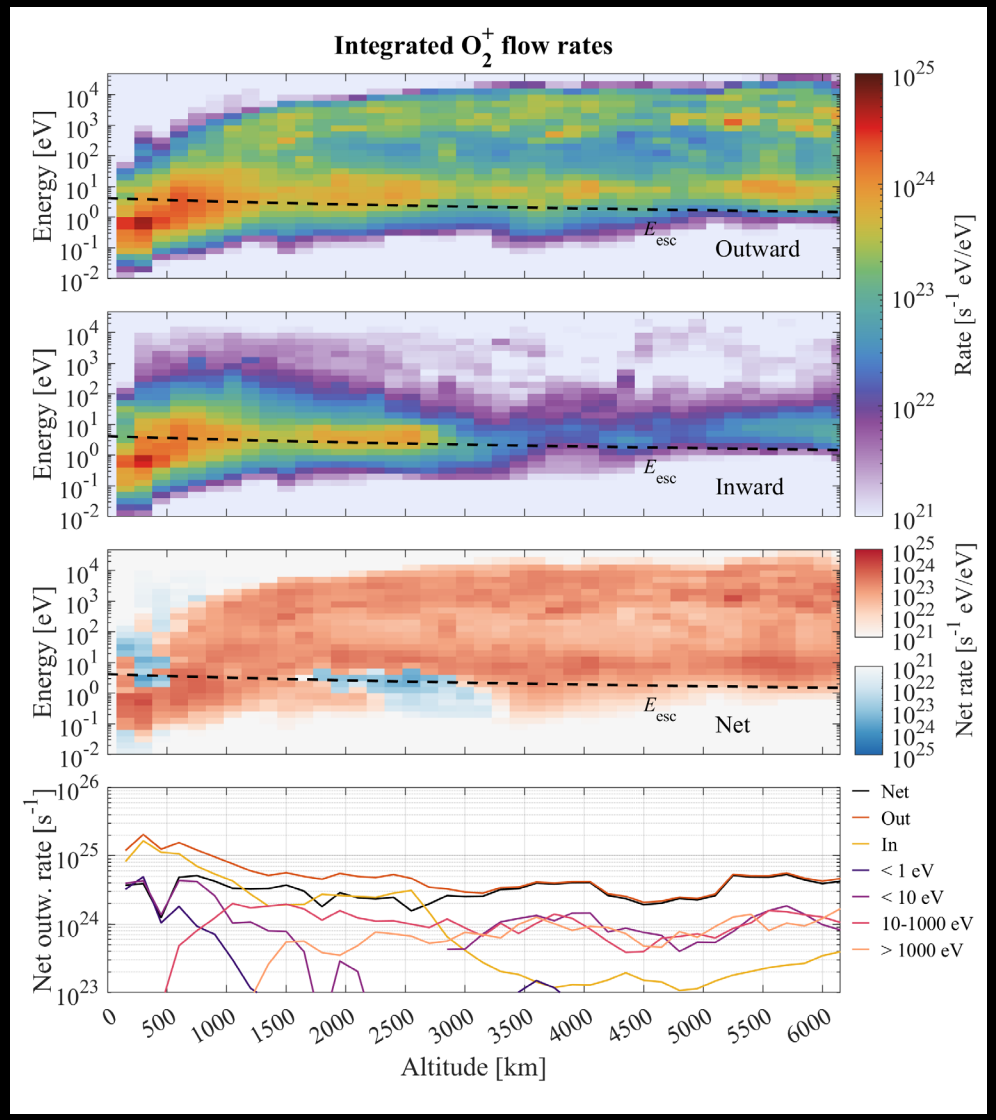
Mars ion return flows increase with EUV

During high EUV conditions, returning gravitationally bound ion flows appear in the Martian magnetotail

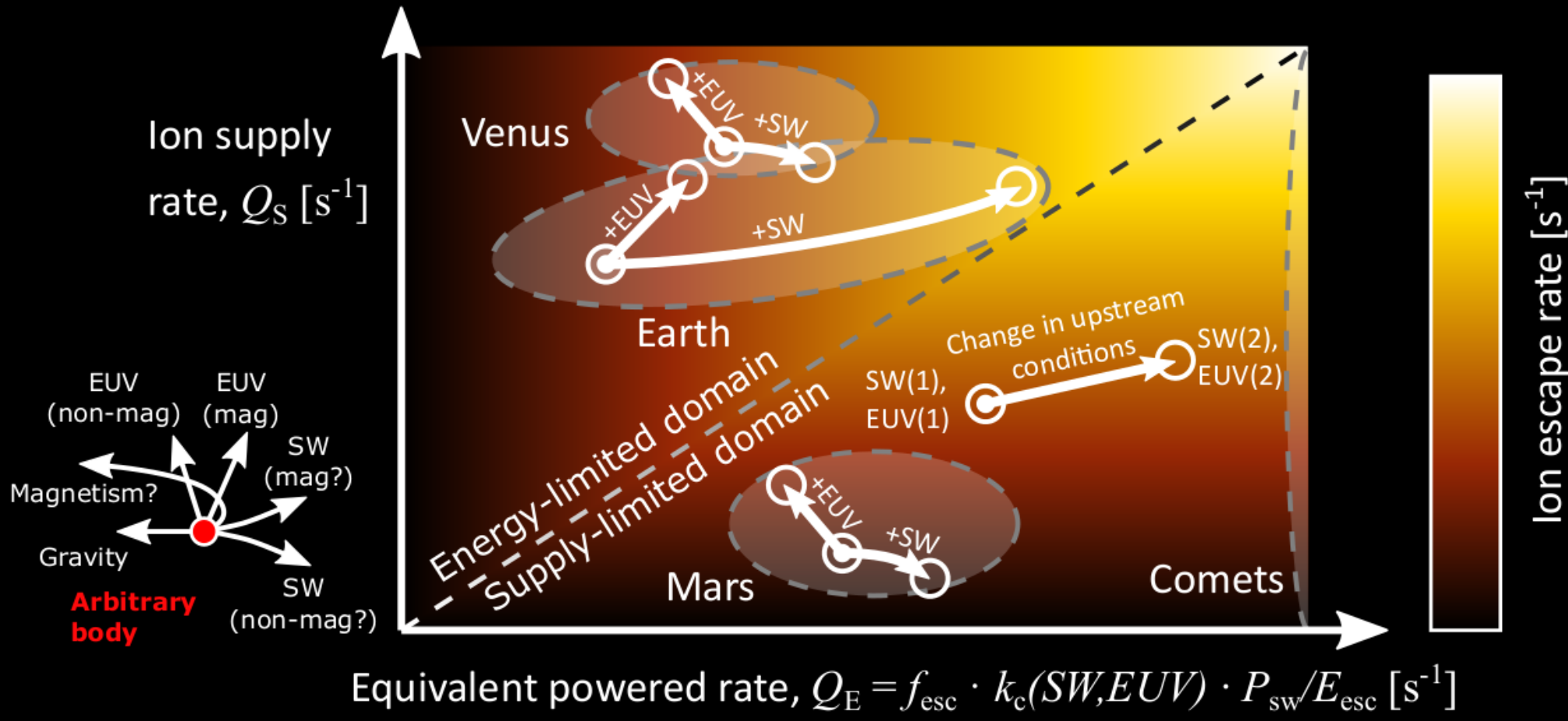


Ramstad et al. [2024], in prep

High EUV



Generalized atmospheric ion escape

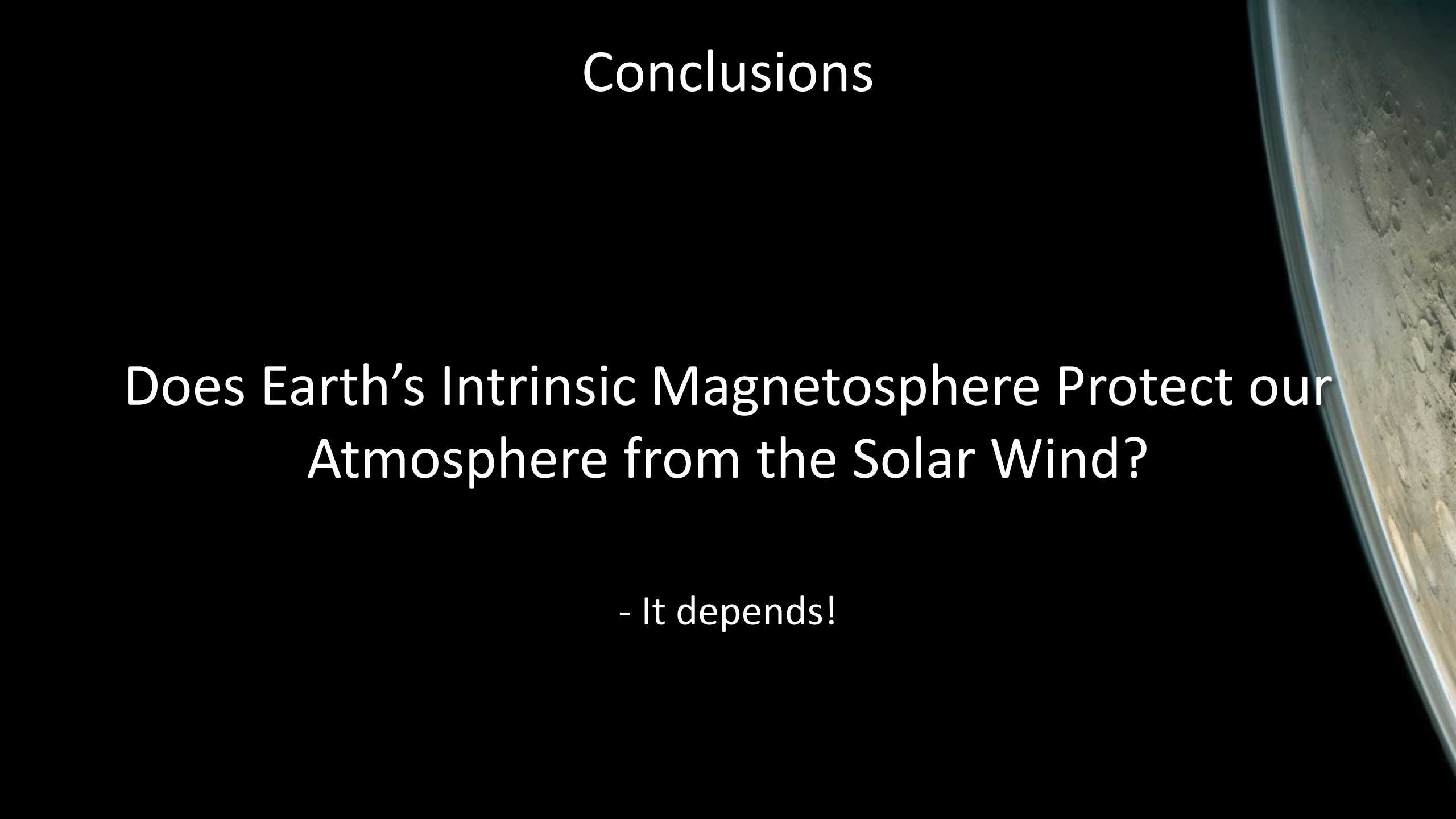


Ramstad & Barabash [2021]

Conclusions

- Varying solar EUV and solar wind have varying and sometimes opposite effects on ion escape from each of the terrestrial planet
- Ion escape from Venus and Earth appears energy-limited
- Earth's magnetosphere makes the ion escape response sensitive to solar wind variations
  - Protects in weak SW, acerbates escape in strong SW
  - SW coupling increases with EUV
- Ion escape from Mars is supply-limited, but on the verge of transitioning to an energy-limited state
- Weak gravity does not necessarily mean high ion escape rates
  - System may be in an ion supply-limited state (Mars)

Conclusions

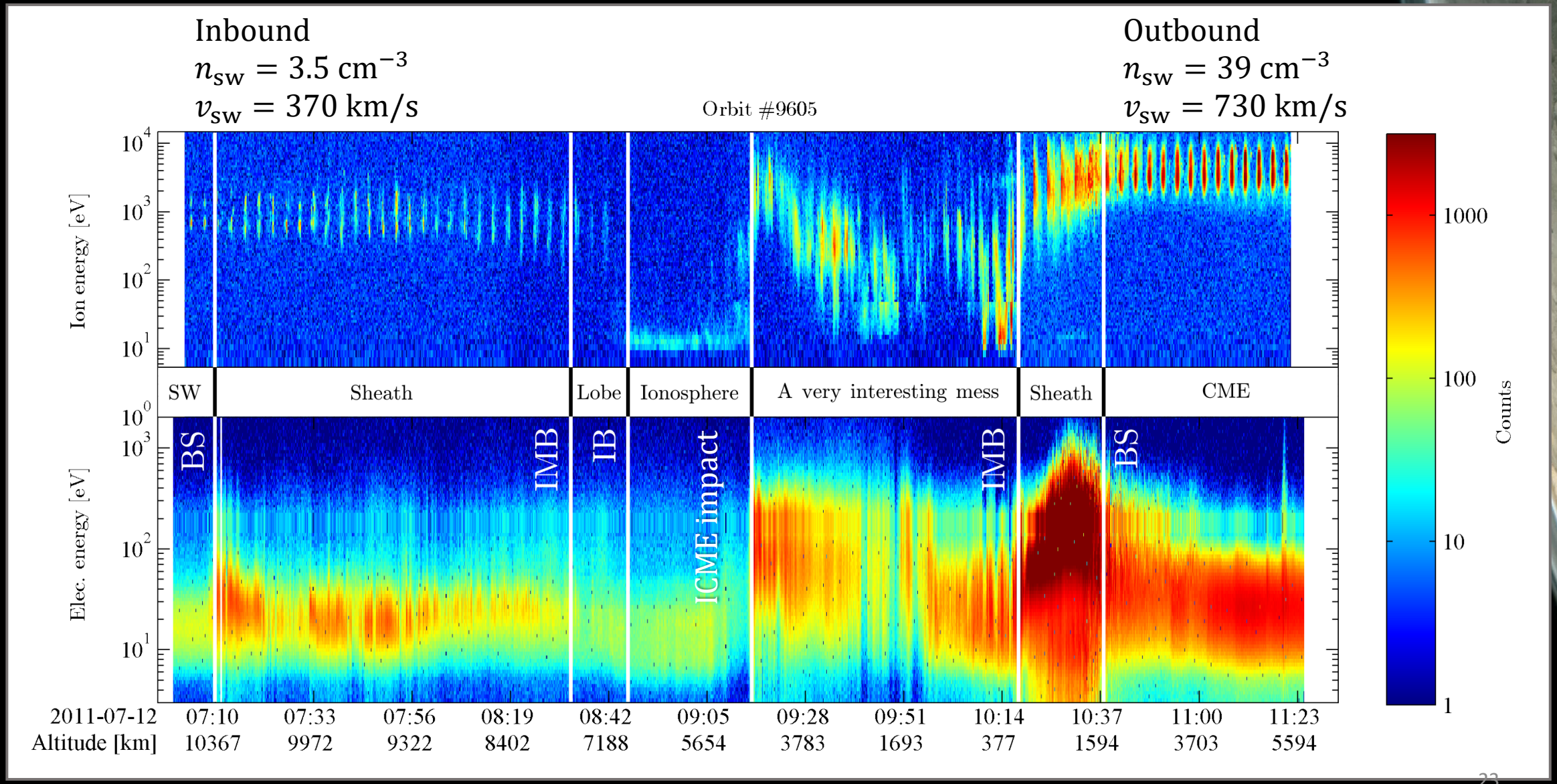


Does Earth’s Intrinsic Magnetosphere Protect our Atmosphere from the Solar Wind?

- It depends!

Extra

Primordial solar wind event



Ramstad et al. [2017]

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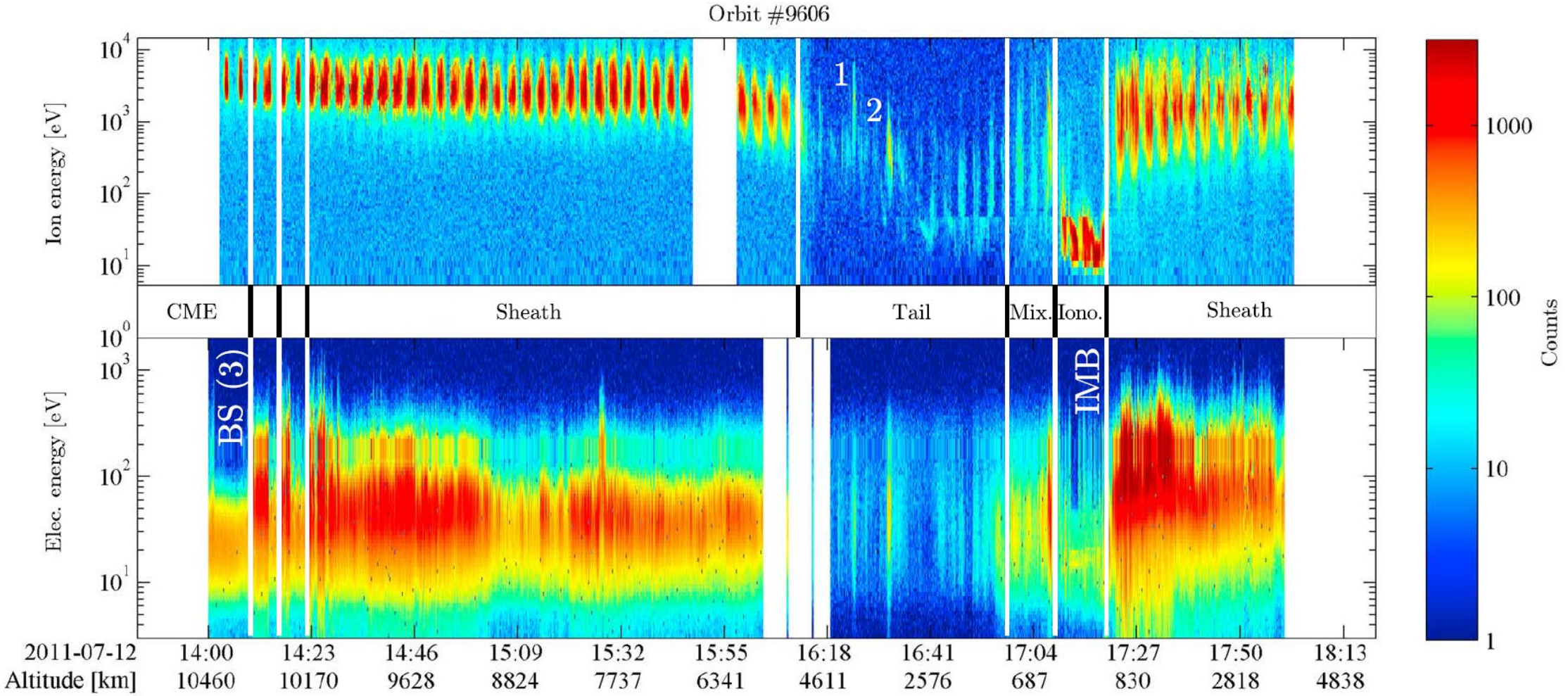

Ramstad et al. [2017]