Upper atmosphere of Venus and impact from solar wind plasma

What we have learned from Venus Express?

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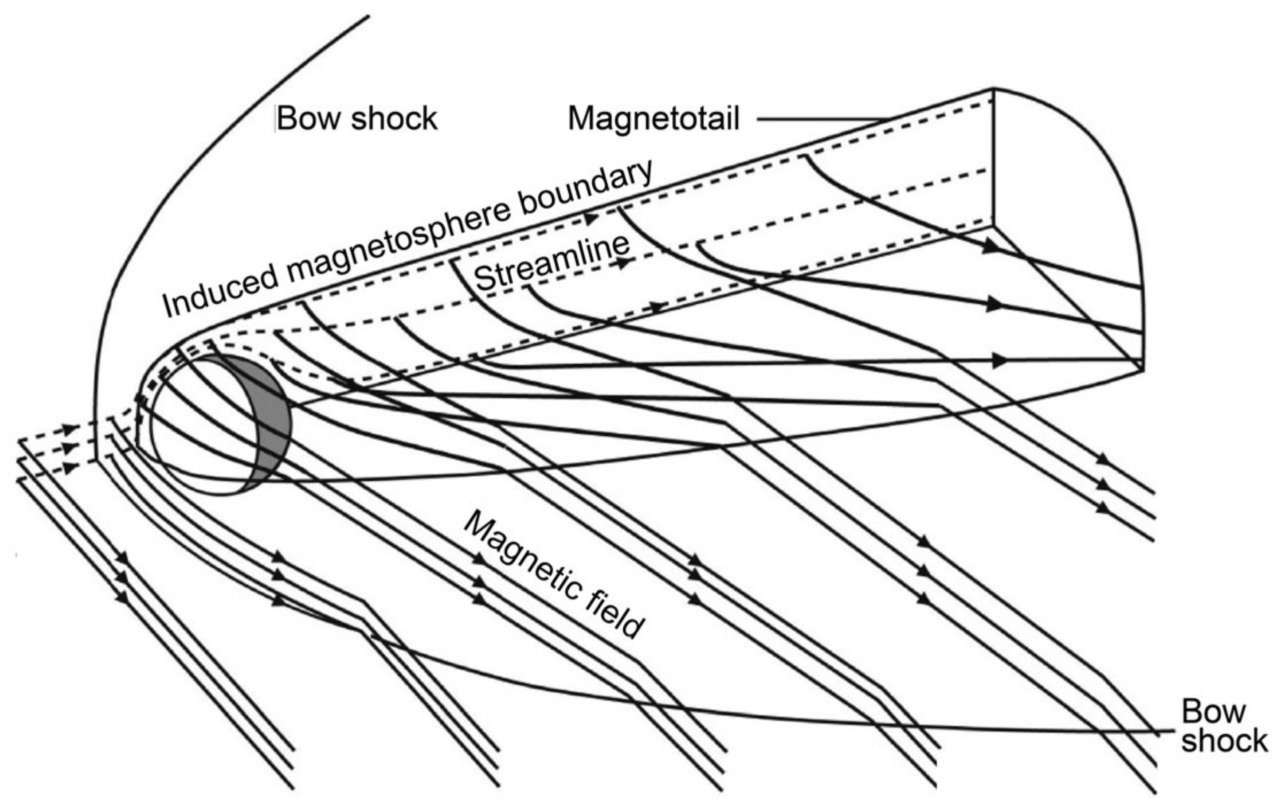
No magnetic field with sufficient atmosphere of Venus
→ the induced magnetosphere

- The solar wind flow makes a characteristic magnetotail pattern, draping
- Energy / Momentum transfer from solar wind to ionospheric plasma. The planetary plasma is energized & escaped (E>10 eV for O^+)
- Direct exposure of the atmosphere in the solar wind indicates the effective removal of the Venusian atmosphere (water) to space
  → Magnetosphere protects the terrestrial atmosphere



Saunders and Russel, 1986

Accelerated planetary oxygen ions can be clearly observed by Venus Express/ASPERA-4

- Integration of the measured flux gives the total escaping flux
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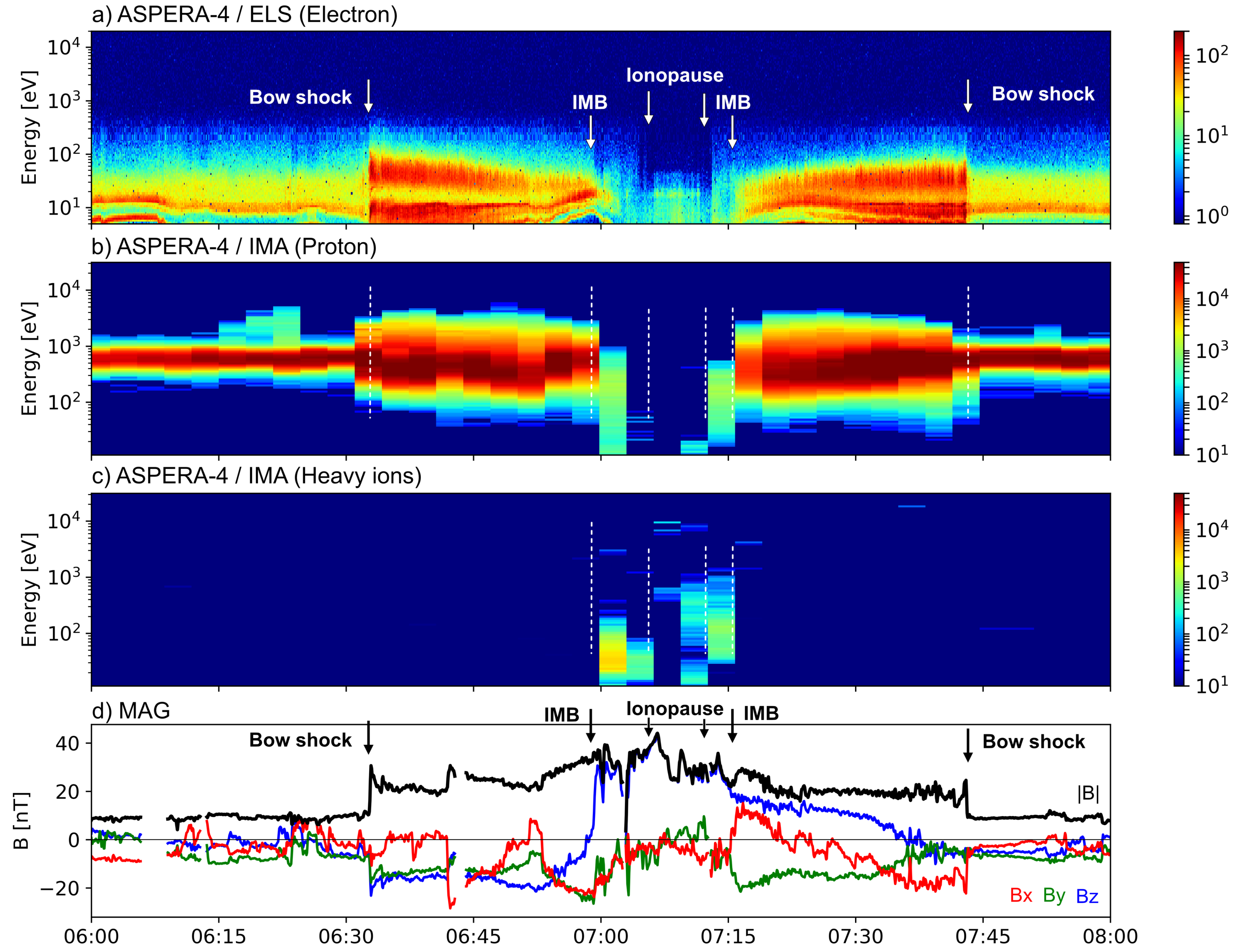
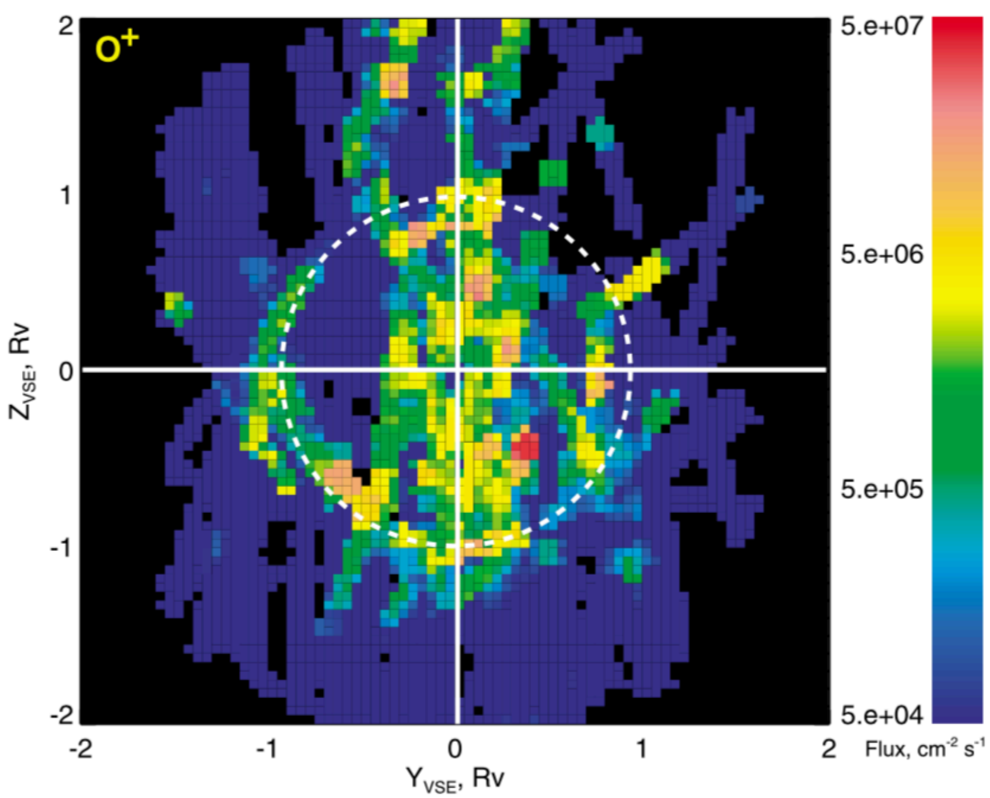
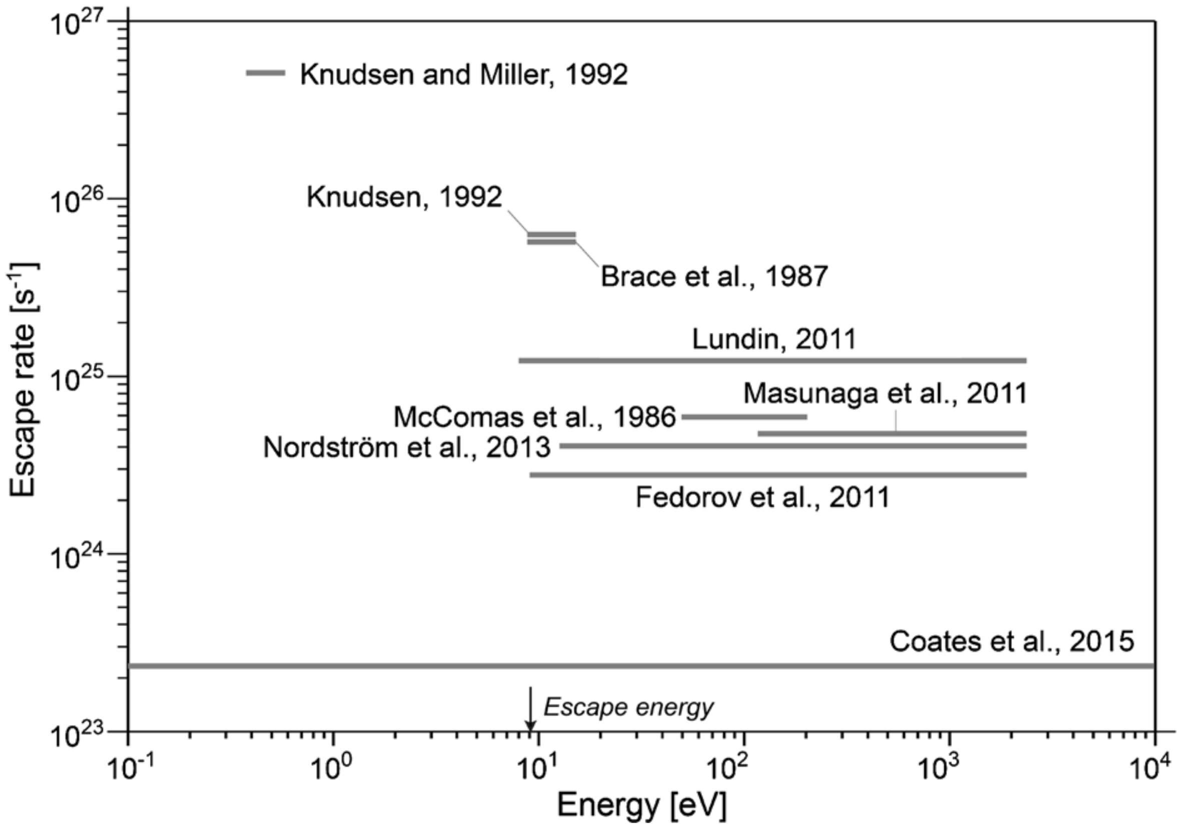


Escaping oxygen from Venus is (3–6)x10^{24} s (~3 mbar for 4 Ga)



Fedorov et al., 2011



Futaana et al., 2017

Comparative perspective

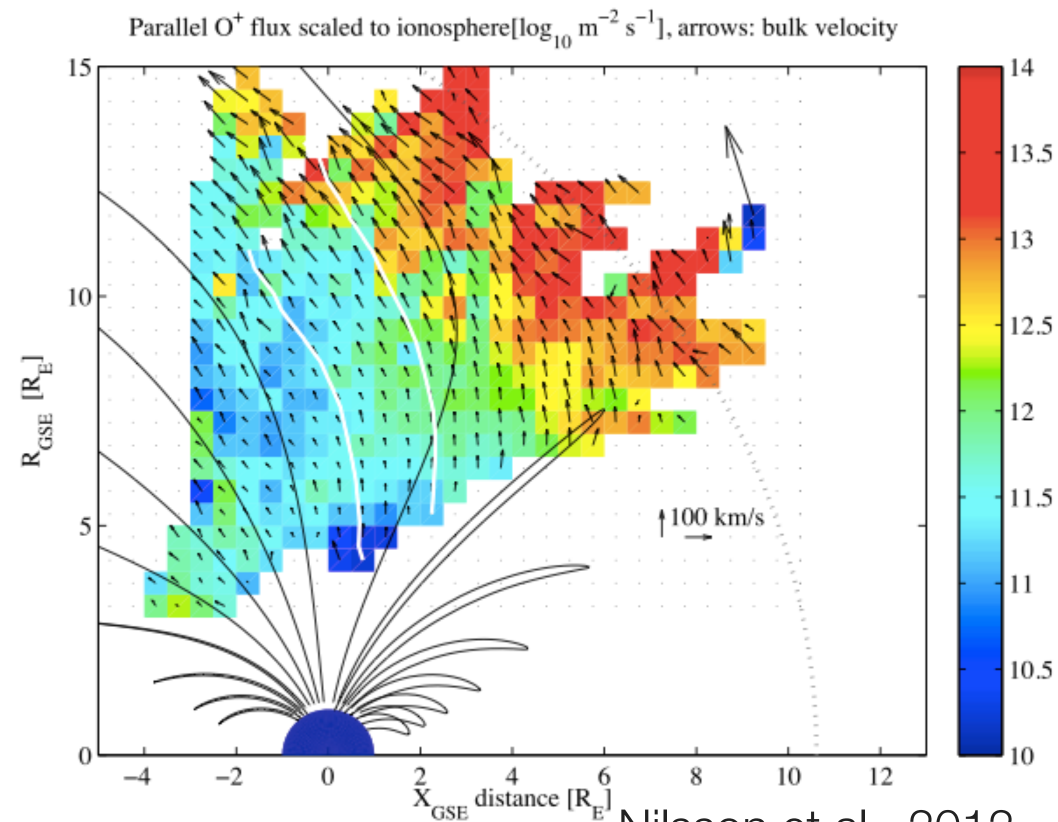
The comparison of oxygen outflow for three planets

- Direct exposure of atmosphere in the solar wind does not increase the ion escaping

The classical view is too simplified

- The keys to consider are
  - Production of oxygen ions
  - Energy injection and transportation
  - Acceleration

Escaping O+ from Earth



Nilsson et al., 2012

Open questions:

- Does the magnetic field really protect the atmosphere?

- What limits the escape flux, injecting energy or available material?

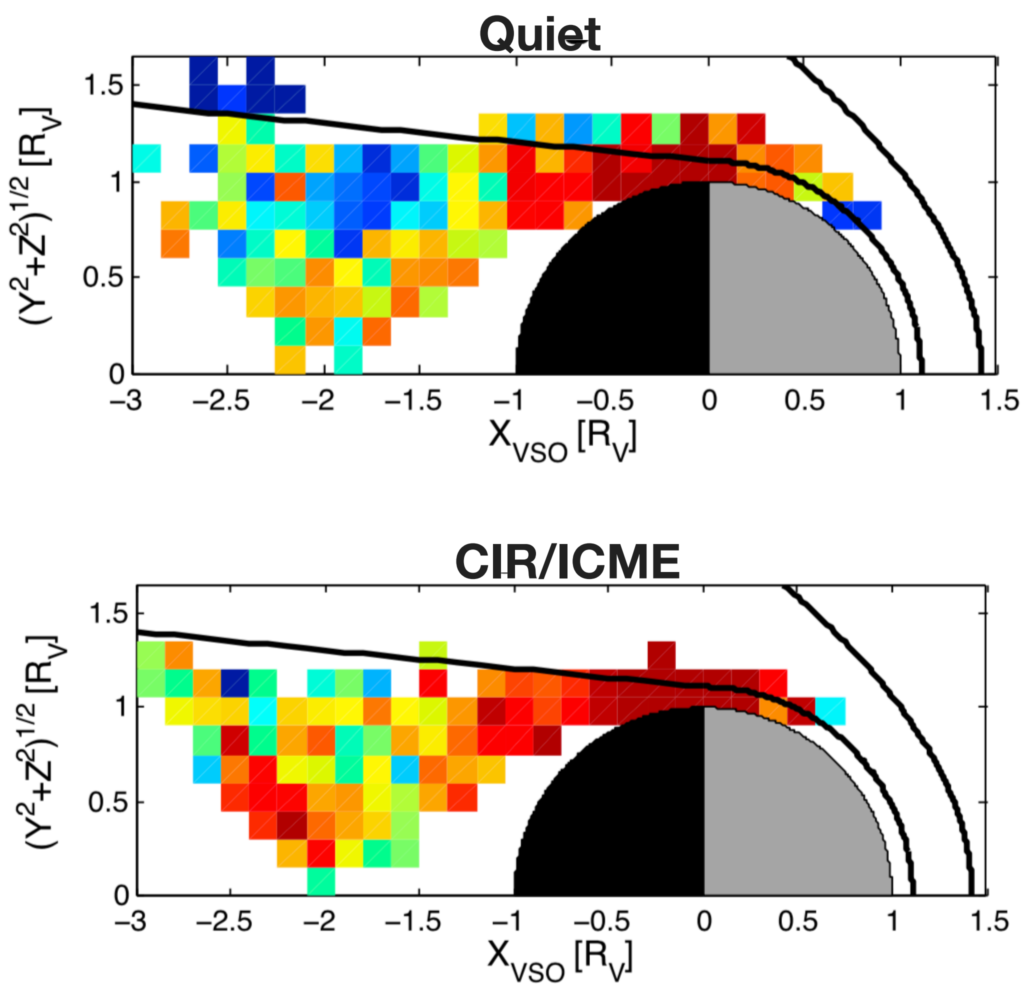
Venus	• $5x10^{24}$ /s
Mars	• $3x10^{24}$ /s
Earth	• $(10–100)x10^{24}$ /s

André, 2012; Slapak et al., 2017; Ramstad et al., 2017; Futaana et al., 2018

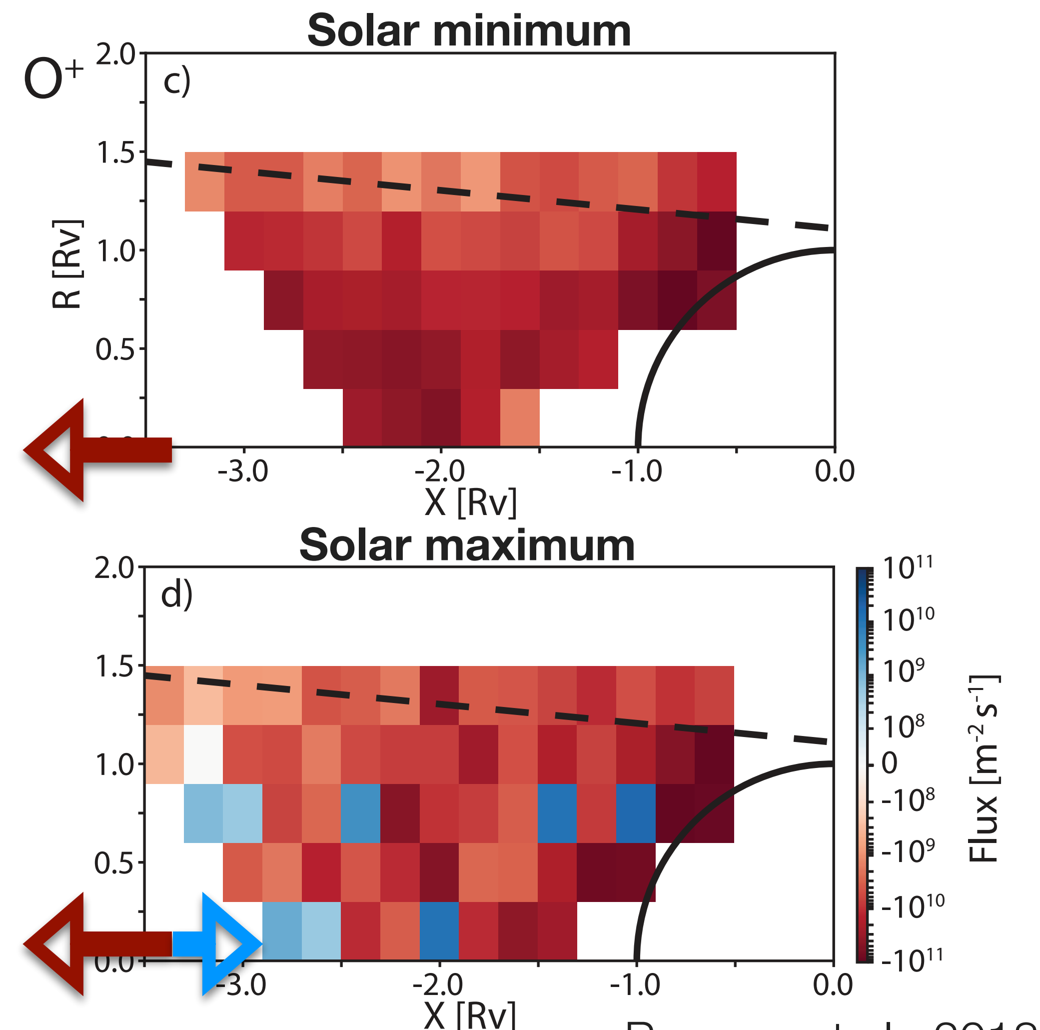
Variations of escaping oxygen ion flux

Do disturbed condition increase the escaping flux?

- Yes: During ICME, 1.7 times higher escaping than usual
- No: In Solar Maximum, 1.5 times lower escaping than in solar minimum



Edberg et al., 2009



Persson et al., 2018

Open question:

- Disturbed CME enhance the outflow flux, while the disturbed solar maximum reduces the flux. Why?

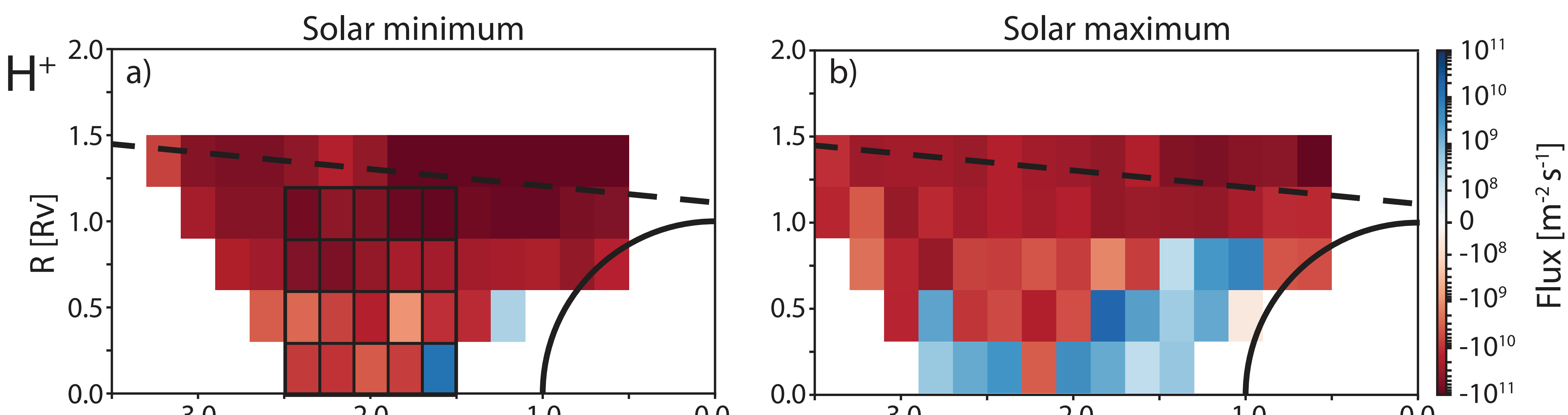
Solar activity dependence of composition

Venus loses water [Barabash et al, 2007]. H+/O+ = 1.9

Solar cycle dependence of H/O ratio

- Solar minimum: 2.6 ... More proton
- Solar maximum: 1.1 ... More oxygen ... closer to ancient Venus

Protons are clearly returning to Venus during the solar minimum



Persson et al., 2018

Open questions:

- What is the H/O escaping ratio for the ancient Venus?

- What is the impact to the evolution of Venus?

Acceleration in the ionosphere

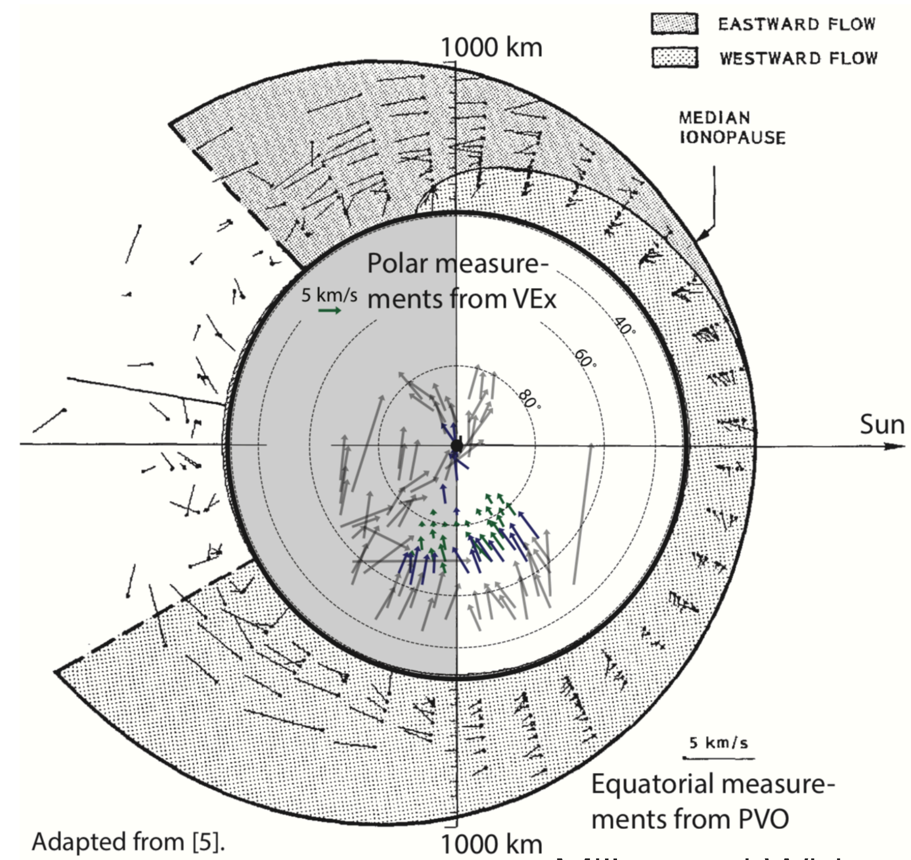
High velocity (~5 km/s) flow below 300 km (exobase)

Dusk-to-dawn direction

- Driving force: Pressure gradient

Vertical components exist

- Precipitation to thermosphere
- Acceleration >400 km



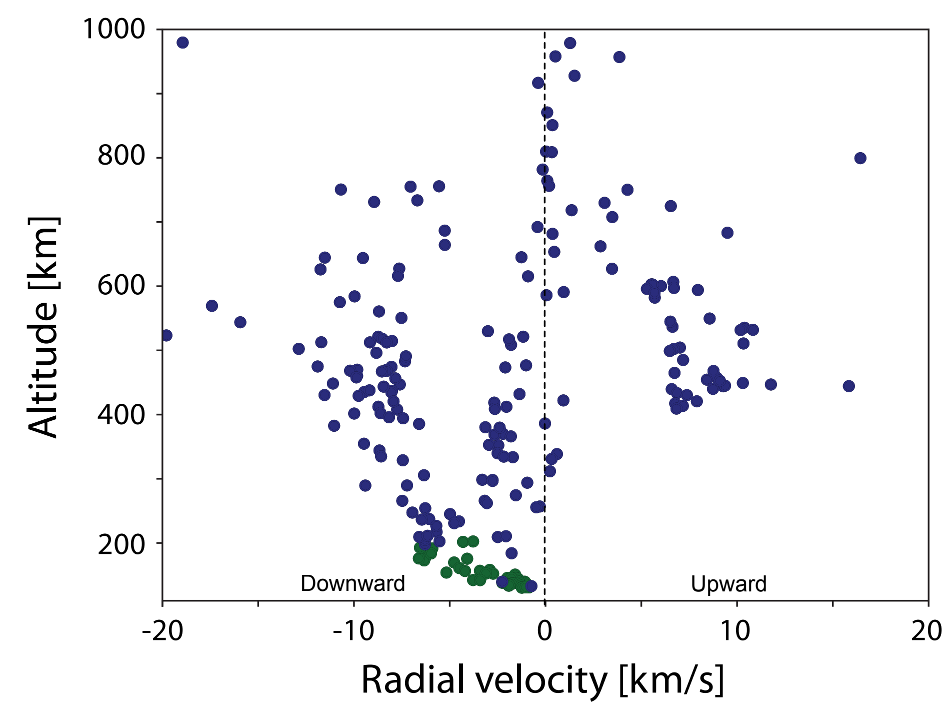
Miller and Whitten, 1991
Persson et al., 2019

Open questions:

- What is the global flow pattern of ionospheric ions?

- How much energy is transferred from and to neutral thermosphere?

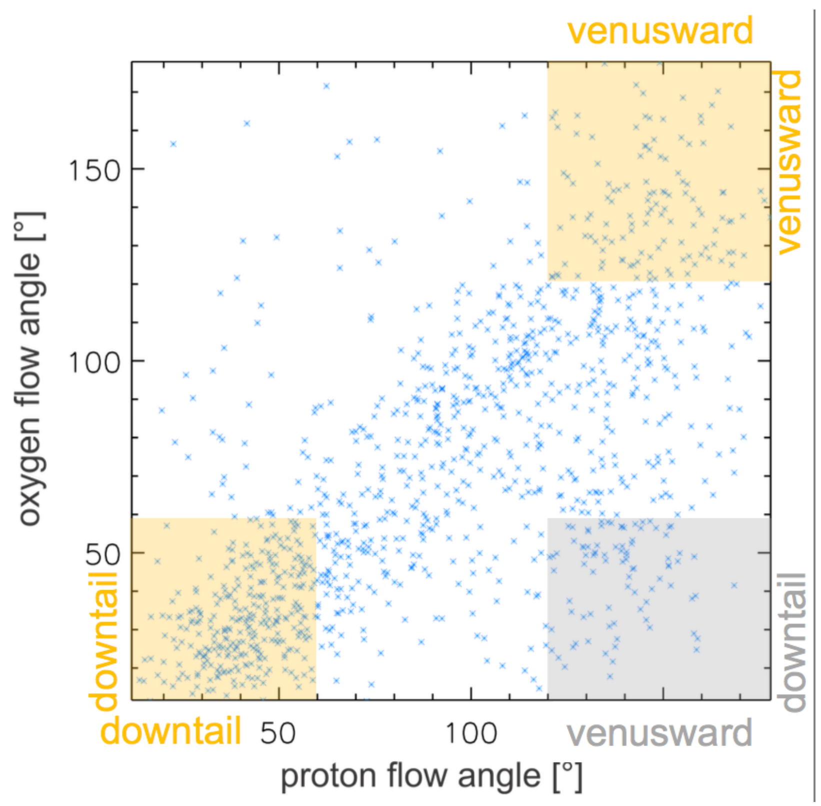
- How do the ionospheric ions get sufficient energy to escape?



Persson et al., in Preparation

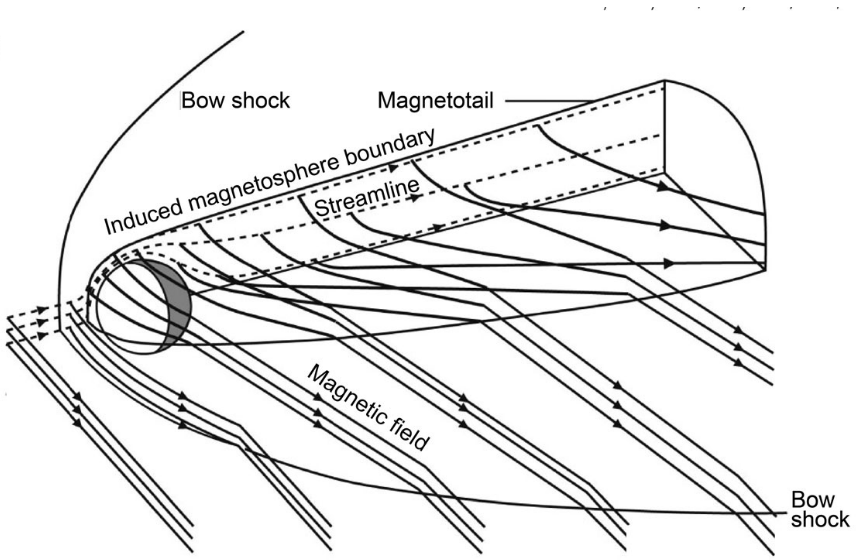
Venusward flux, back to the planet

- Sometimes different flow directions for H^+ & O^+ are observed
- Venusward flux is frequently seen with "multiple plasmasheet crossings" [Masunaga et al., 2019]



Kollmann et al., 2016

Classical picture



Open questions:

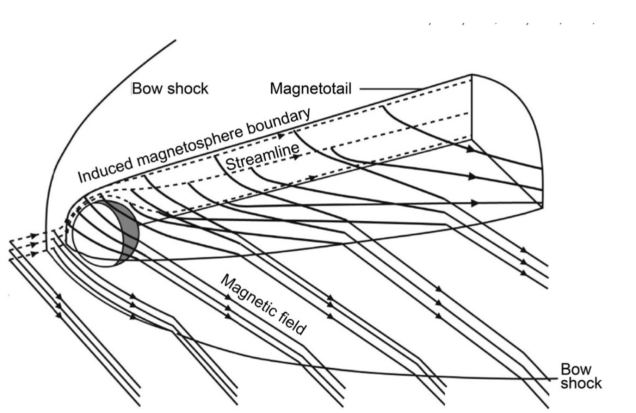
- When and how are the outflowing ions returned to Venus?

- What is the impact of the return flow to the history of Venus?

The paradigm is shifting!

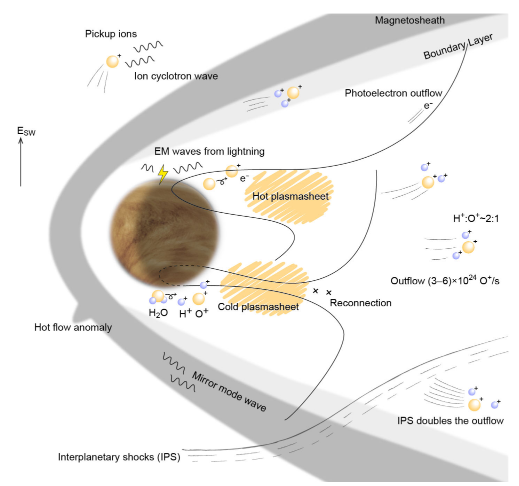
Pre-Venus Express

Saunders and Russell, 1986



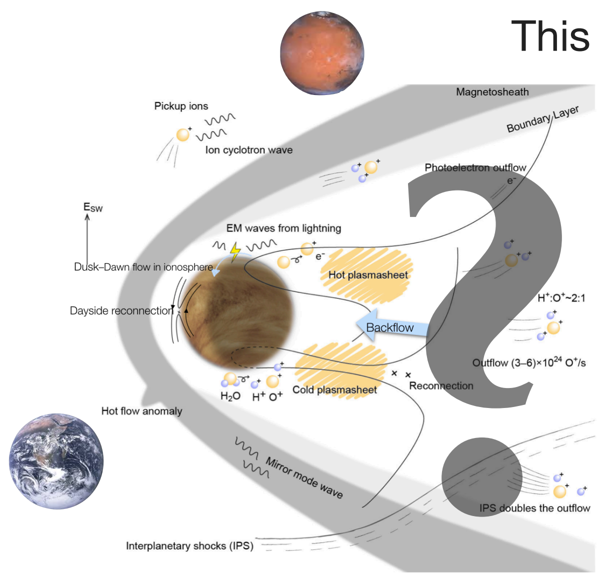
VEX (at mission completion)

Futaana et al., 2017 (Venus III book)



VEX post mission analysis

This talk



Venus Express ASPERA-4 and MAG measurements recently revealed the unexpected characteristics of the plasma environment:

- Outflowing flux of Venus ionospheric plasma via magnetotail is lower than that of the Earth
- Anti-correlation of outflowing fluxes on the solar activities is discovered
- The outflowing composition (H/O ratio) strongly depends on the solar activity
- Dusk–to–dawn high-speed flow of oxygen ions inside the ionosphere is found
- Frequently, the magnetotail structures do not follow the classical draping picture