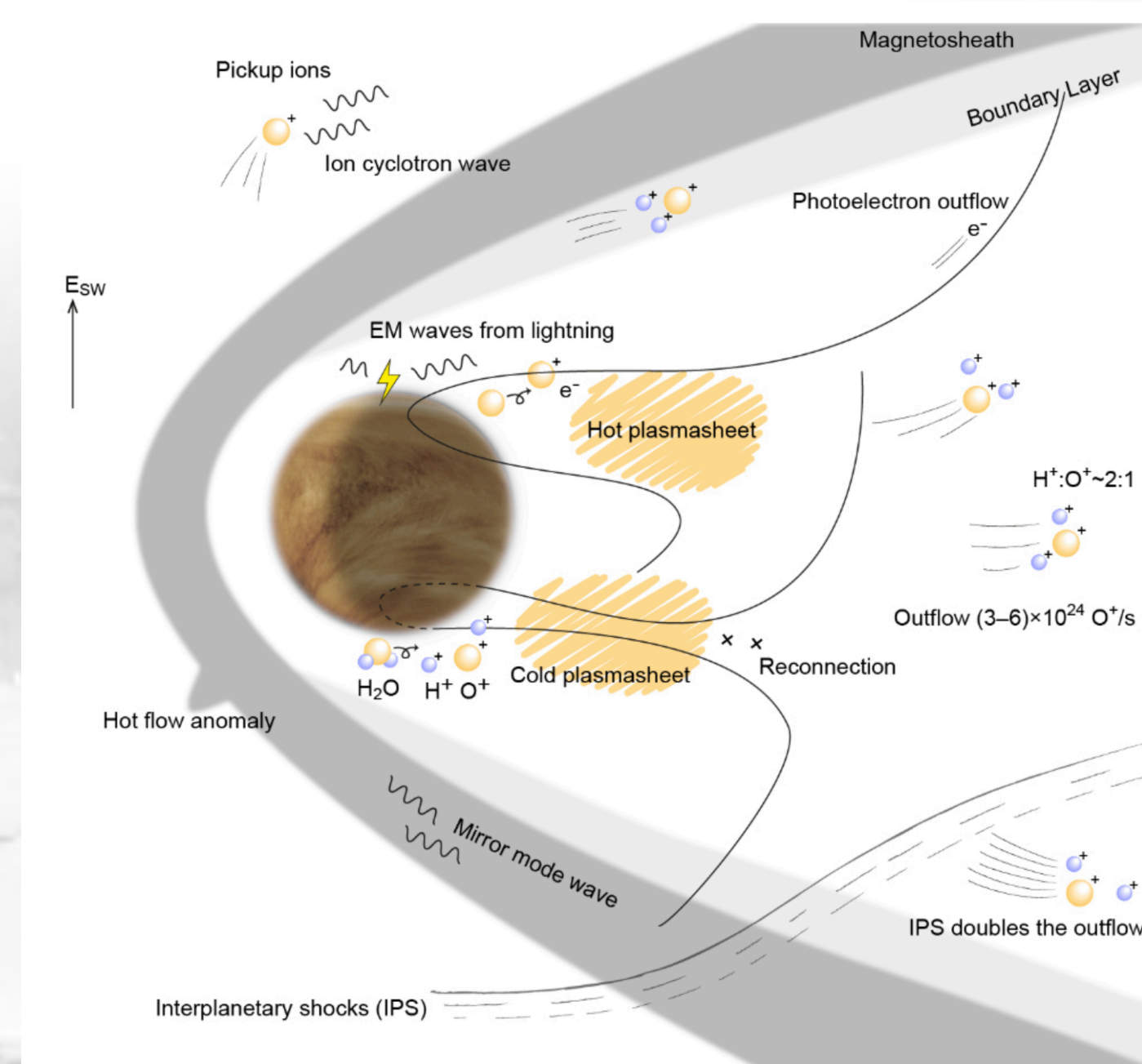


# The Venusian upper atmosphere and its solar wind interaction

**Yoshifumi Futaana** (*Swedish Institute of Space Physics, Kiruna, Sweden*)

*Principal Investigator of ASPERA-4 instrument on ESA's Venus Express mission*

futaana@irf.se

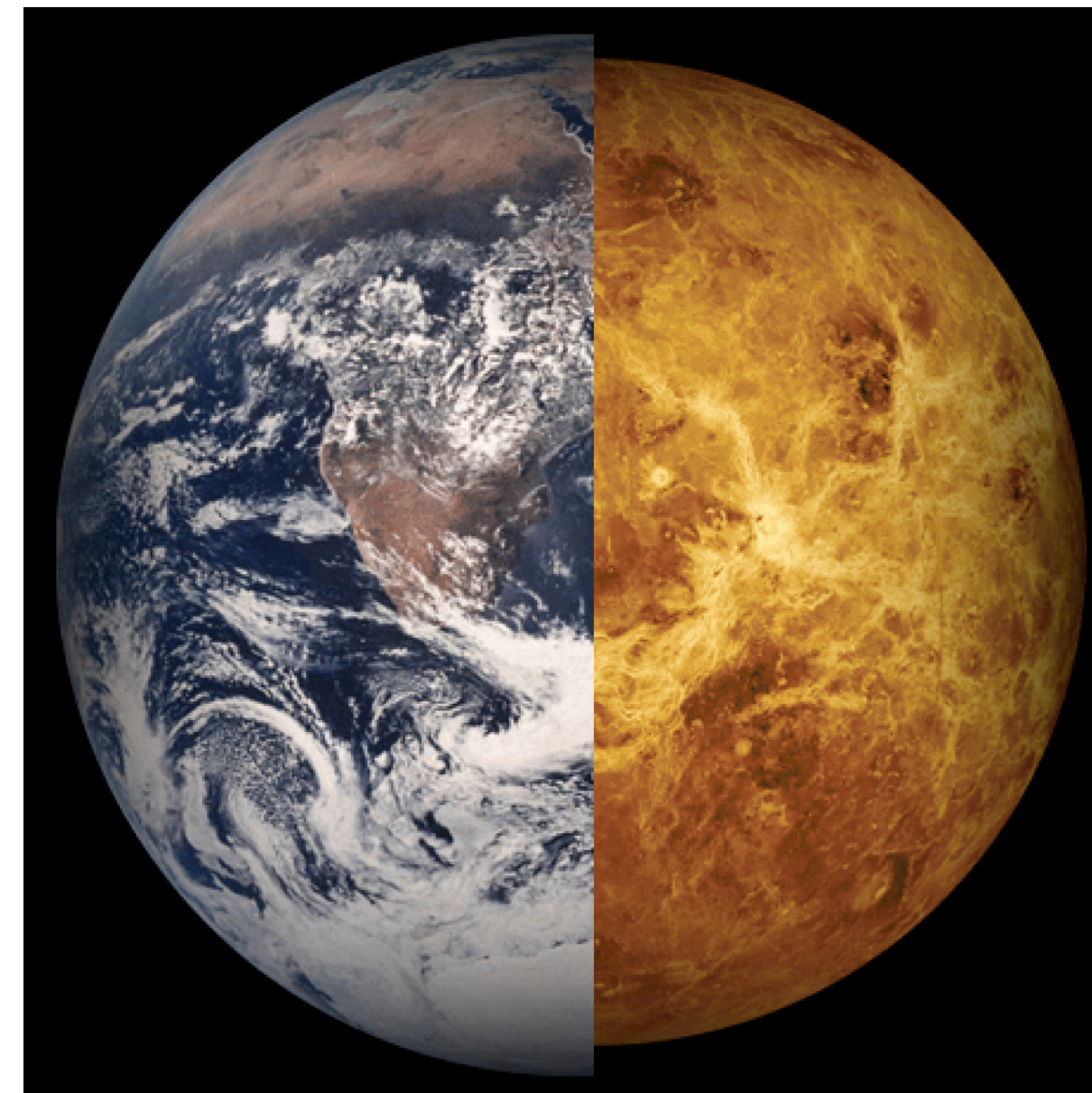


Futaana+17, SSR

# Why Venus?

Venus is the Earth's twin, but completely different

- Why so different?
  - Planets are diverse. Exoplanets provided us further samples.
  - Detailed study with in situ exploration is only possible for solar system objects like Venus



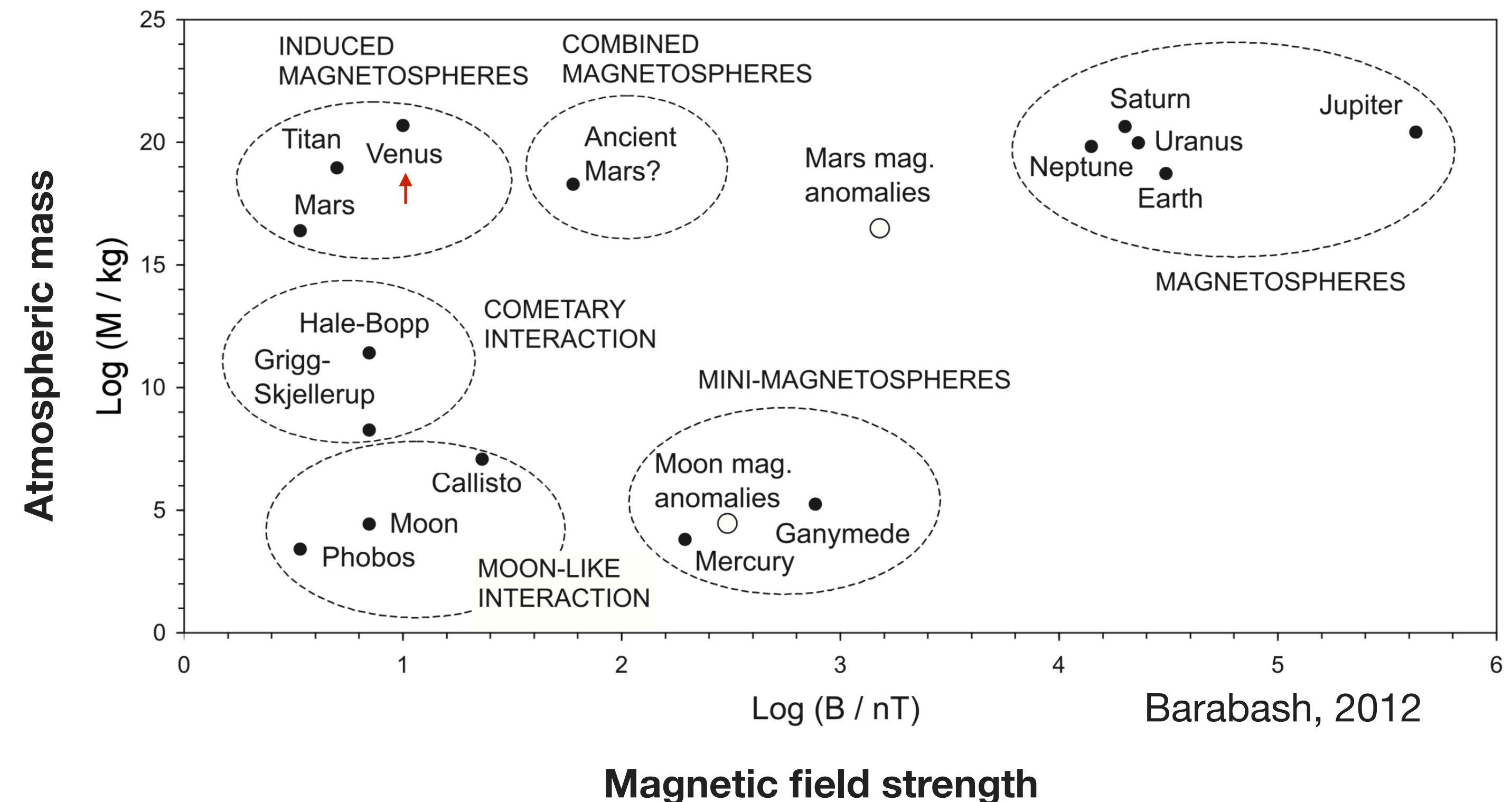
(c) NASA

# Diversity of plasma interactions

## The types of plasma–planet interactions

- Presence of the magnetic field
- Presence of the atmosphere (ionosphere)

Venus represents “induced magnetosphere” type planets





# Solar wind–Venus interaction (induced magnetosphere)

Direct coupling between solar wind and ionosphere

A boundary formed to balance the solar wind plasma and induced current inside the ionosphere (MHD-planet)

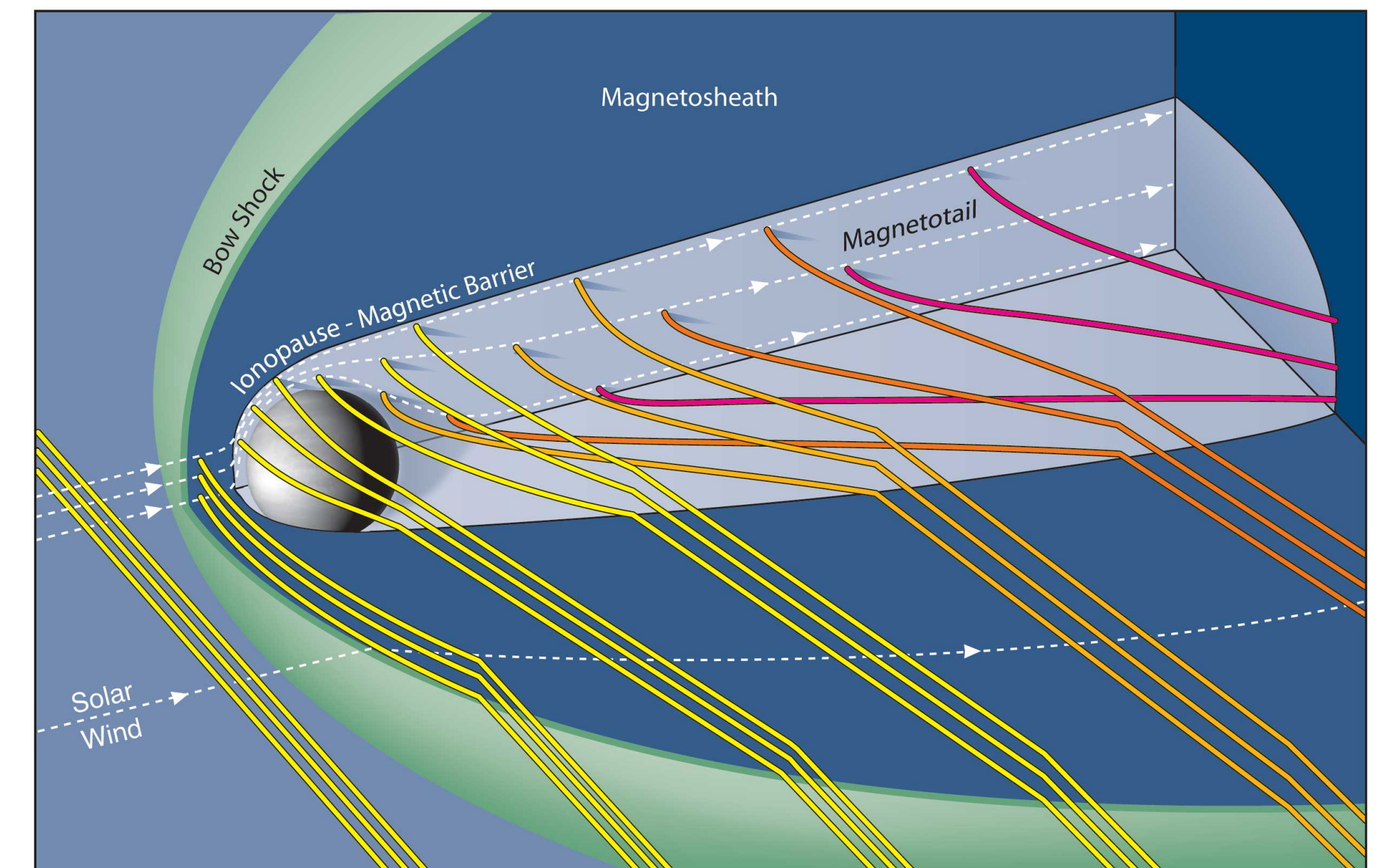
- Magnetic pileup boundary, magnetic barrier
- Induced magnetosphere boundary
- Ion composition boundary
- Ionopause (particularly for old literature, but should be used with care)

The bow shock is formed

Energy and momentum flow

- from the solar wind to the upper atmosphere and to the magnetotail

$$\frac{\rho v^2}{2} = \frac{B^2}{2\mu_0} = nkT_e$$



After Saunders and Russell (1986), redrawn at <https://lasp.colorado.edu/home/mop/resources/graphics/>



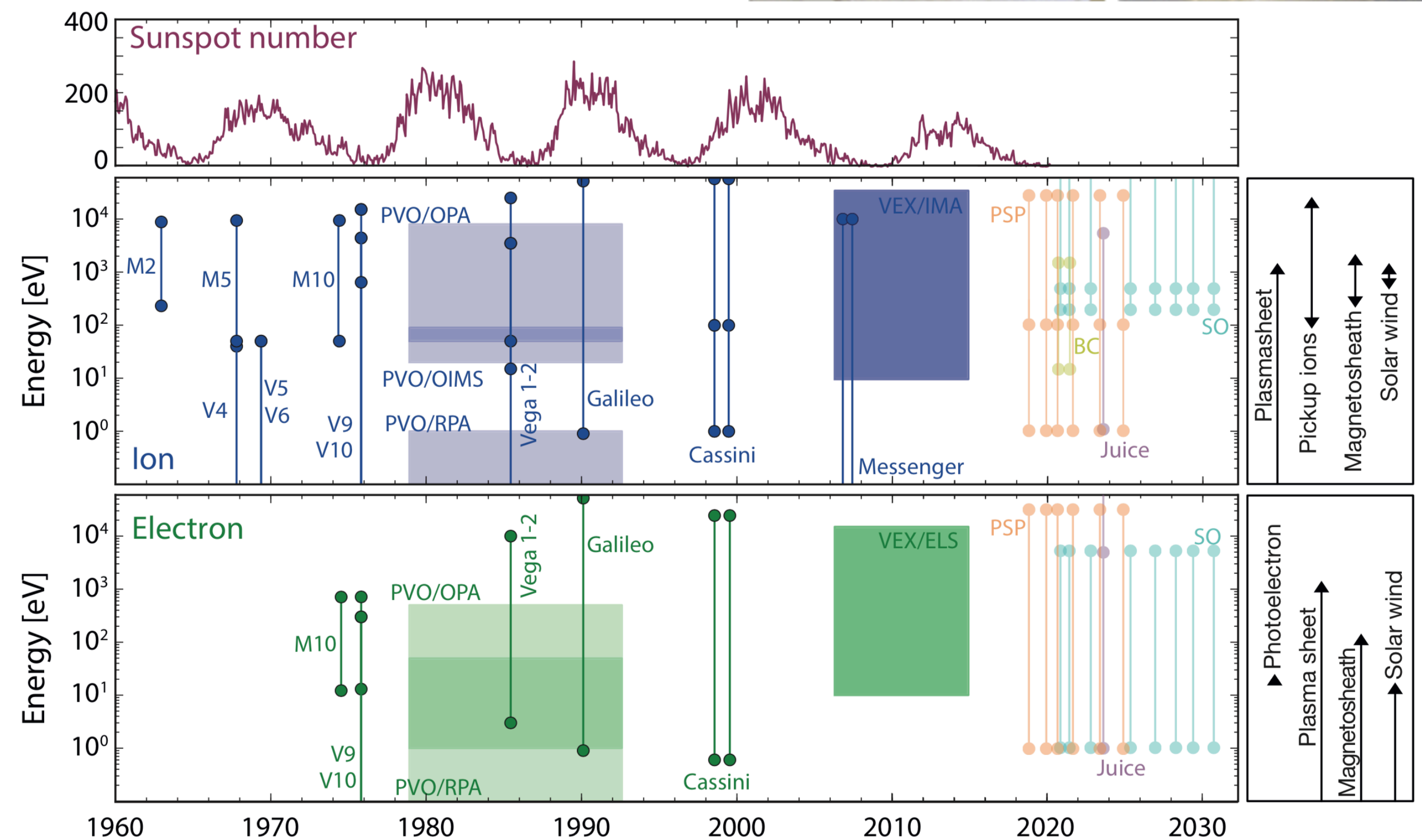
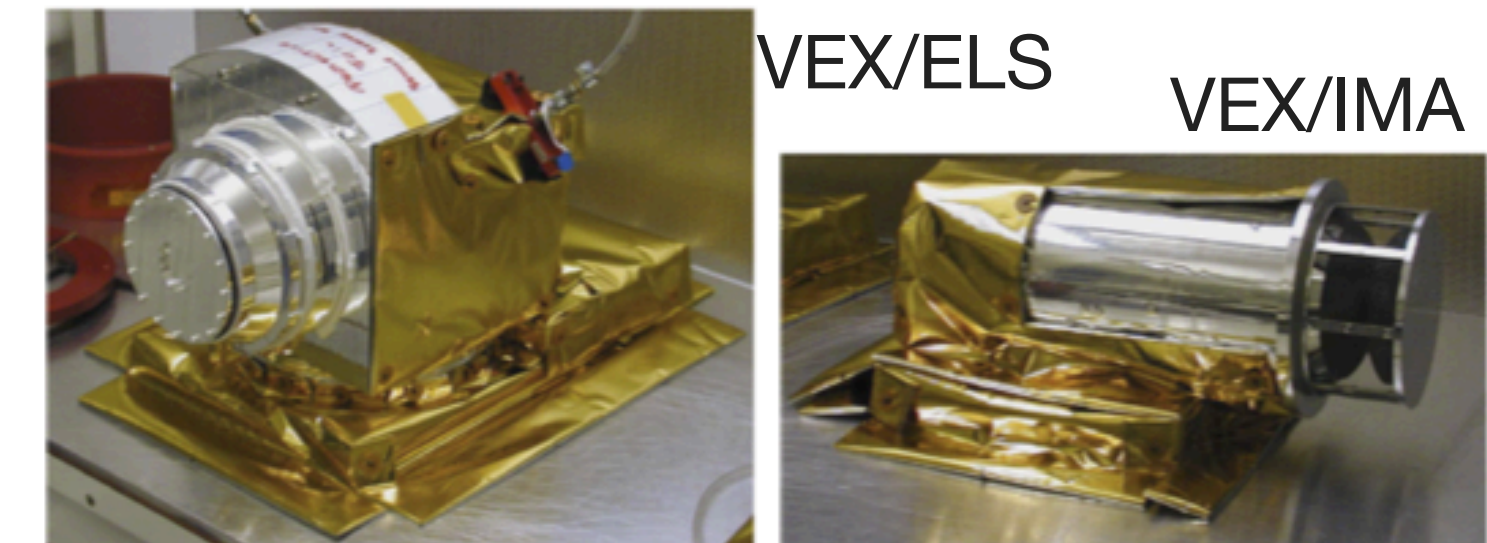
# Venus missions (space plasma instrumentation)

## Venus Orbiters

- Pioneer Venus (1978–92)
- Venus Express (2006–14)

## Venus Flybys (near future)

- Parker Solar Probe
- Solar Orbiter
- Bepi Colombo
- JUICE



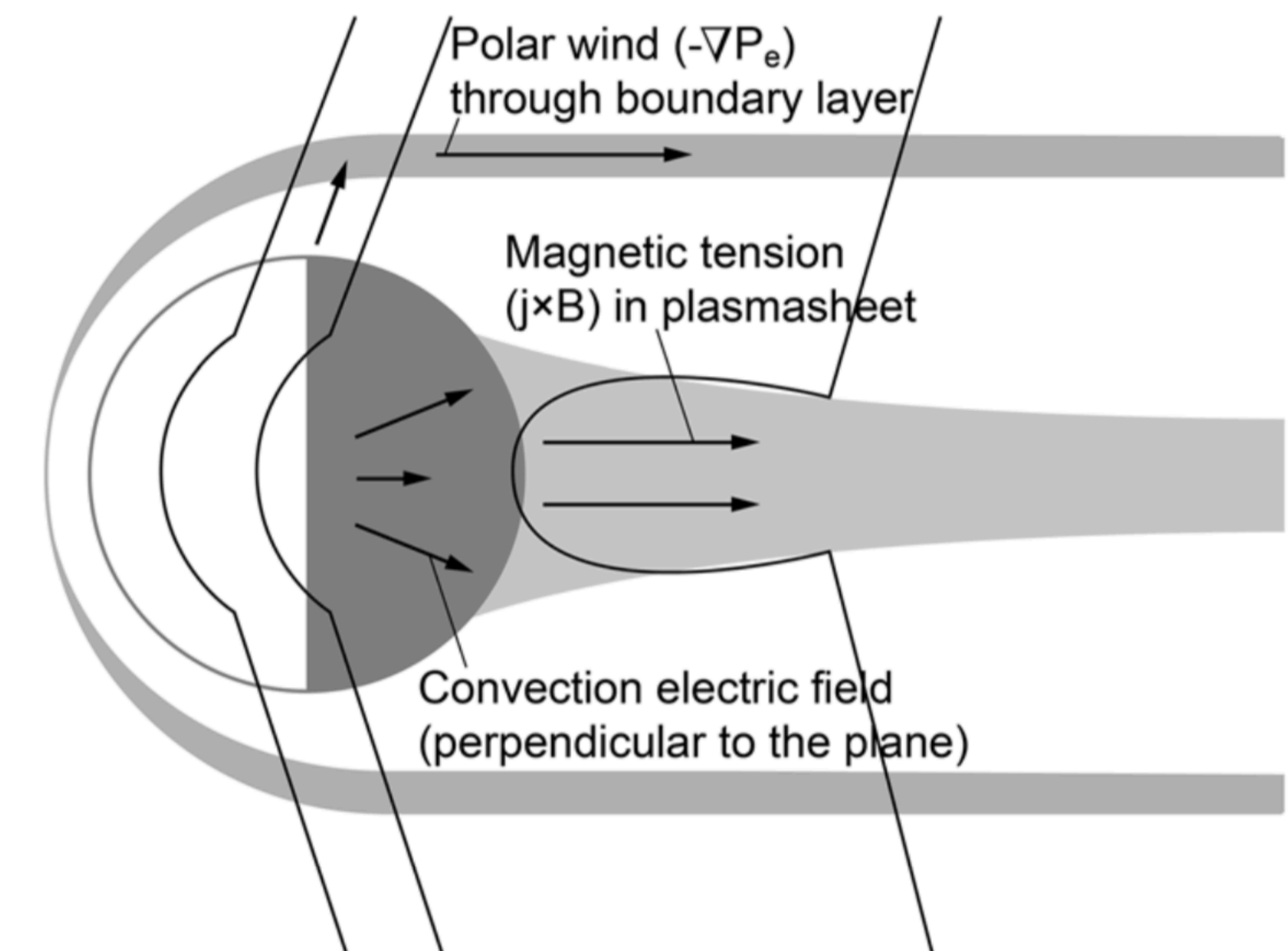
[Adopted from Futaana+2017]

# Atmospheric loss to space

High D/H ratio in the Venus atmosphere hypothesized water loss to space over billions of years

- Escape energy  $\sim 10$  eV for O
- Plasma processes (electric fields) can accelerate ionospheric ions

$$E = E_{conv} + E_{ps} + E_{pw} = -V \times B + \frac{J \times B}{n_e e} - \frac{\nabla P_e}{n_e e}$$



[After Futaana+17]



# Atmospheric loss to space

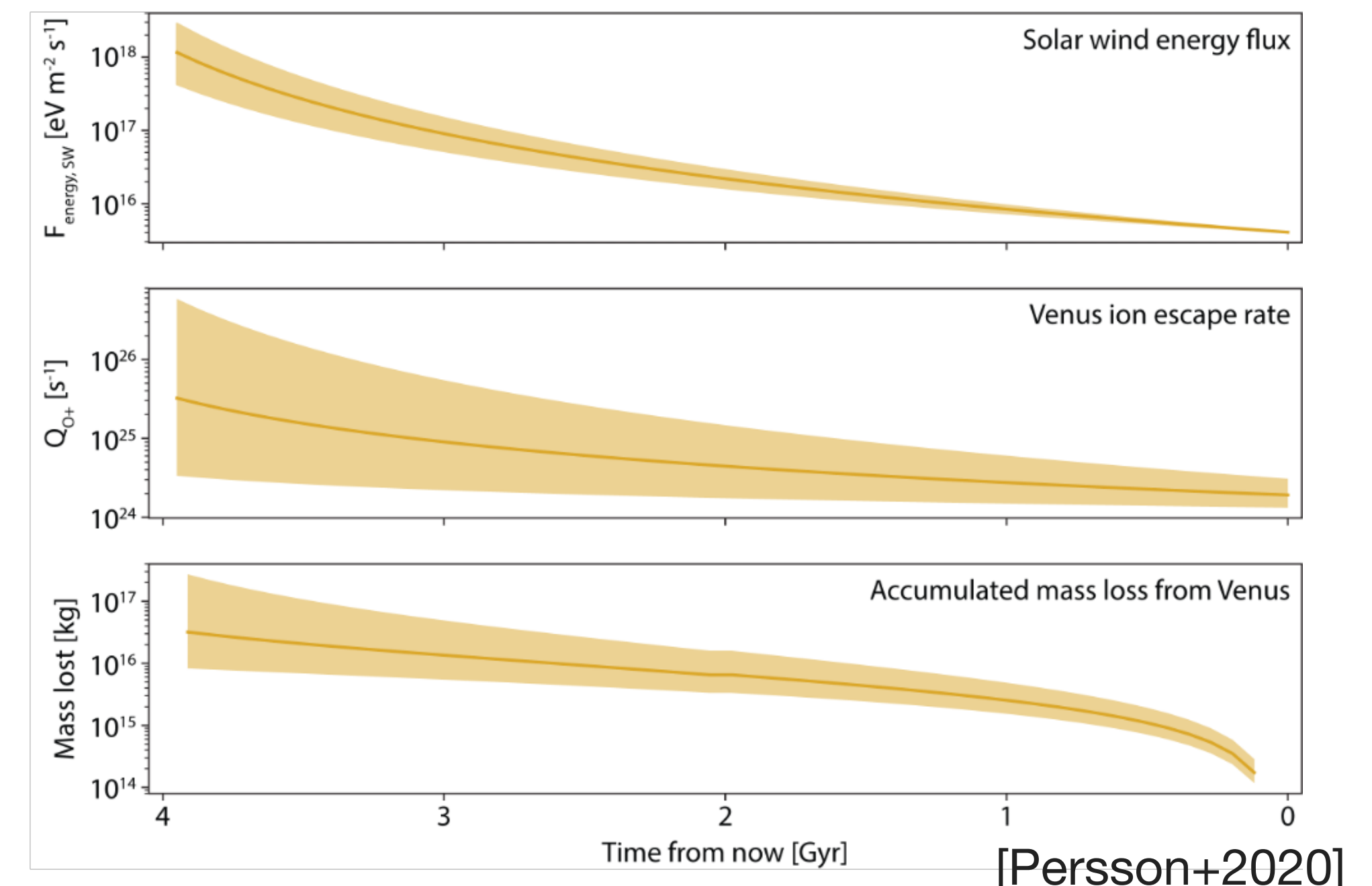
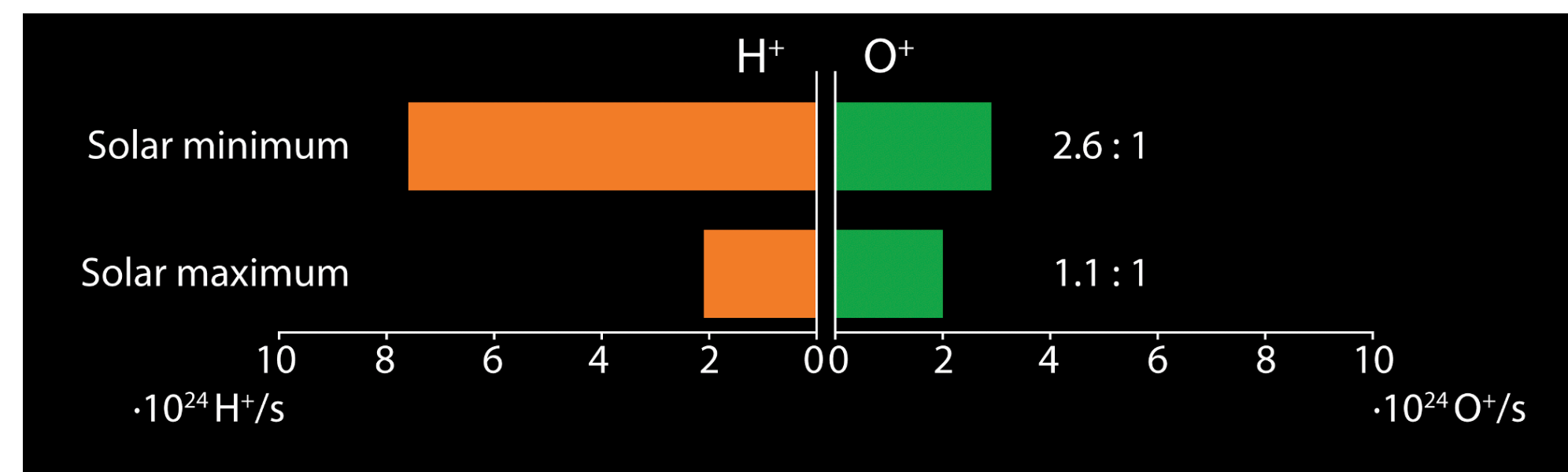
Venus Express experimentally confirmed that Venus is losing water to space

The accumulated amount of water loss over Venus history is 0.02–0.6 m

- Primordial ocean of 10s–100s m [Way+2016]

The higher atmospheric loss at solar minimum than maximum

- Solar maximum is a proxy of the past

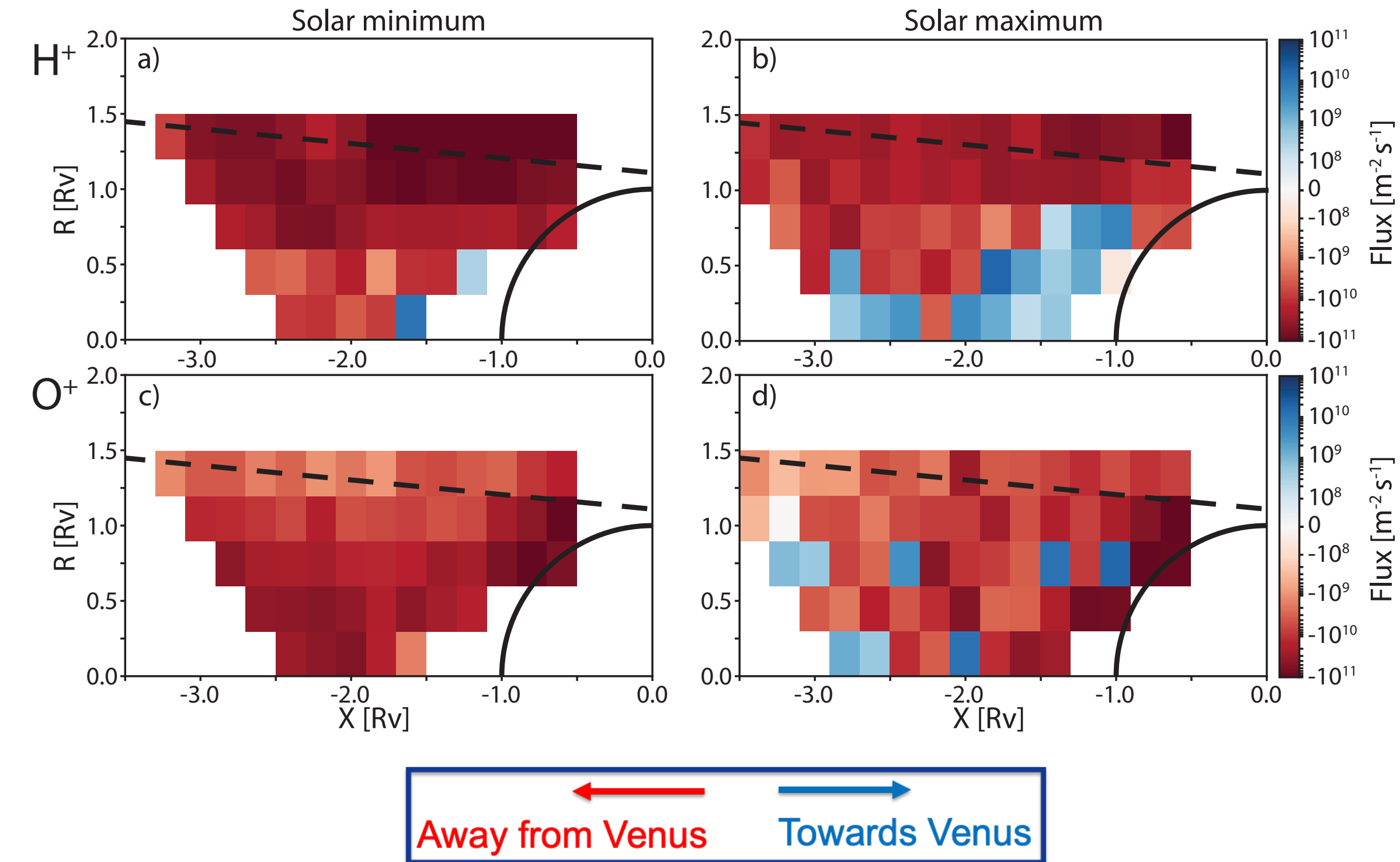


# Why is the water loss so low?

Return flow (ion flow back to Venus) is dominant during solar maximum

- Plasma processes in the magnetotail “protect” the atmosphere
- Magnetic reconnection (?)

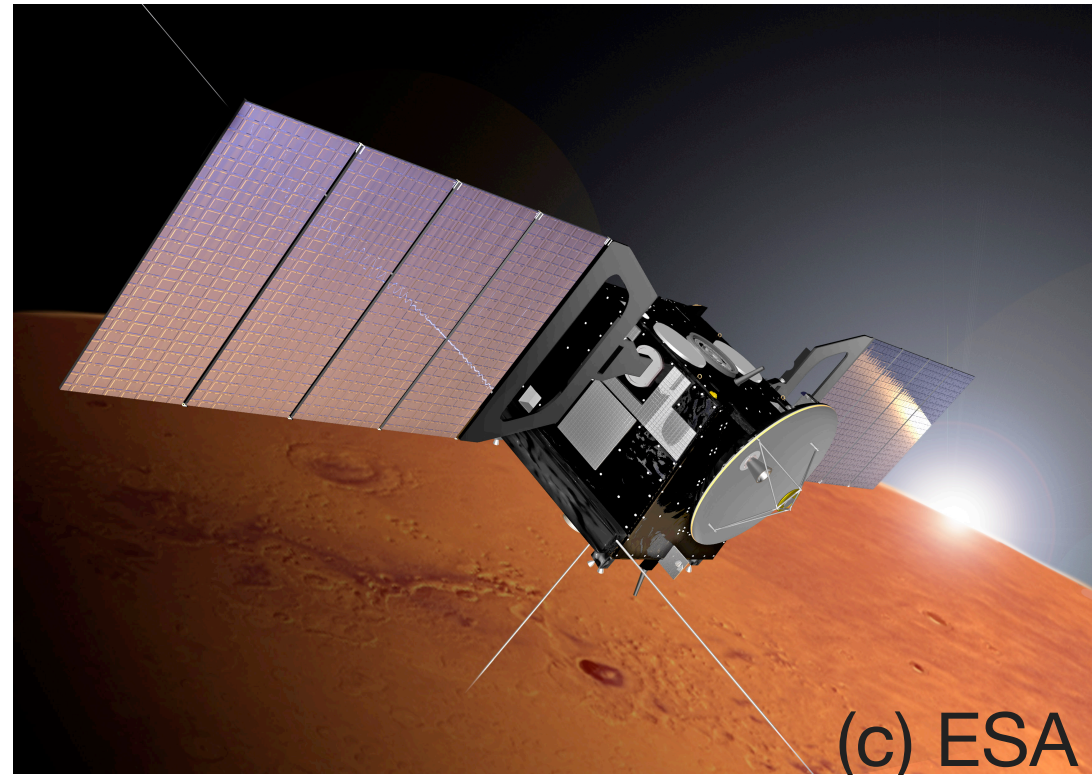
**Knowledge gap:** Physical processes driving the plasma dynamics in the magnetotail



[Persson+2018]



# A possible future mission, 1. Space plasma exploration

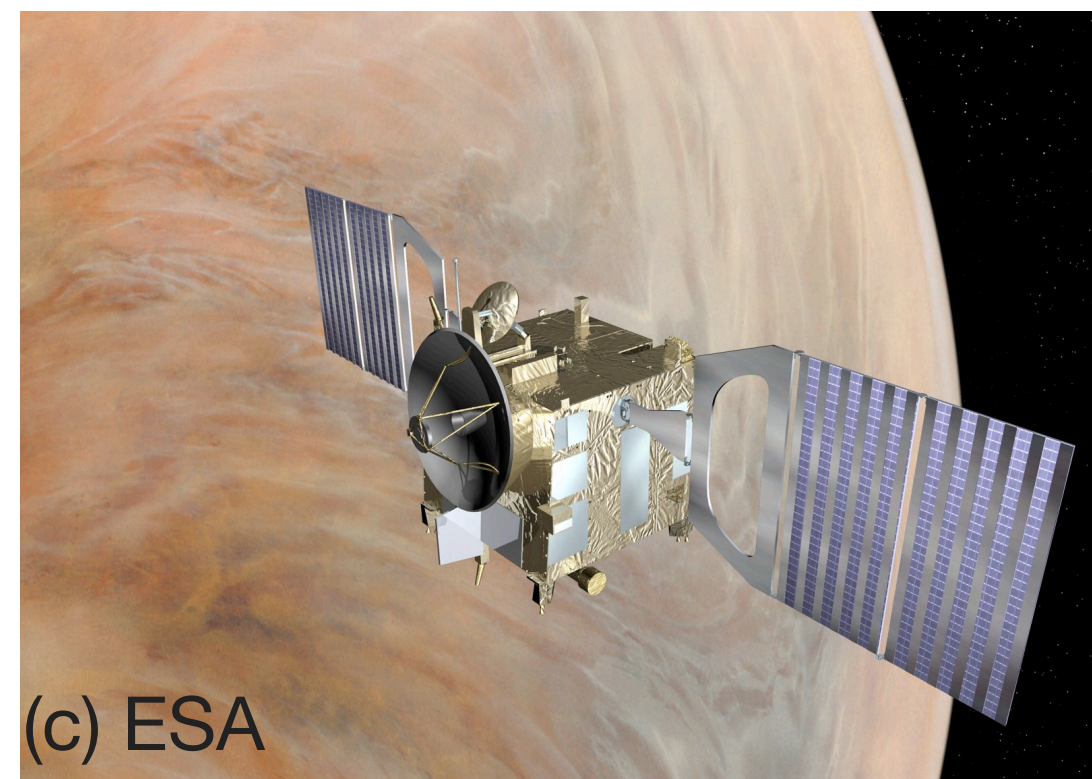
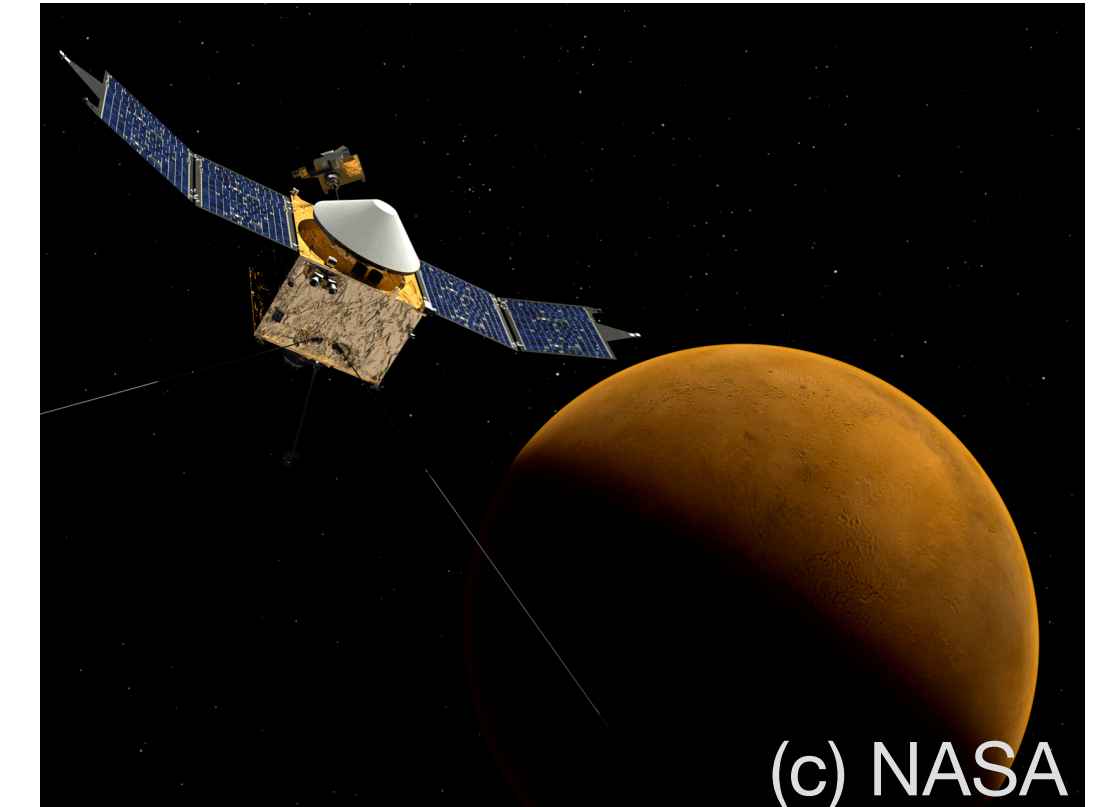


**Mars Express (2003–)**

Ion, electron, ENA

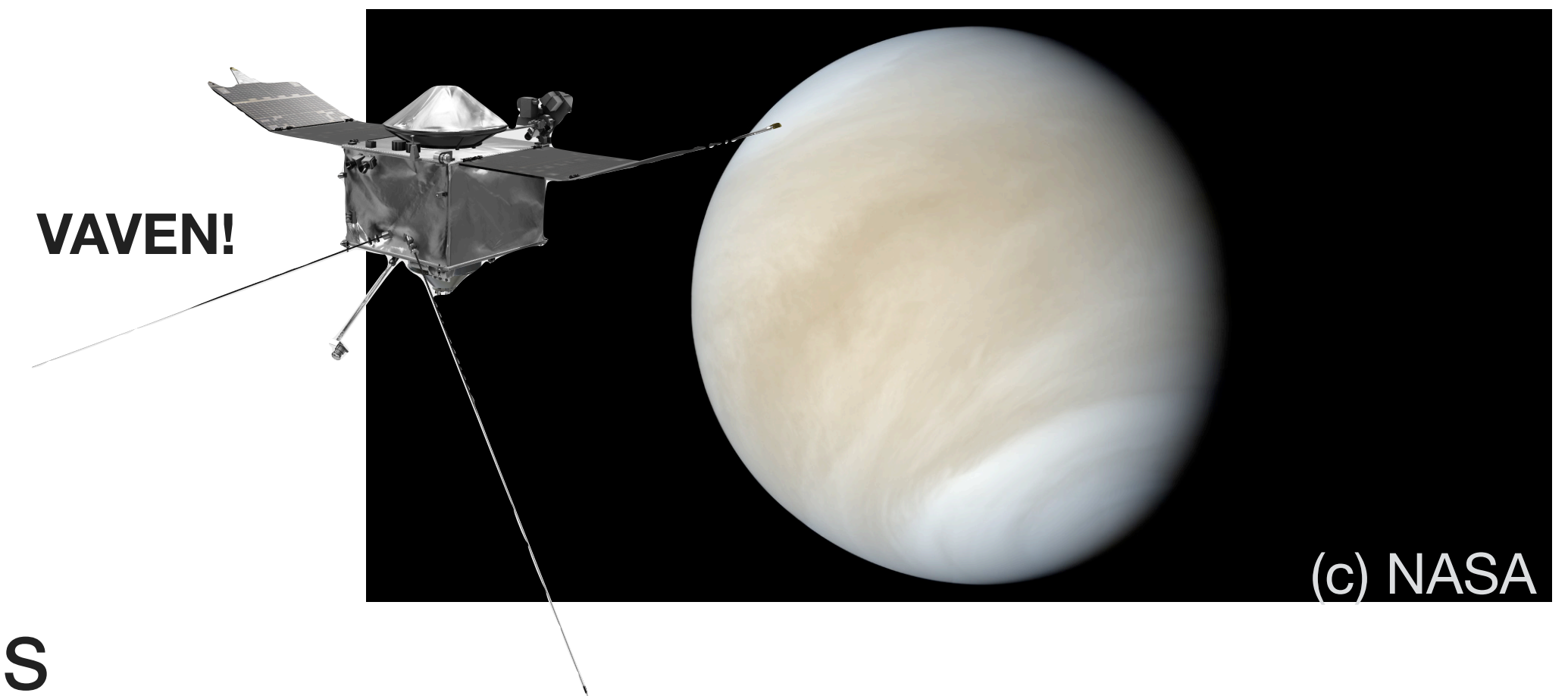
**MAVEN (2015–)**

Ion, electron,  
magnetometer  
thermal plasma  
Neutrals  
Langmuir probe,  
SEP, ...



**Venus Express (2006–)**

Ion, electron, ENA  
Magnetometer



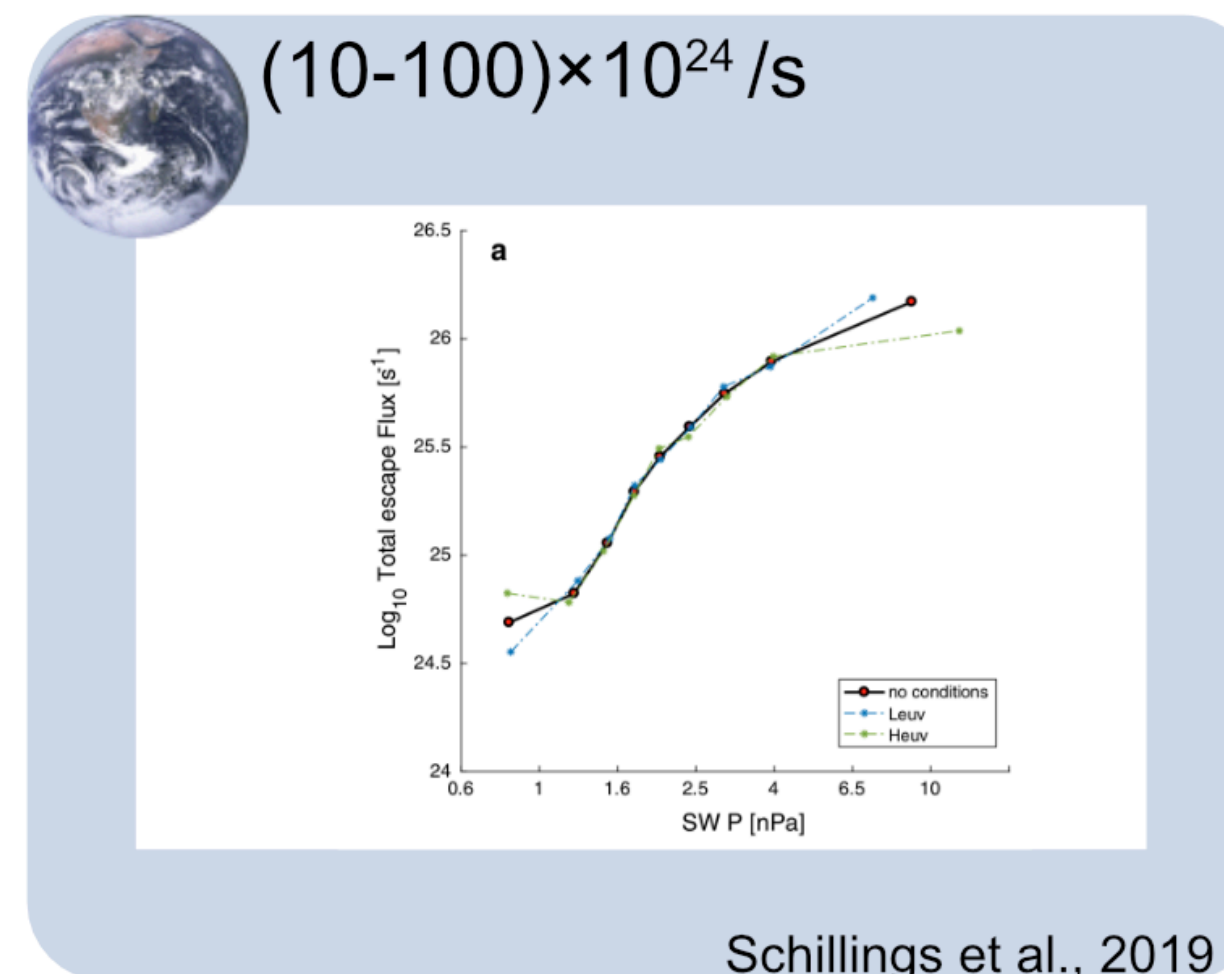
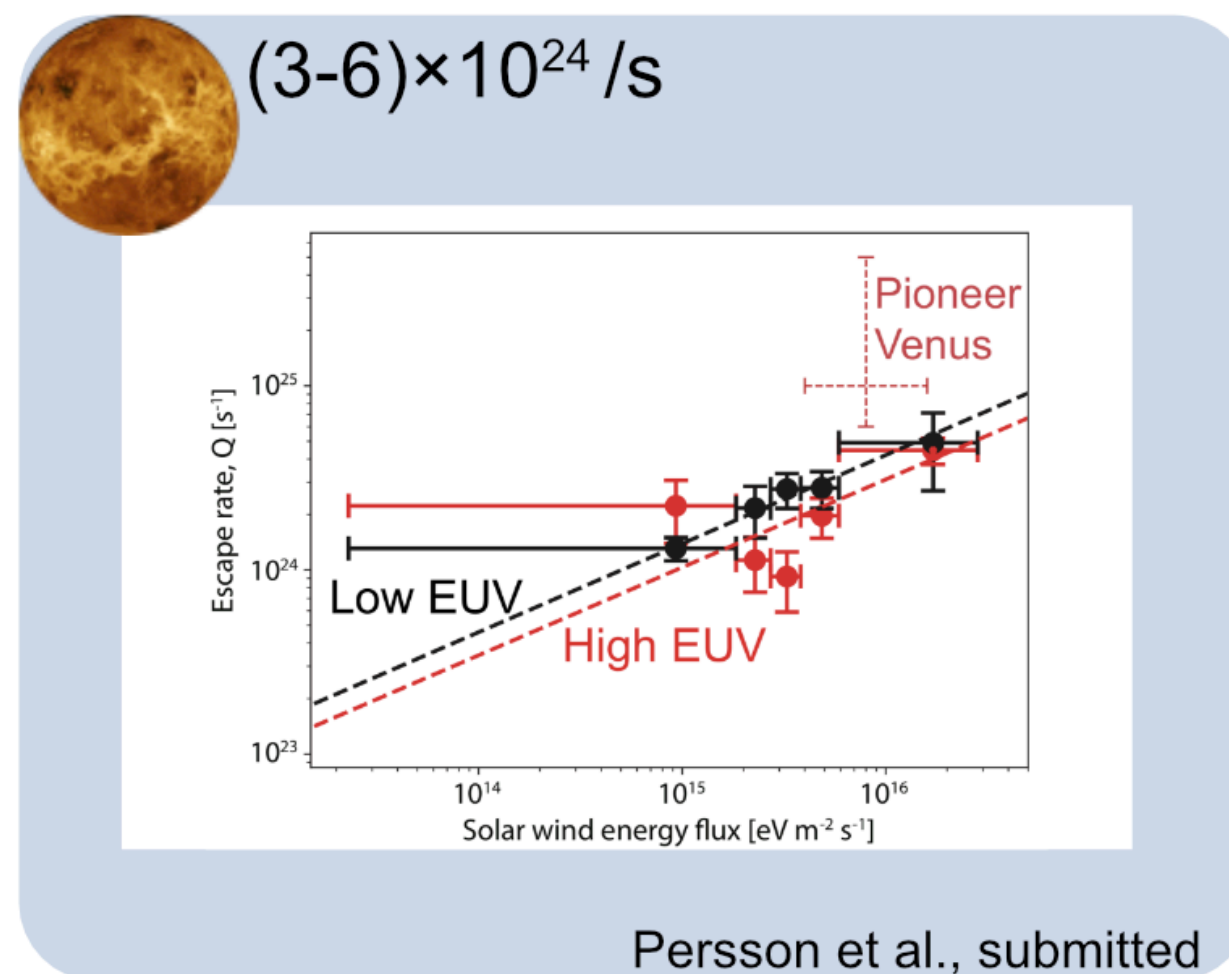
## Comprehensive plasma exploration to Venus

- Similar to MAVEN to Mars followed by Mars Express, “VAVEN” for Venus plasma investigation
- Science questions
  - How do the induced magnetosphere dynamics respond to the upstream parameters?
  - How much the dynamic magnetosphere impact the atmospheric loss from Venus?

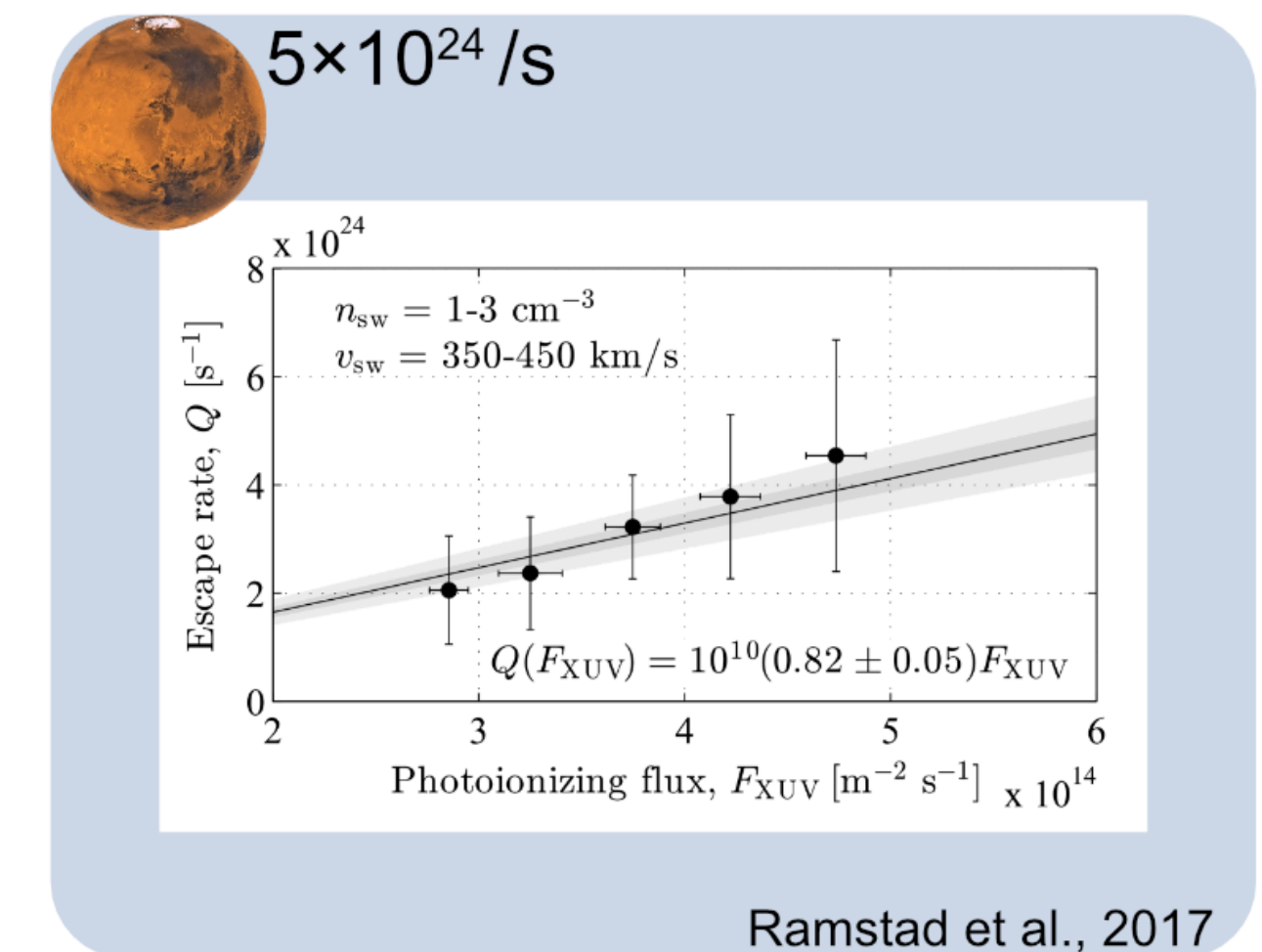


# Ion acceleration in the ionosphere

Total escape rate depend on SW energy / momentum inputs



Total escape rate depend on ion production in the ionosphere



## Venus, Earth, Mars comparison

- The water loss at Venus and Earth is regulated by the solar wind energy input
- The water loss at Mars is regulated by the photoionizing flux

**Knowledge gap:** How the ionospheric particle obtain energy from <1 eV (ionosphere) to escape energy (~10 eV for Venus & Earth, ~2 eV for Mars)

# Another possible future mission, 2. MIT coupling

Explore the key acceleration region in the ionosphere (150–600...1000 km)

- Thermal plasma, fields, and neutral mass spectroscopy
- Science questions
  - How are the ionospheric ions accelerated above the escape energy in the ionosphere?
  - How do thermosphere–ionosphere–magnetosphere–solar wind coupling work?

