Mission completed

Review of ASPERA-4 results on Venus–solar wind interaction: After 8 years operation at Venus

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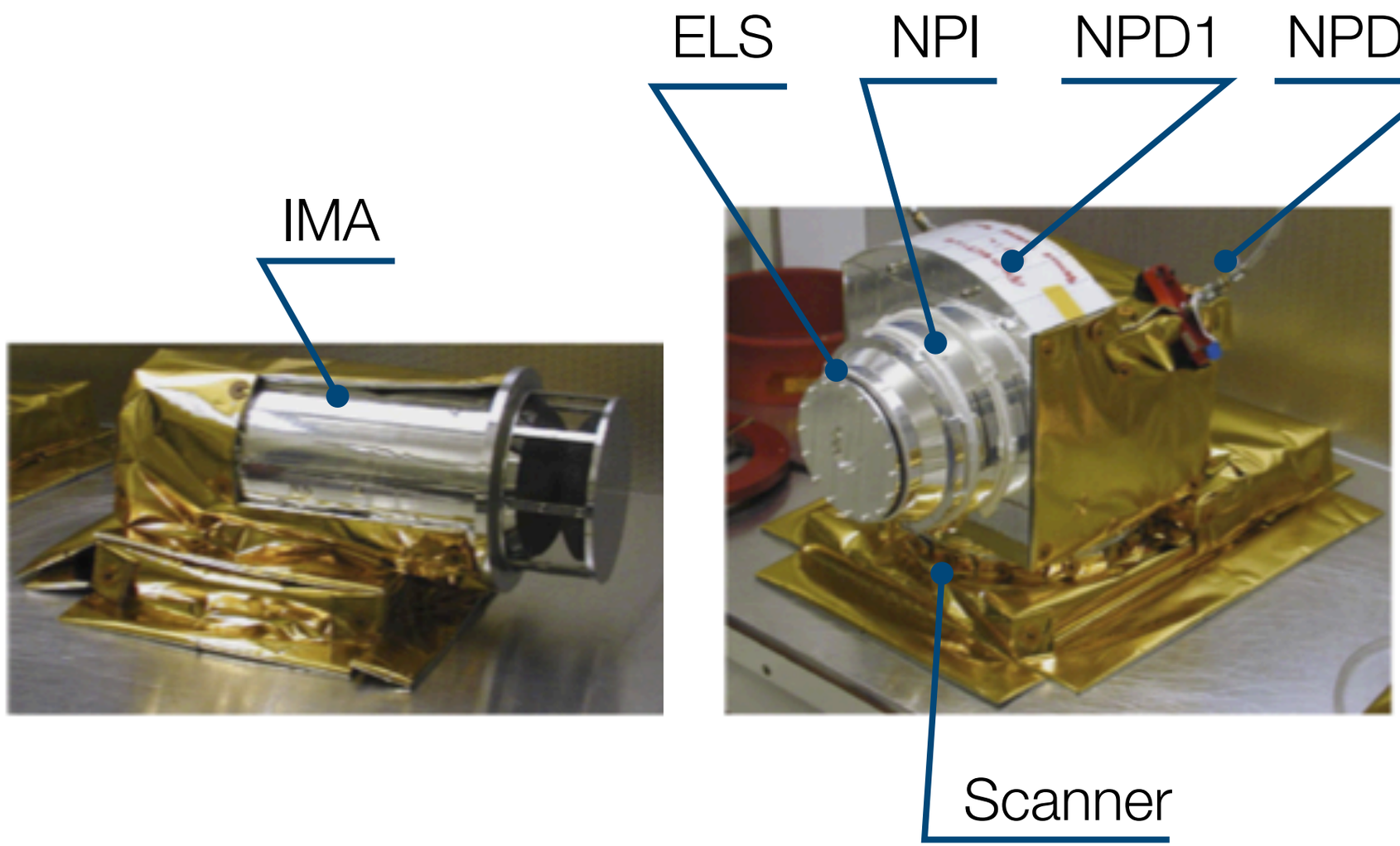
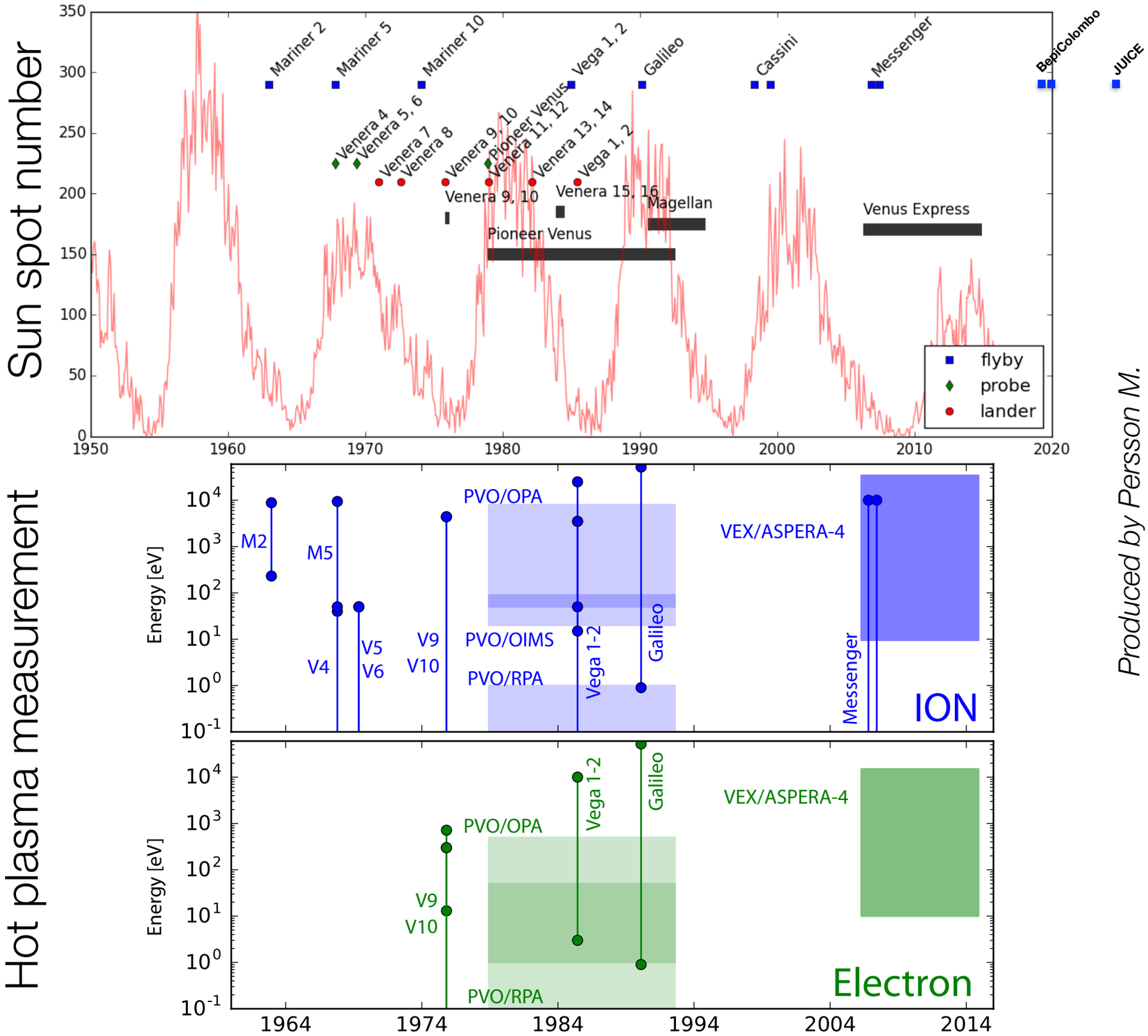
ASPERA-4 instrument

$$\text{ASPERA-4} = \text{IMA} + \frac{\text{ELS} + \text{NPI} + \text{NPD} \times 2}{\text{Scanner}}$$



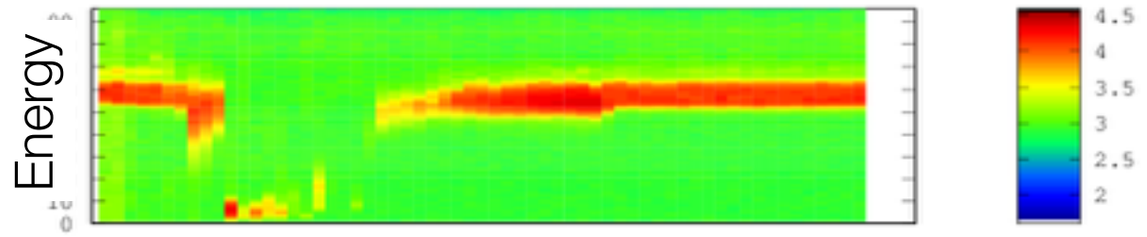
History of Venus Exploration



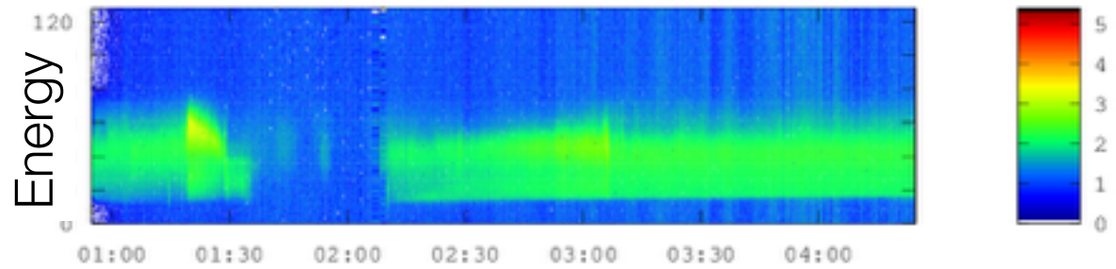
First & last data

First data near Venus (2006-05-15)

IMA

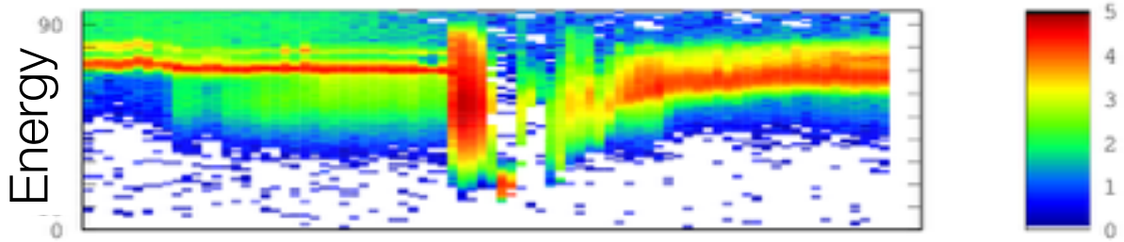


ELS

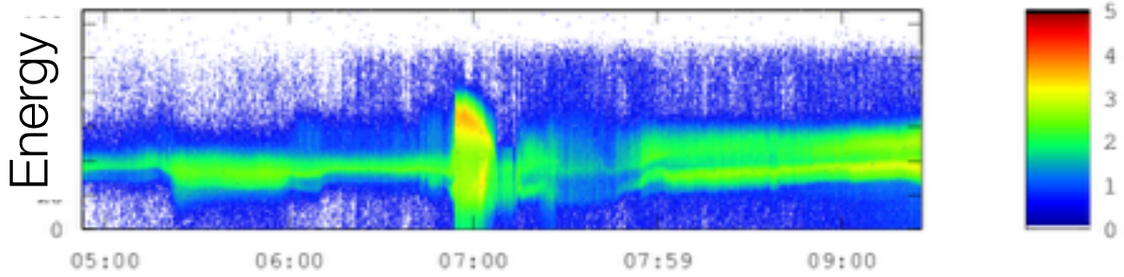


Last data near Venus (2014-11-26)

IMA



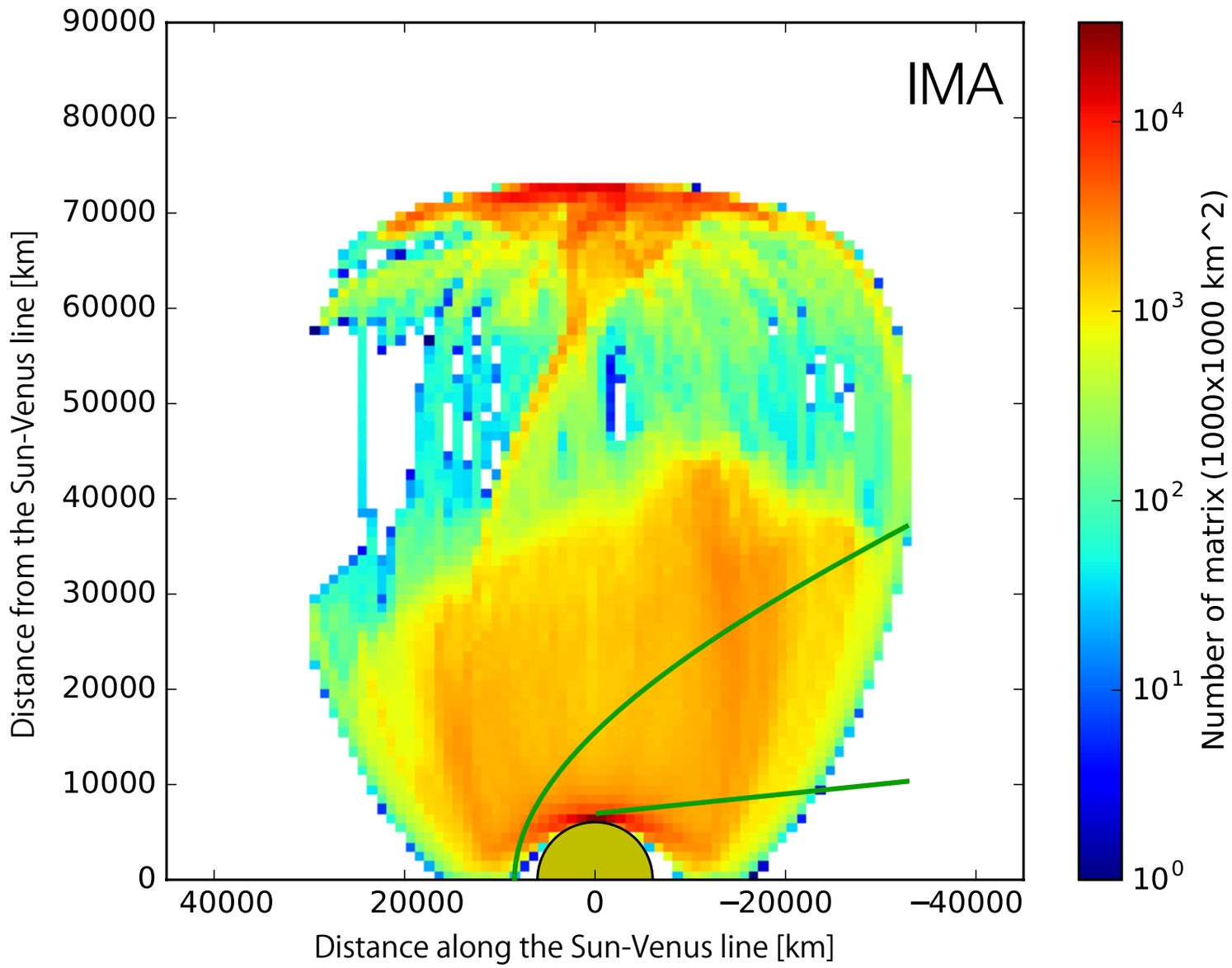
ELS



Almost no degradation over 8.5 years, or 2000 pericenter pass, operations in space

Data coverage

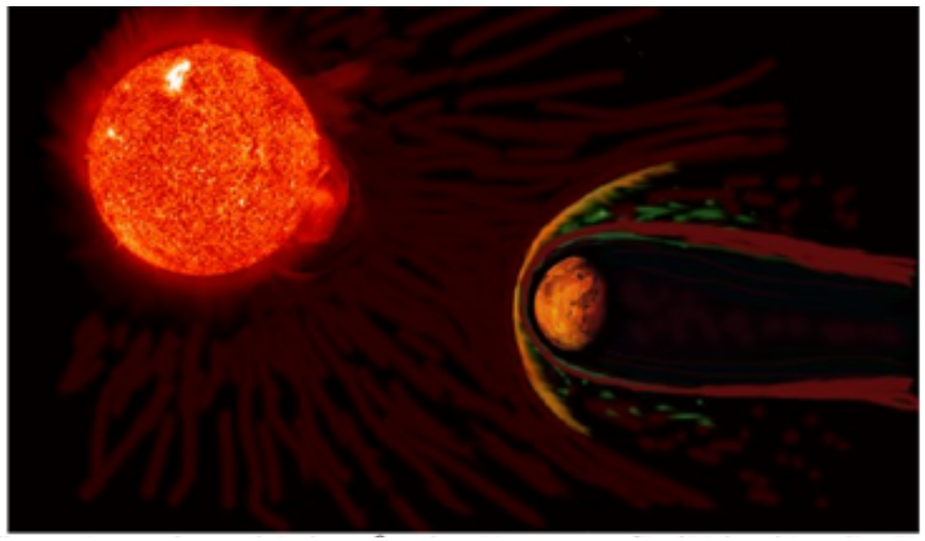
	IMA	ELS	NPI	NPD	scan	Observation time	Notes
Pericenter	✓	✓	✓[1)]	✓[2),3)]	Fix	3–6 hr near pericenter	Venus environment
Eclipse	✓	✓	✓	✓	Fix or Scan	In shadow	Limited scanner operation
Apocenter	✓	✓	✓[1)]	✓[2)]	Fix	1–2 hr near apocenter	Avoid WOL



Scientific objectives

- Venus: No intrinsic magnetic field. Atmosphere interacts with solar wind directly.
  - Different from Earth. Rather similar to Mars.

- Original scientific goals
  - Atmosphere coupling with the solar wind
  - Mass addition/removal from the atmosphere
  - Structure of the induced magnetosphere
  - Mass composition of the escaping plasma
  - Loss of water
  - Neutral–plasma interaction
  - Comparative planetology (Earth, Mars)

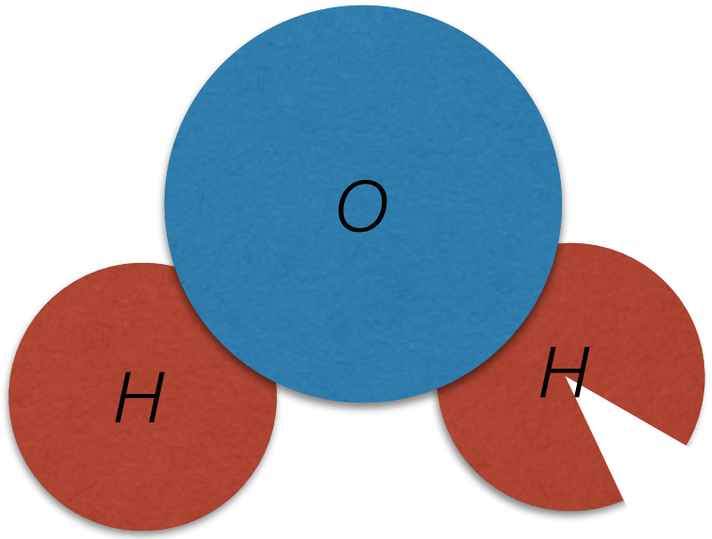


- Extended phases
  - Long-term variabilities (solar-cycle)
  - Lower ionosphere (aerobraking)

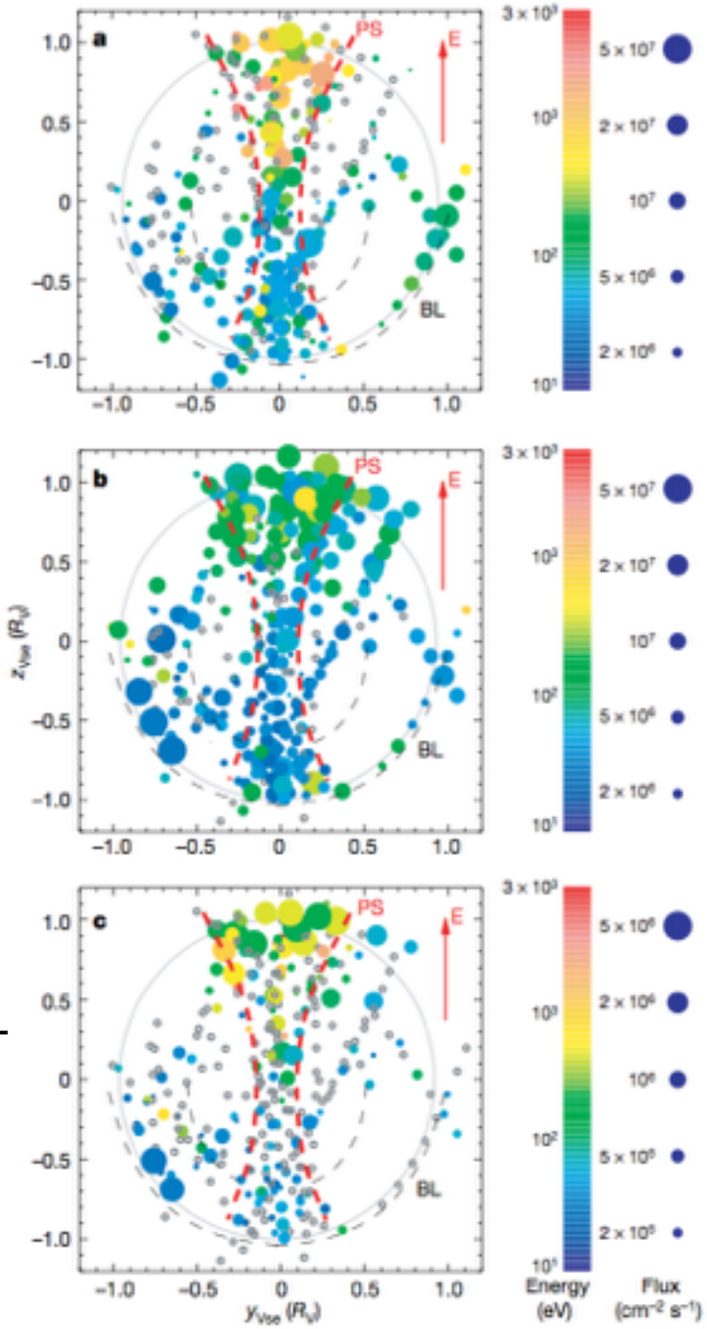
Science 1: Stoichiometric escape

- Venus loses water!

H+ / O+ = 1.9



O+



H+

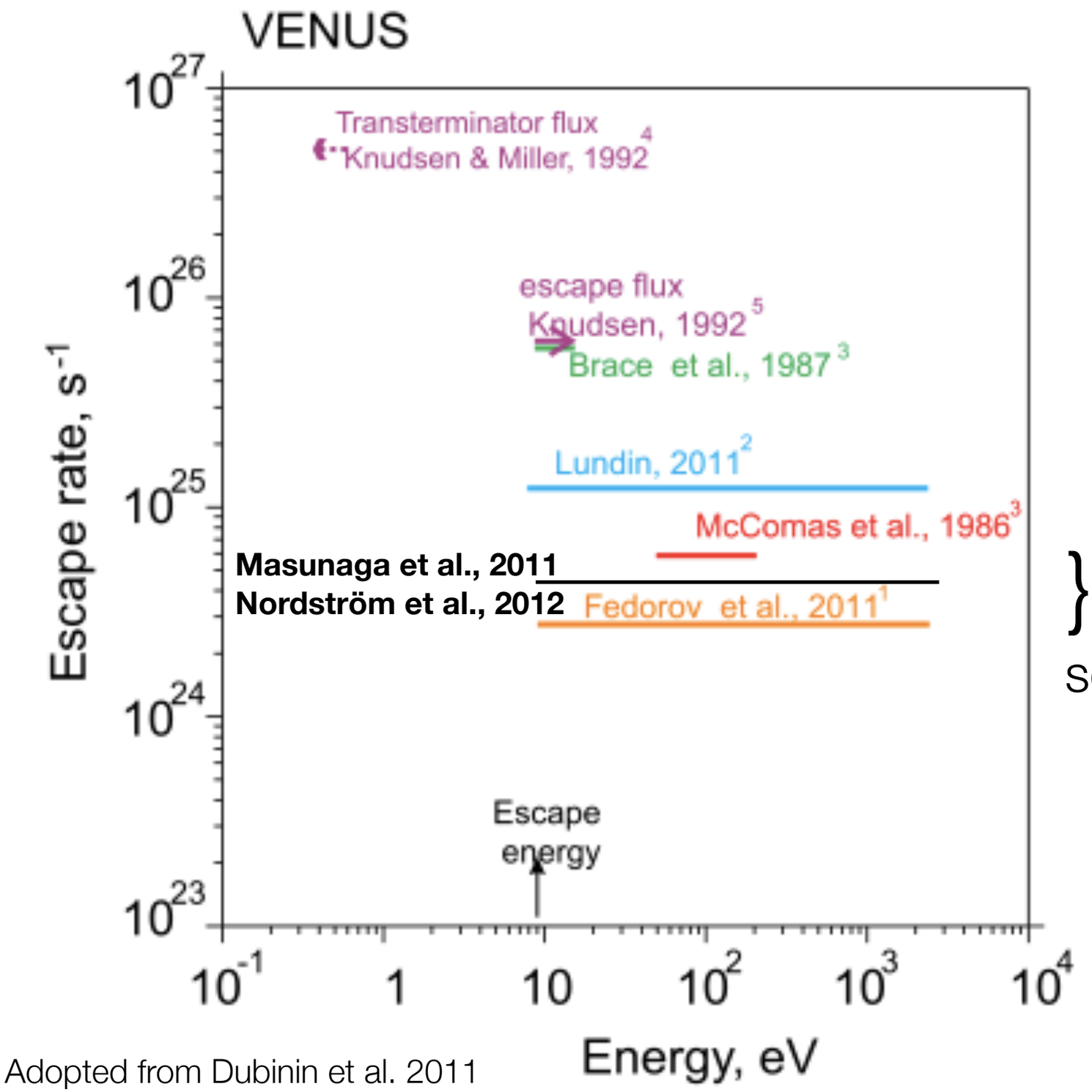
He++

Venus loses water!

Ongoing work: Dependence on Solar activity

Barabash et al. 2007

Science 1: Outflow flux

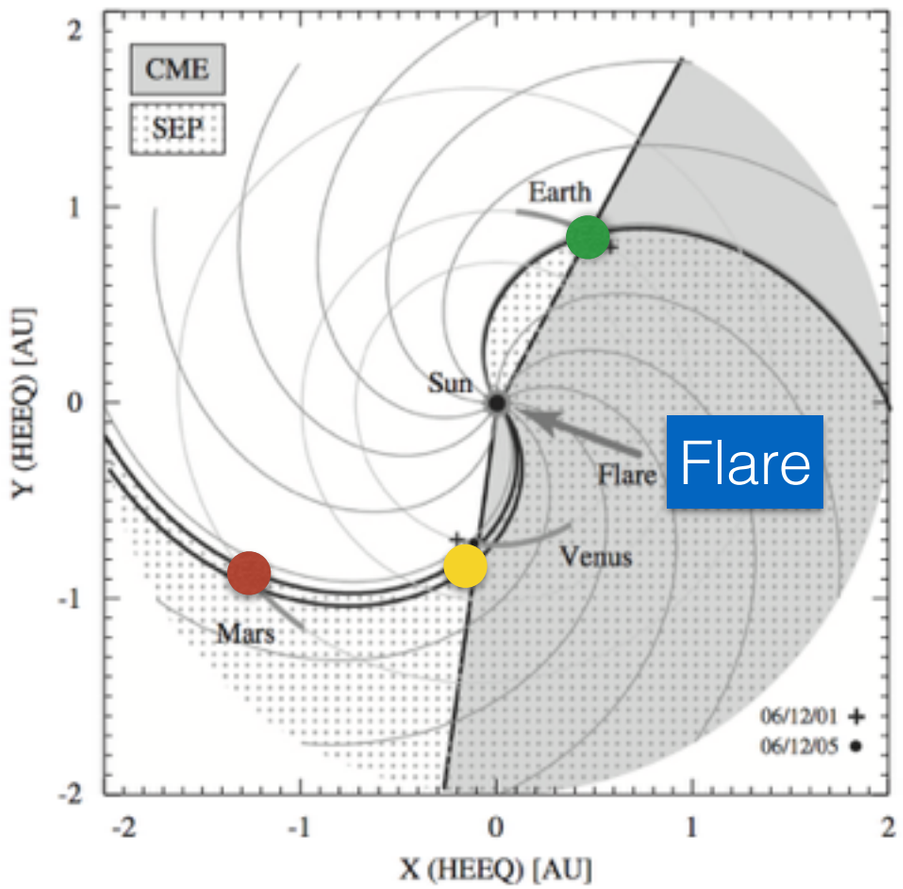
- 

} 3-6 x 10^{24} /s at solar minimum

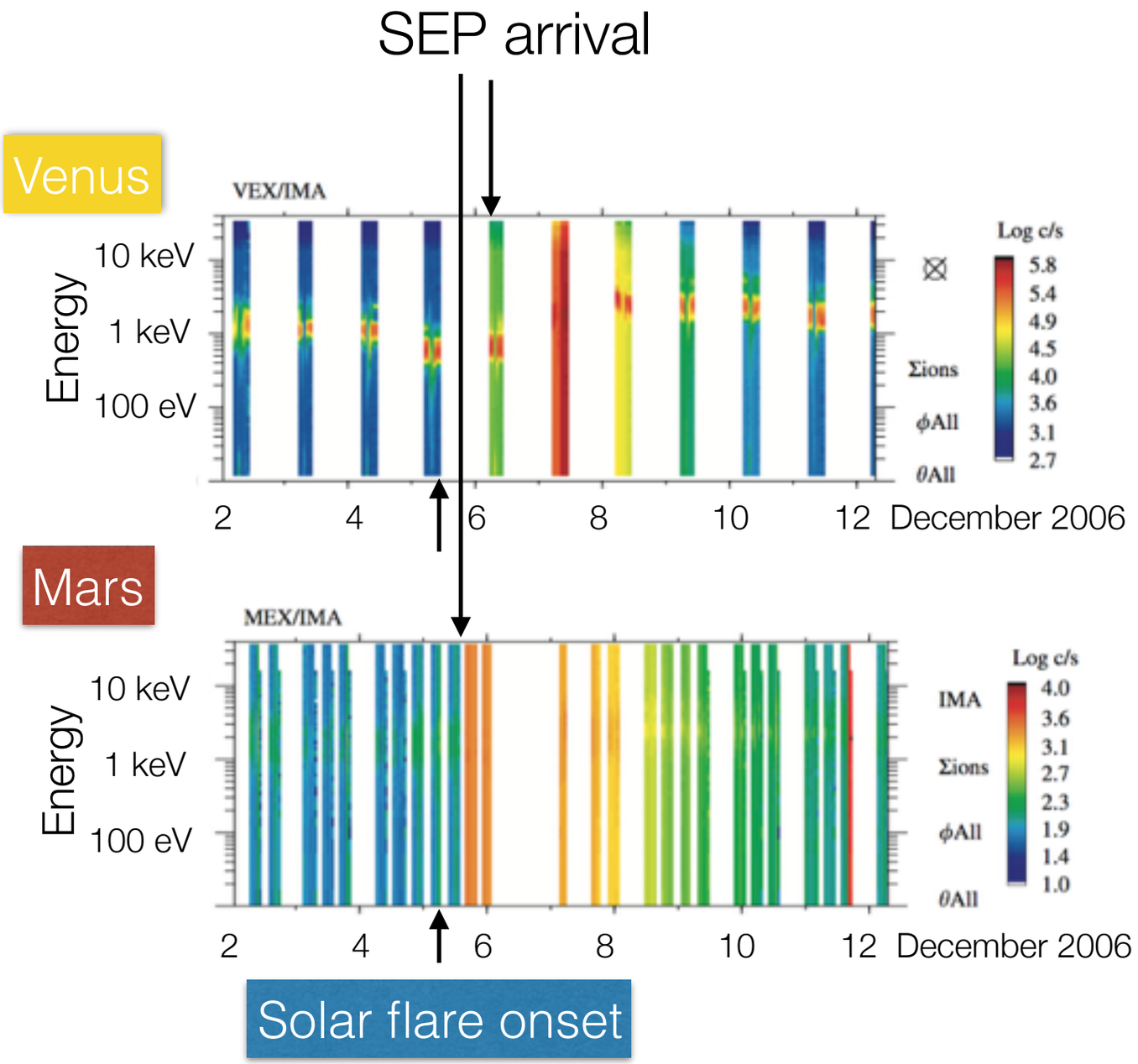
Adopted from Dubinin et al. 2011

Ongoing work: Comparative aspect

Science 2: Space weather impact

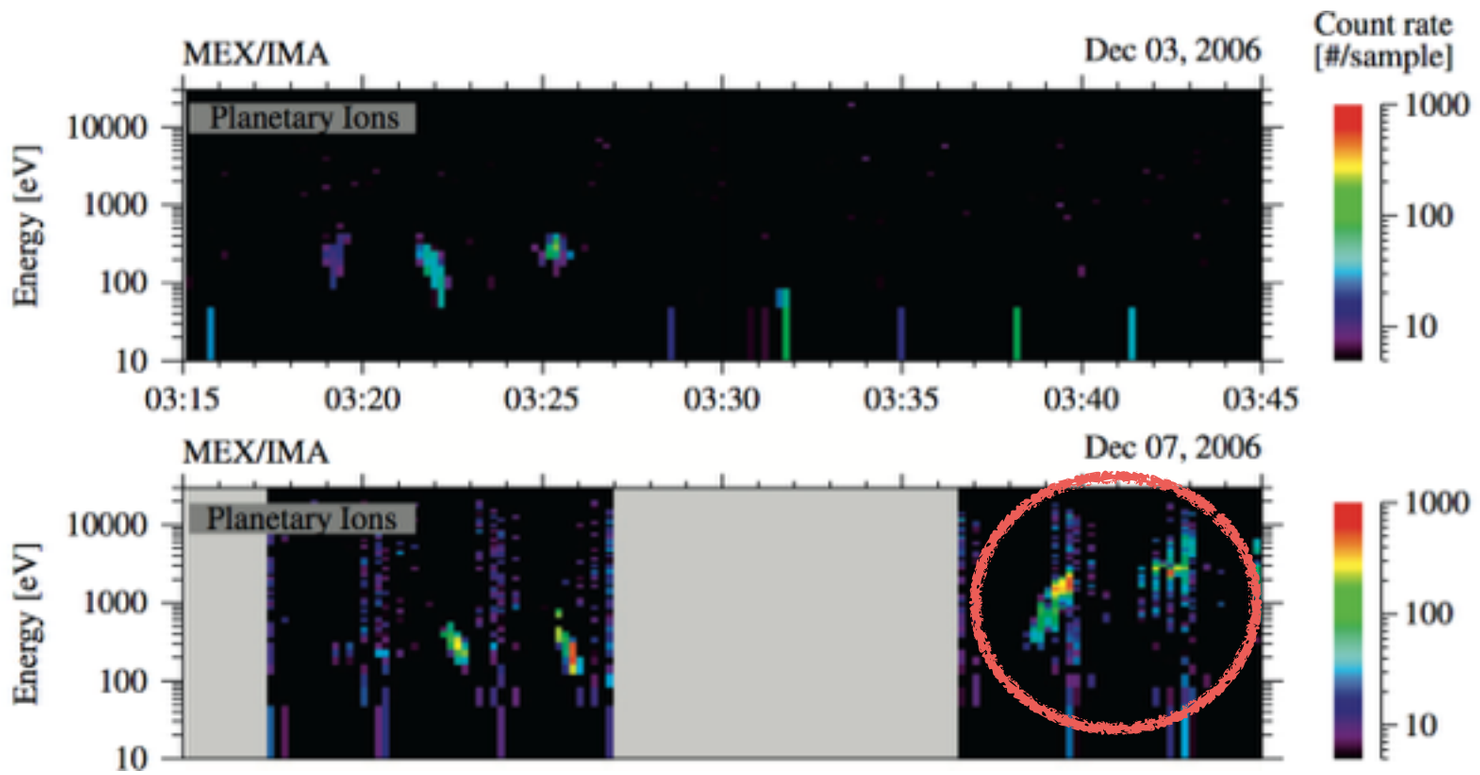


Flare



Futaana et al. 2008

Science 2: Space Weather impact (Mars)

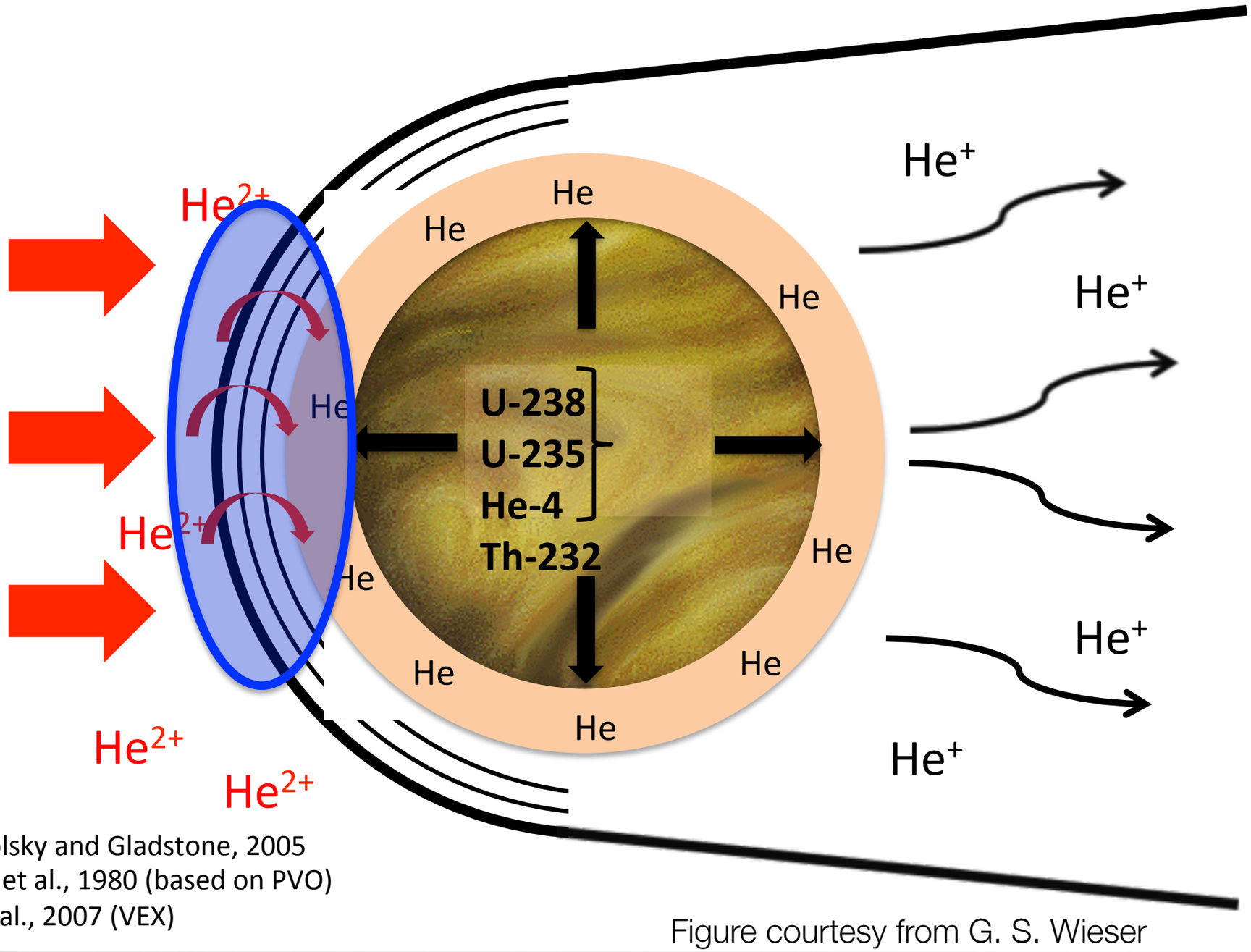


- "Storm" enhanced escaping flux by >10x (clearly seen at Mars)
- *Further investigations*
  - *Mars comparison (MEX, MAVEN). Aurora. Nightglow...*

Science 3: Helium balance

Pre-ASPERA-4 knowledge: product < escape

Pre-ASPERA-4 Hypothesis: product + input ~ escape



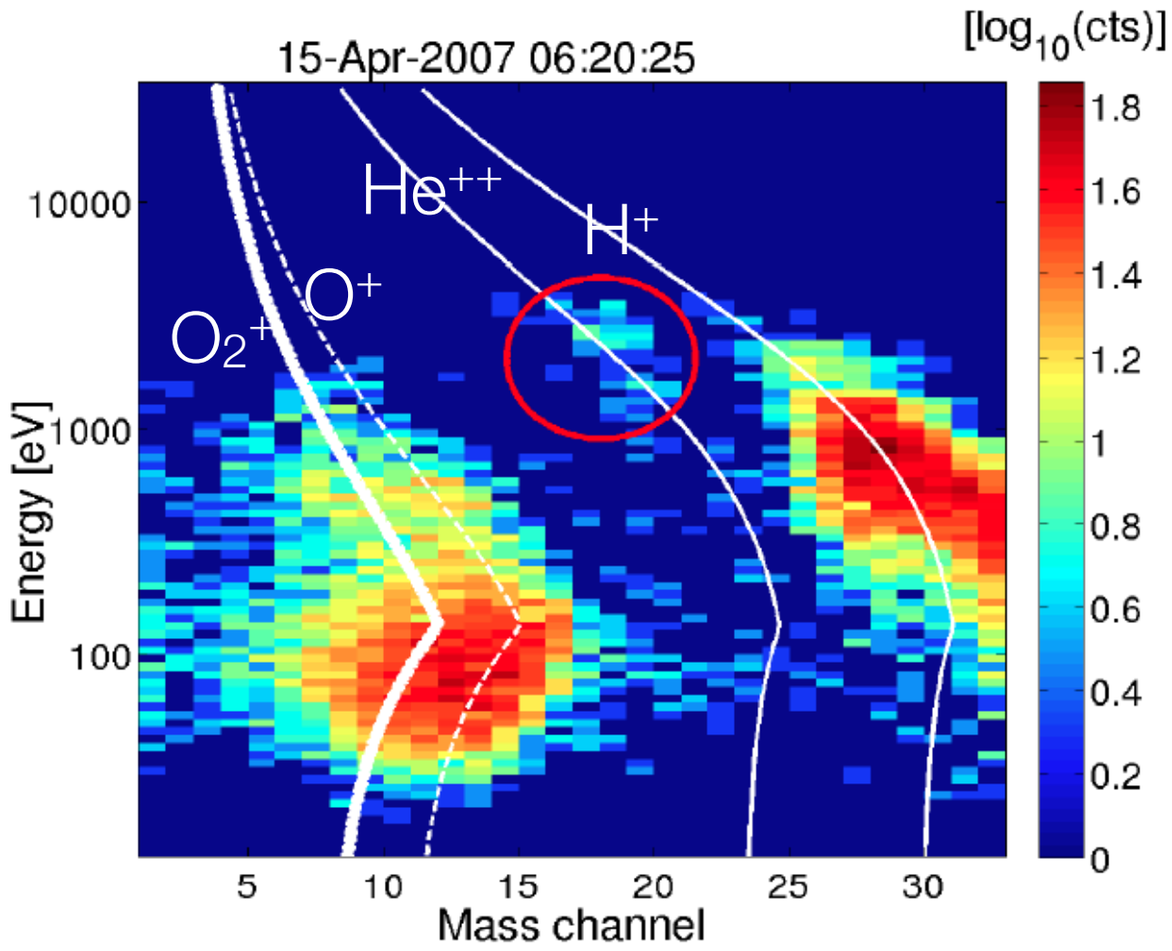
Krasnopolsky and Gladstone, 2005
Gombosi et al., 1980 (based on PVO)
Zhang et al., 2007 (VEX)

Figure courtesy from G. S. Wieser

Science 3: He^{++} observations

Pre-ASPERA-4 knowledge: product < escape

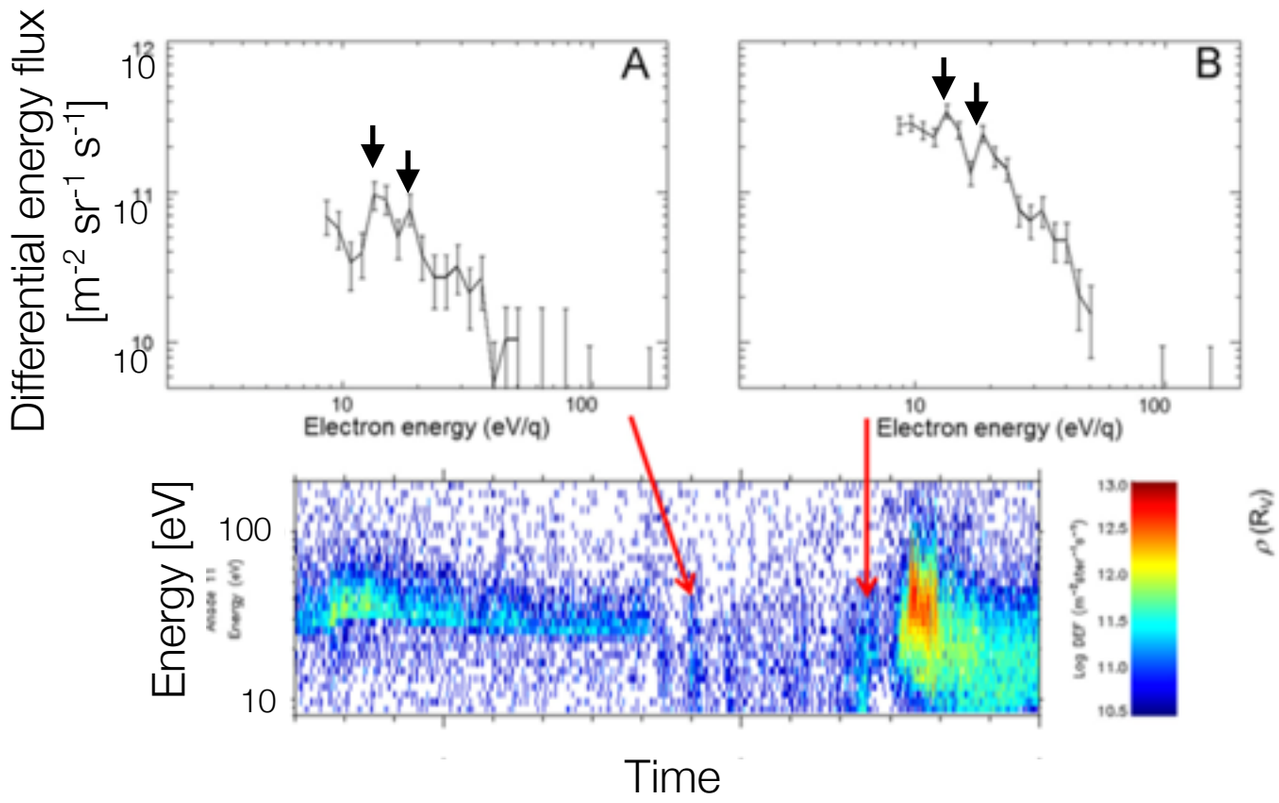
Post-ASPERA-4 knowledge: product + input < escape



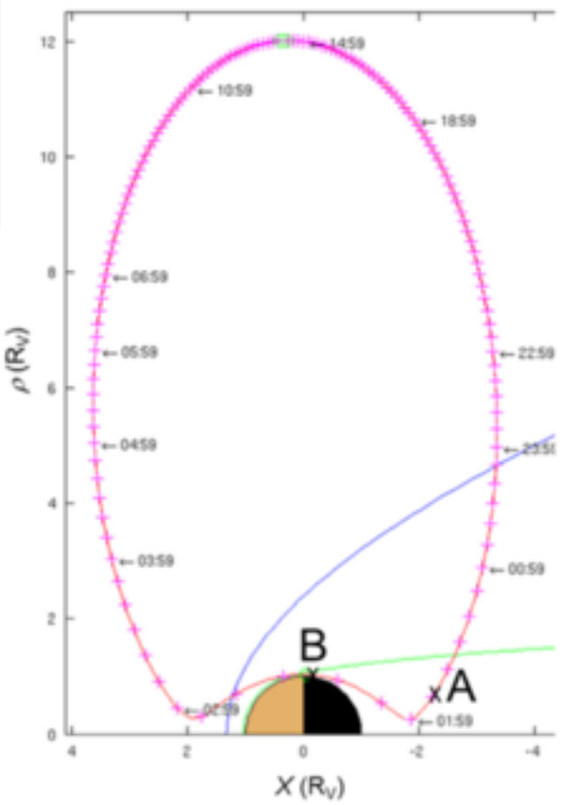
Stenberg et al., 2015

- Yet unaccountable balance by SW precipitation (solar min)
  - The average net inflow: **~10^{21} s^{-1}** (Stenberg et al., 2015)
  - The escape of He+: **8x10^{22} s^{-1}** (Fedorov et al., 2011)

Science 4: Photoelectrons



Coates et al., 2015

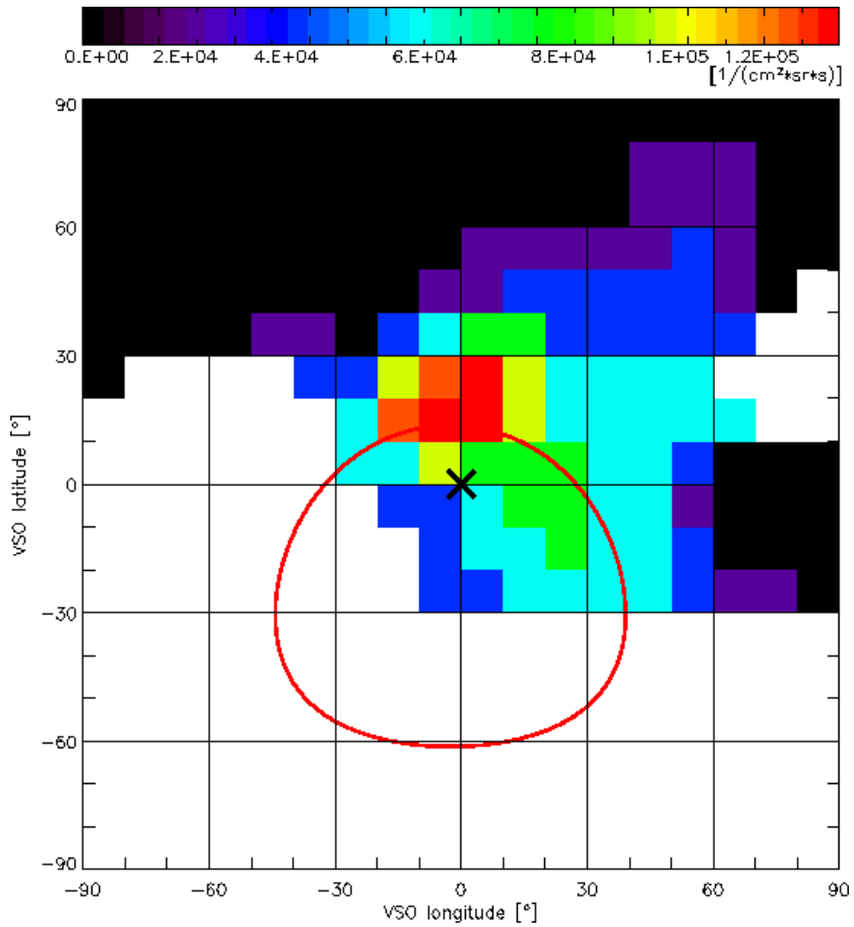


- Photoelectrons present in the shadow
- Estimated loss of atmosphere ~2.2x10^{23} [/s]

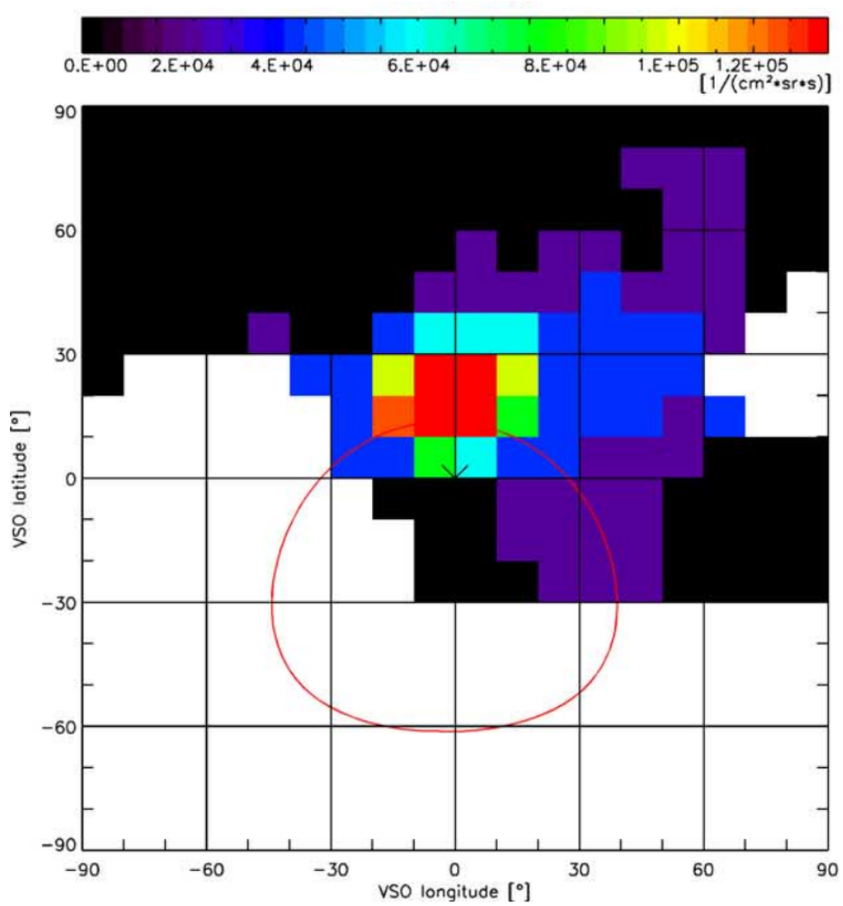
Science 5: Energetic Neutral Atoms

- First ENA images of Venus ever.
  - The observed tailward flow of hydrogen ENA is magnetosheath plasma neutralized by exosphere (but assuming less dense than expected)
- ENA for diagnosing exosphere sounding
- No Oxygen ENA found

ASPERA-4/NPD observation (2006)



Model (VIRA + MHD)



Galli et al., 2008

Summary

- **Mission completed – Science forever**

- ASPERA-4, the IRF (Kiruna) led instrument has achieved many high-impact scientific results to the field of Venus plasma environment.

- The efforts of producing scientific results are continuing.

- We would like to appreciate all the community who has supported the mission and the instrument; all the scientists and engineers, Swedish National Space Board, ESA, and industry!