Escape and precipitation rates at Venus

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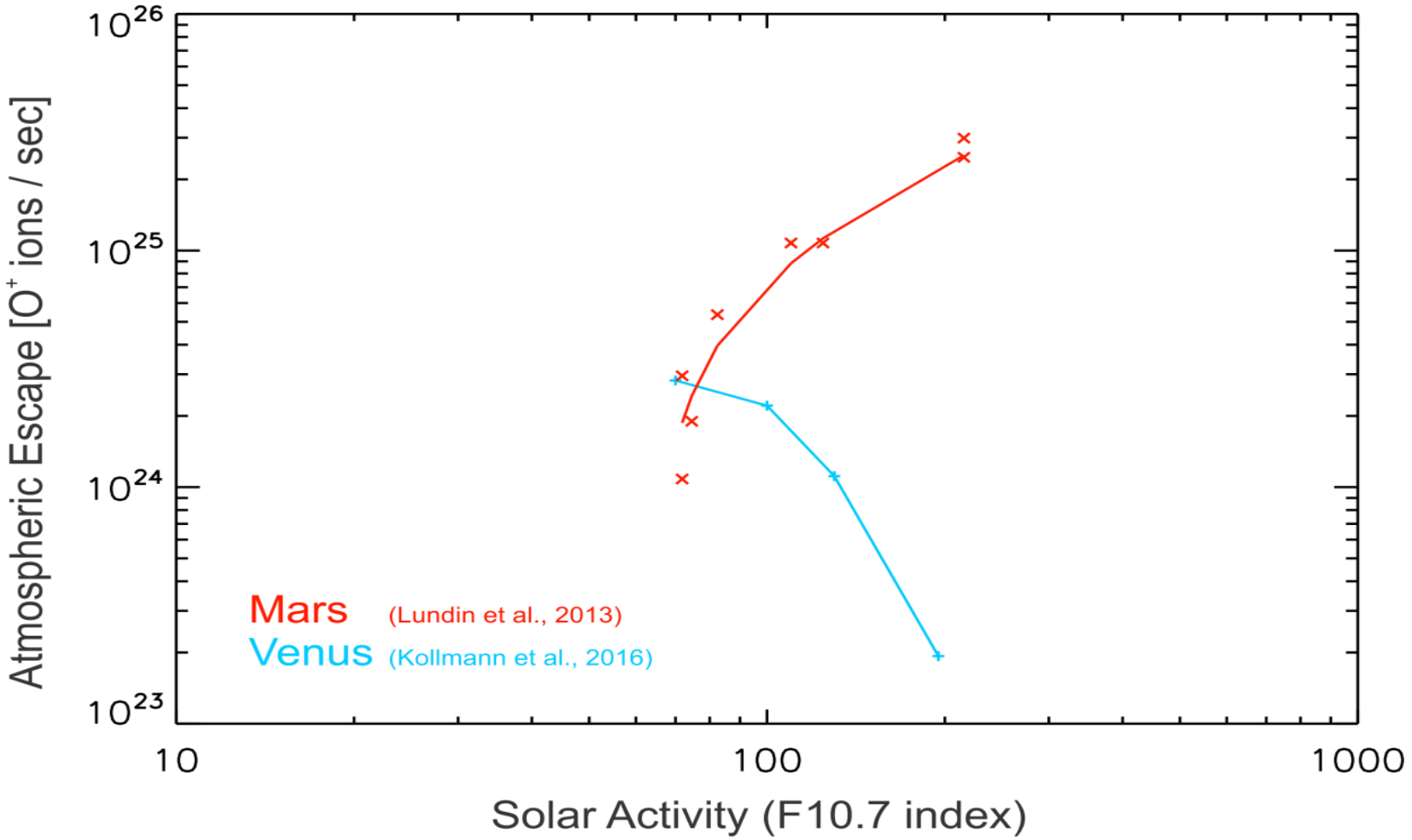
Context: Average escape rates

		H^+ (s^{-1})	O^+ (s^{-1})	O_2^+ (s^{-1})	CO_2^+ (s^{-1})	Total (kg/s)
Mars	**Lundin+1990** Phobos	-	~$30x10^{24}$	-	-	**0.8**
	Barabash+2007 MEX 2004-2006	-	$0.2x10^{24}$	$0.2x10^{24}$	$8x10^{22}$	**0.02**
	Jakoski+2017 MAVEN	-	-	-	-	**0.1**
	Lundin+2011 VEX 2006-2009	$39x10^{24}$	$12x10^{24}$	-	-	**0.38**
Venus	**Nordström+2013** VEX 2006-2009	$14x10^{24}$	$5.2x10^{24}$	-	-	**0.16**
	Kollmann+2016 VEX 2006-2014	-	$2.0x10^{24}$	-	-	**0.05**
Earth	**Yau+1988**	-	$72x10^{24}$	-	-	**1.8**
	Seki+2001	-	$5x10^{24}$	-	-	**0.1**
	Borovsky+2008	$\leq 2x10^{26}$	~$10x10^{24}$	-	-	**~0.5**

Even the role of a magnetic field is unclear.

Open question



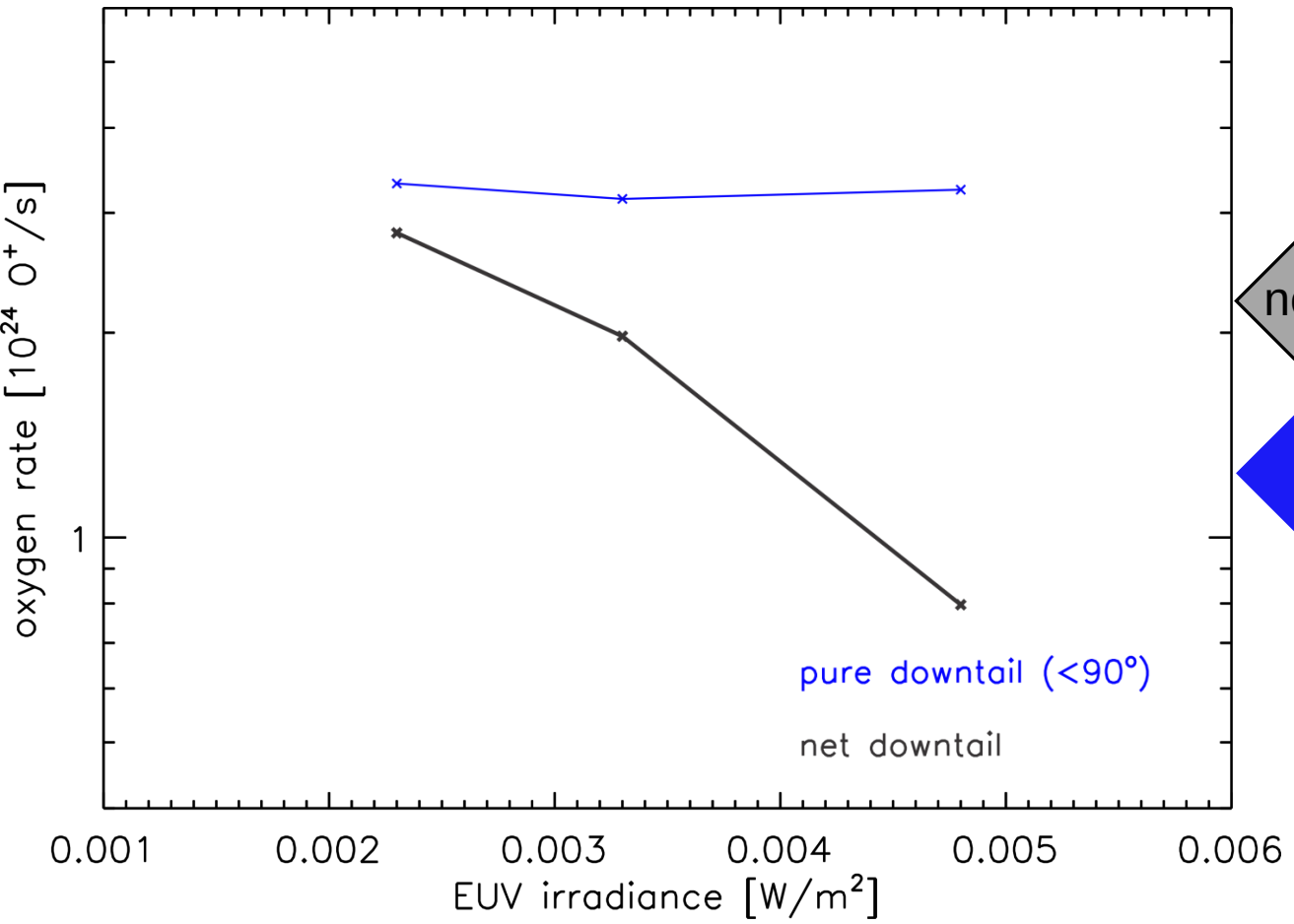
- Venus and Mars scale oppositely.
- Escape rates change by factor of a few.

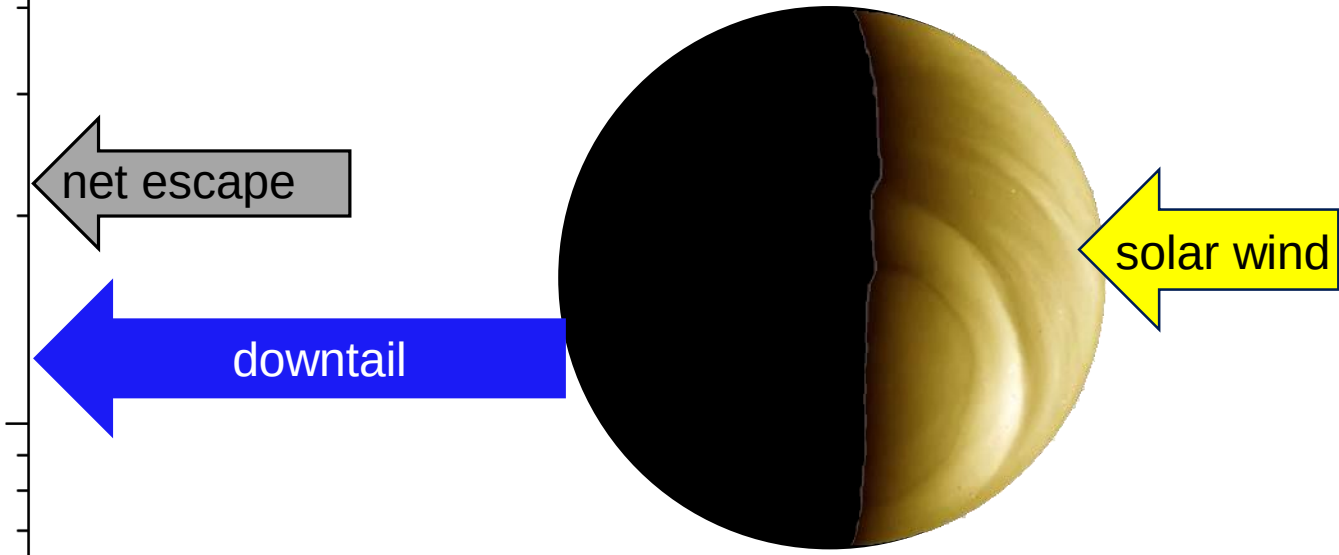
Outline

- Venus escape rate components.
- Venus return flows:
  Properties and possible drivers.
- Venus and Mars comparison.

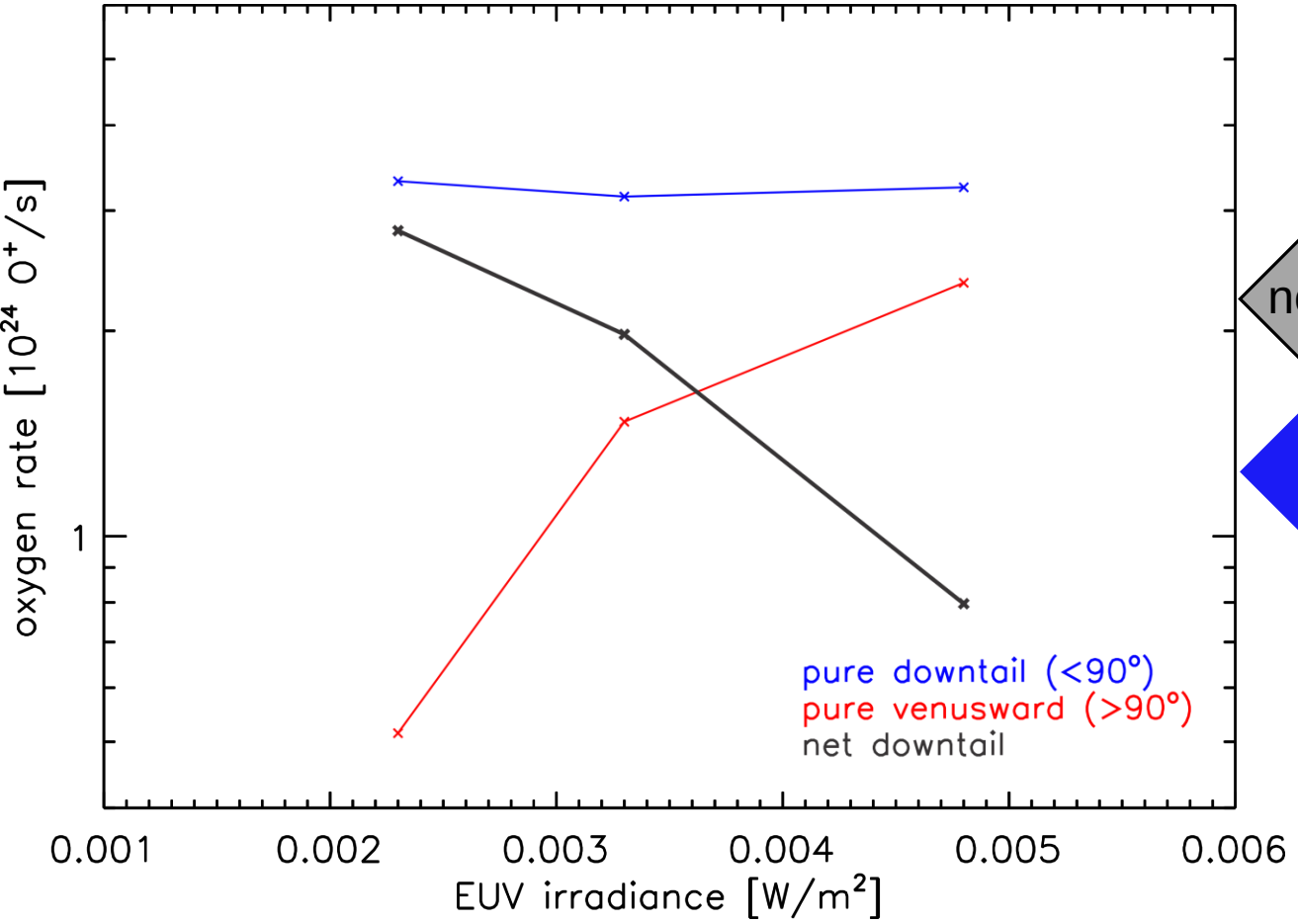
Data from Venus Express / ASPERA-4 / IMA instrument (Barabash et al, 2007).

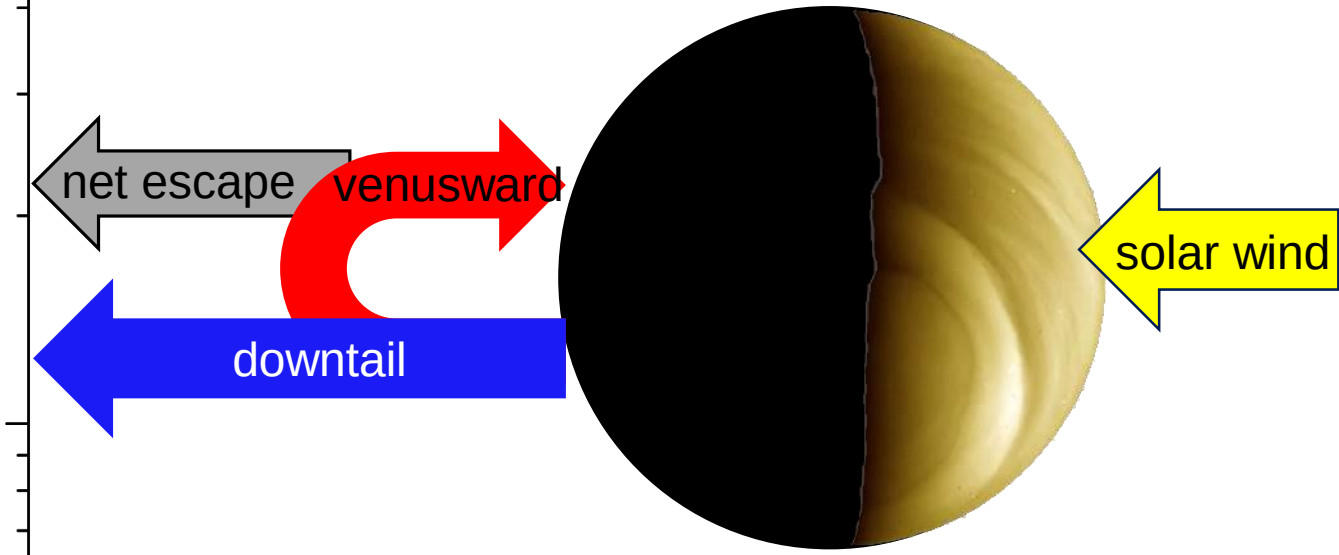
Flow components





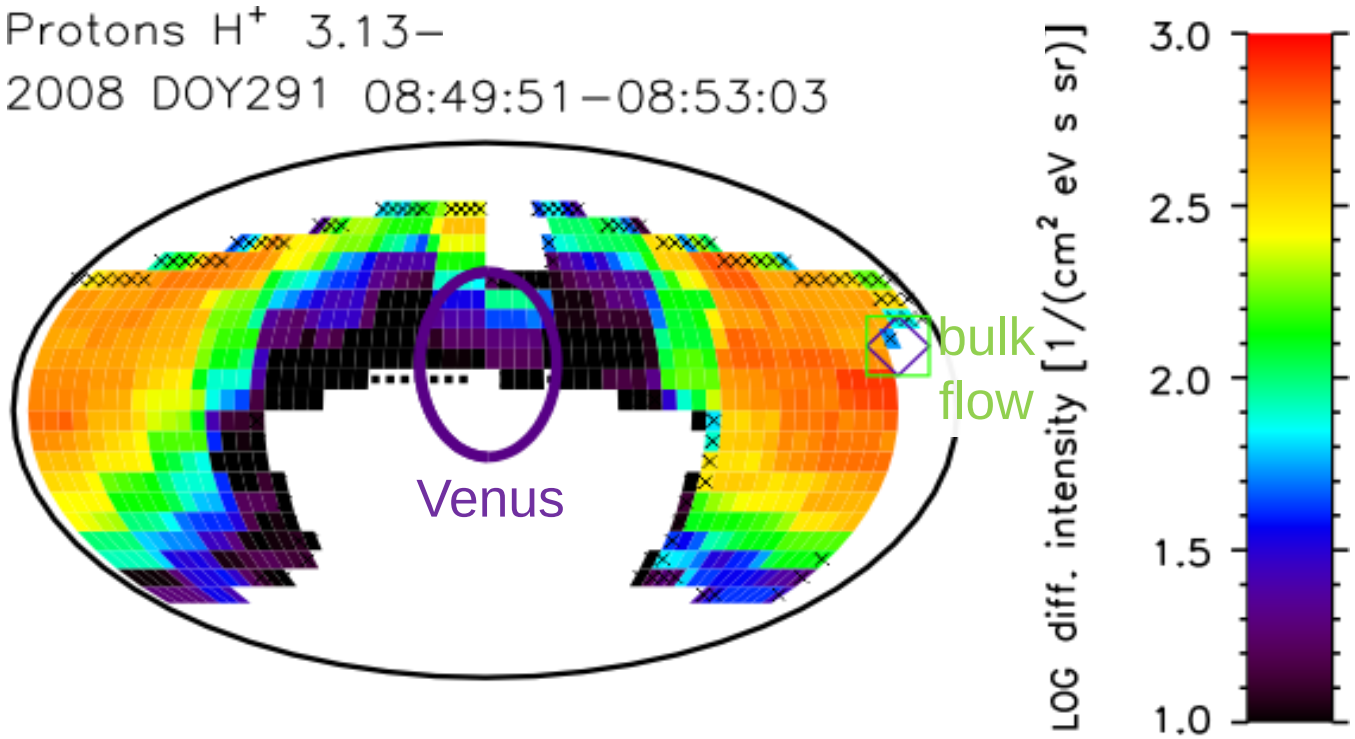
Flow components

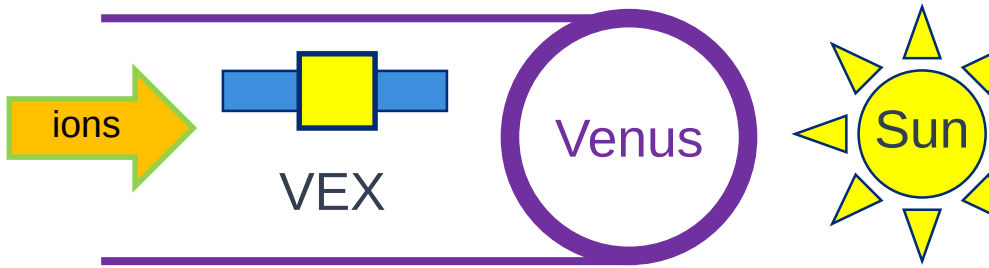




Flow components

Venusward flows

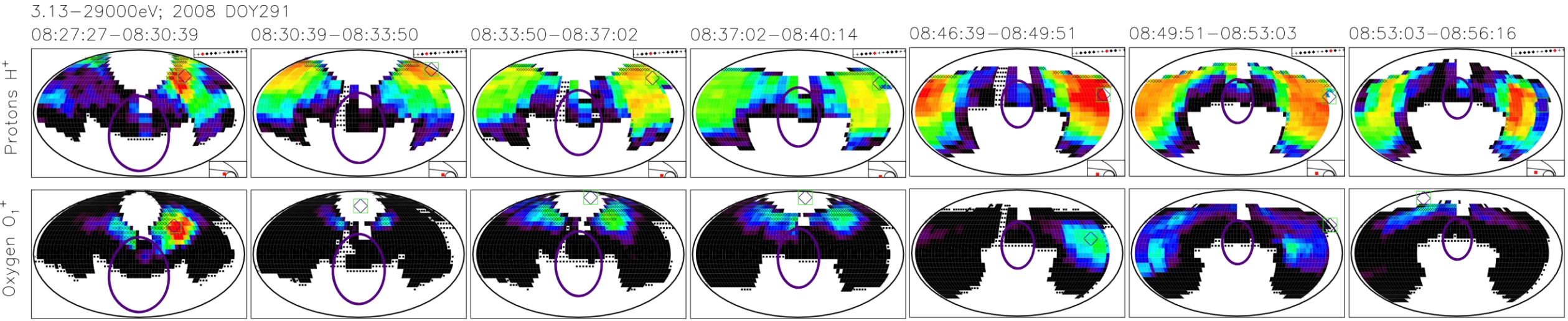




Skymap of >3eV intensity

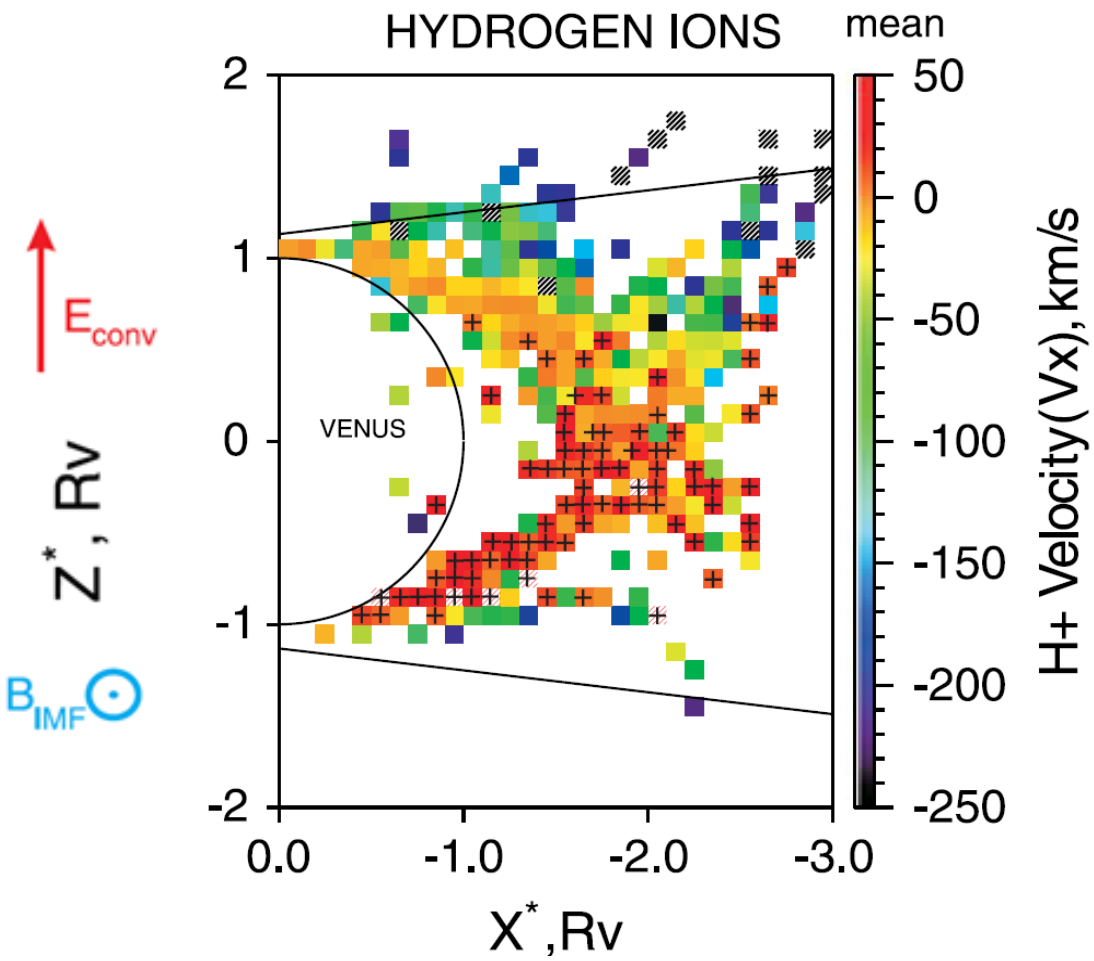
Kollmann et al., 2016

Venusward return flows



- Venusward flows here during 70% of this magnetotail crossing.
- Protons and oxygen flows not aligned.

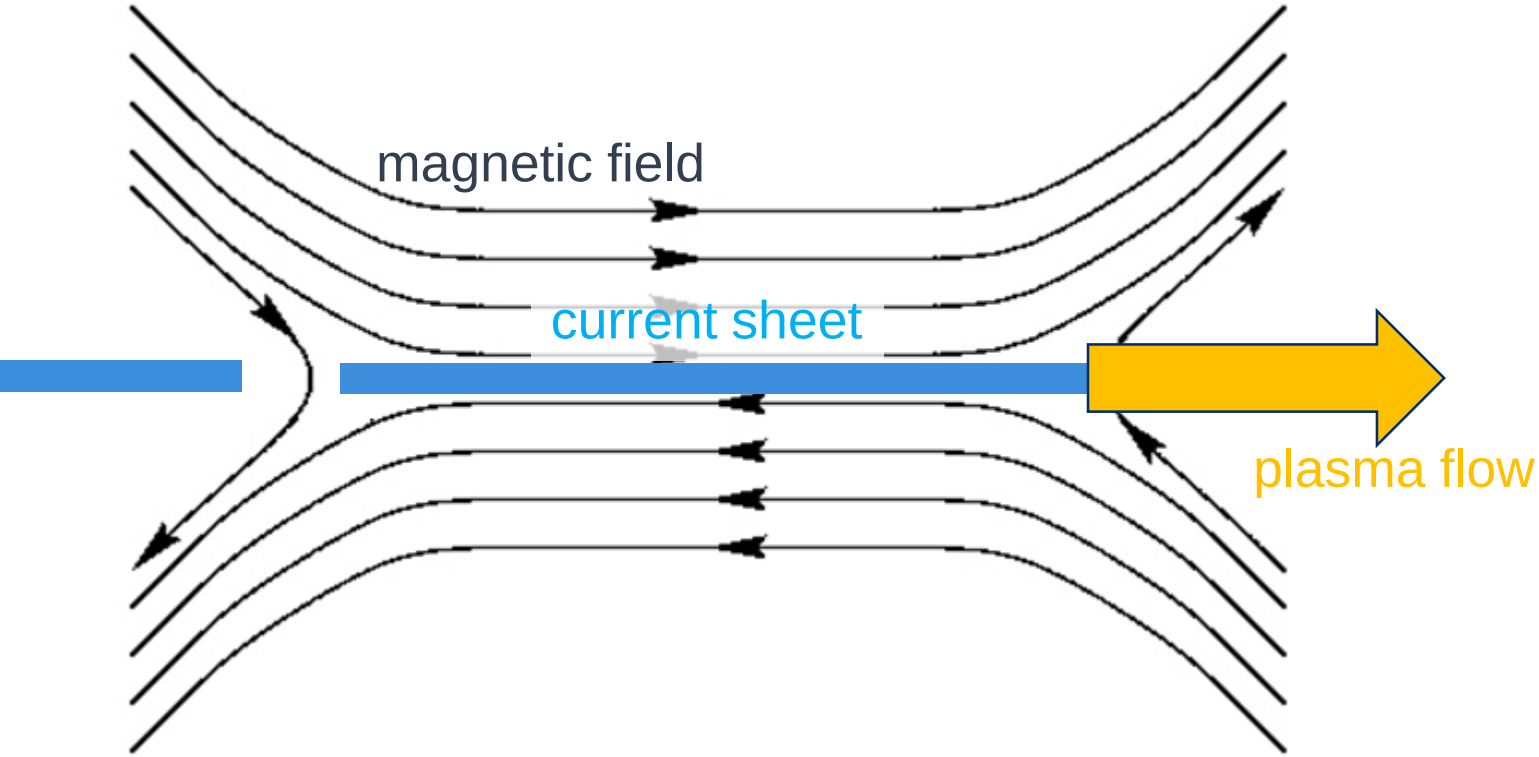
Venusward return flows



Venusward flows mostly in –zVSE hemisphere.
→ Organize with IMF field

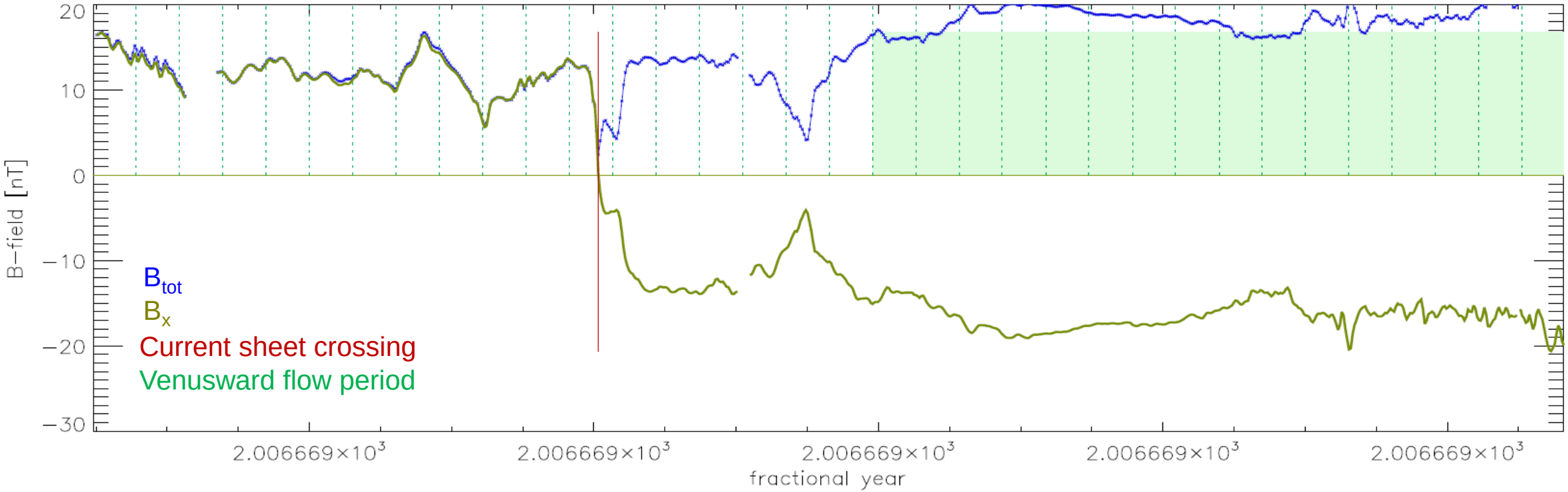
Dubinin et al., 2013

Physical driver: Reconnection?



If venusward flows from reconnection, then should
occur near the tail current sheet and/or correlate with sheet flapping.

Physical driver: Reconnection? No.



If venusward flows from reconnection, then should
occur near the tail current sheet and/or correlate with sheet flapping.
However, **we do not find correlations**, for example:
30% venusward flows occur during orbits with single current sheet crossing.
Probability for VEX seeing one sheet crossing is always 30%.

Physical driver: Gravity? No.

Gravity dominates

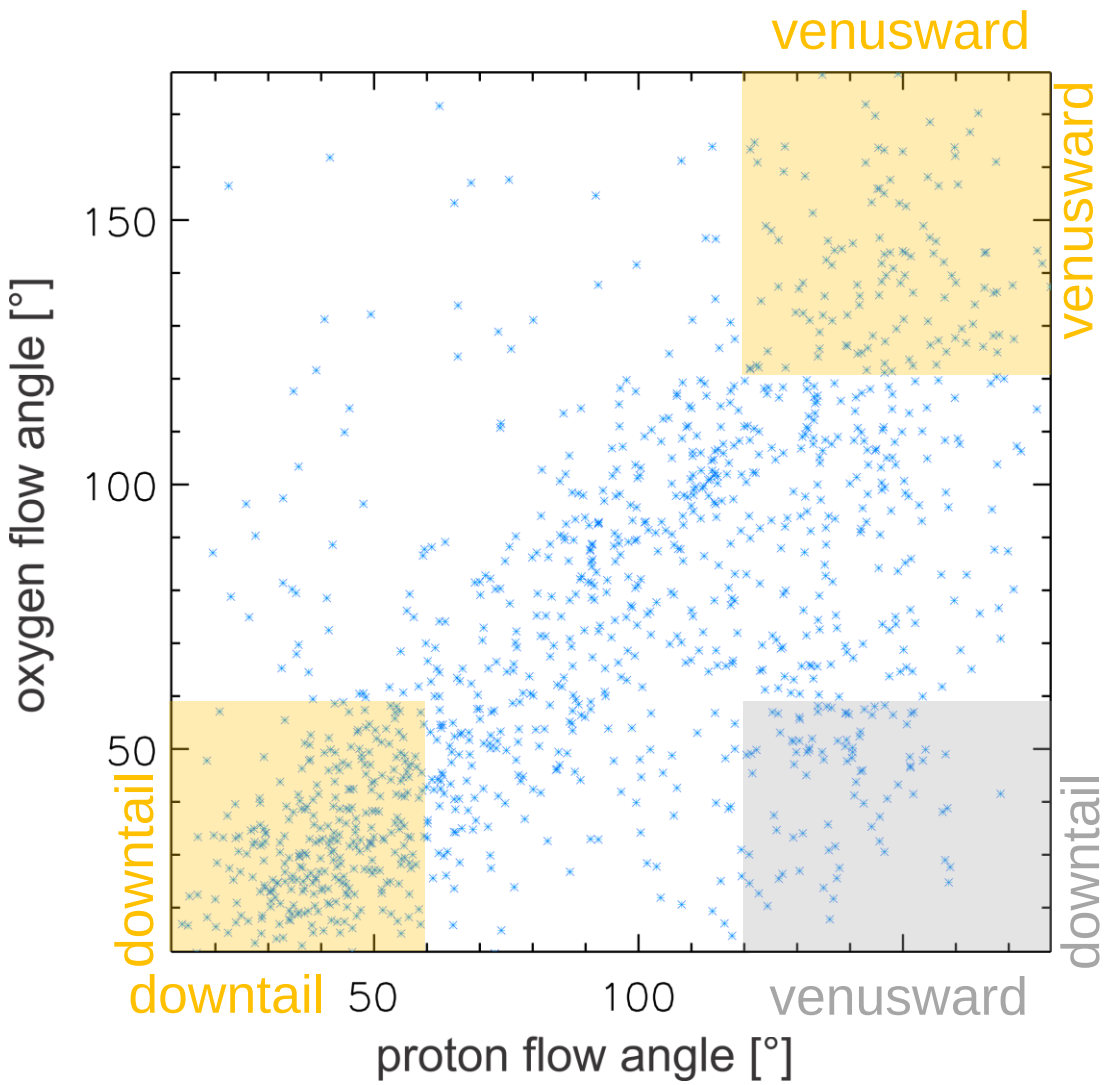
$$a_{tot} = \frac{GM}{r^2}$$

Acceleration a_{tot} independent on ion mass m.

Gravity competes with charge (q) dependent force

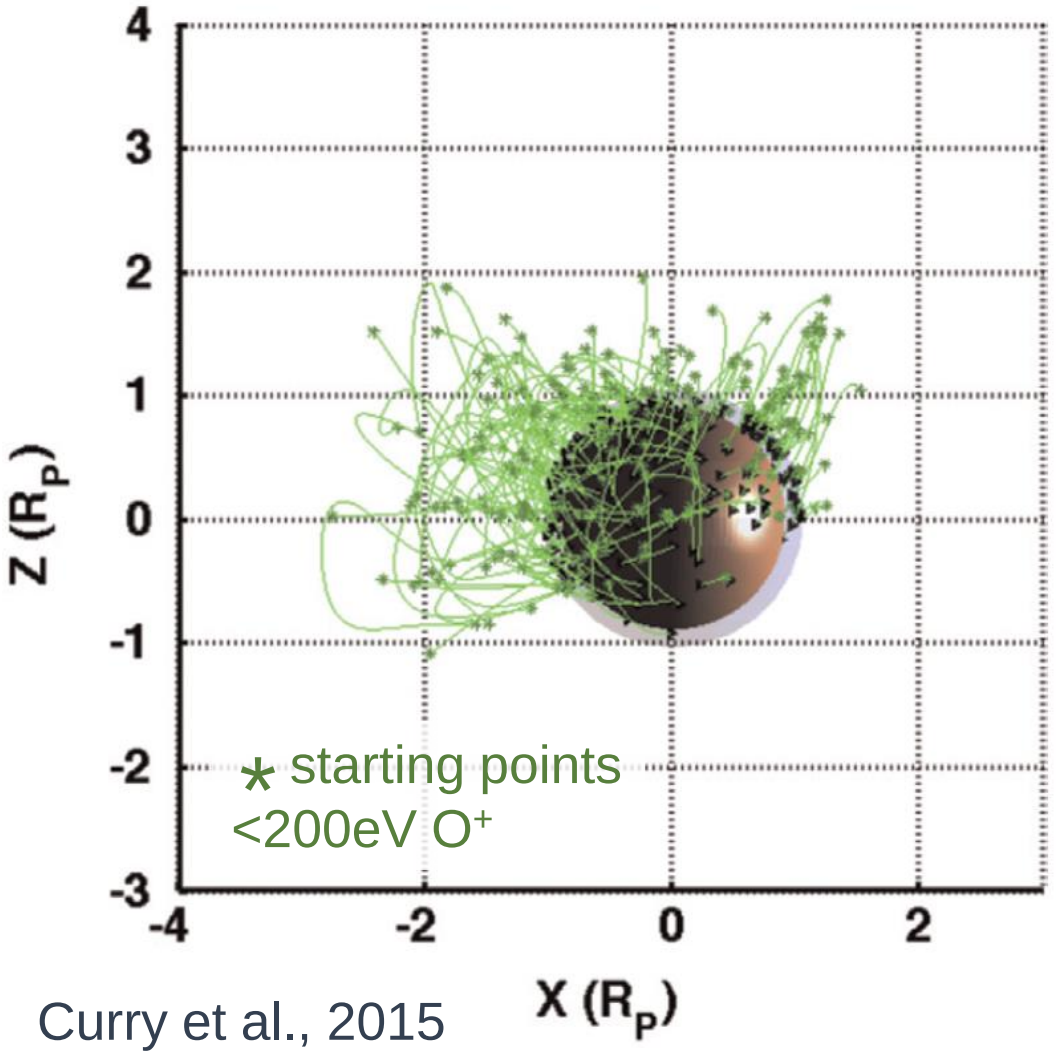
$$ma_{tot} = \frac{GmM}{r^2} - q(E + vB)$$

Large-m ions return faster.

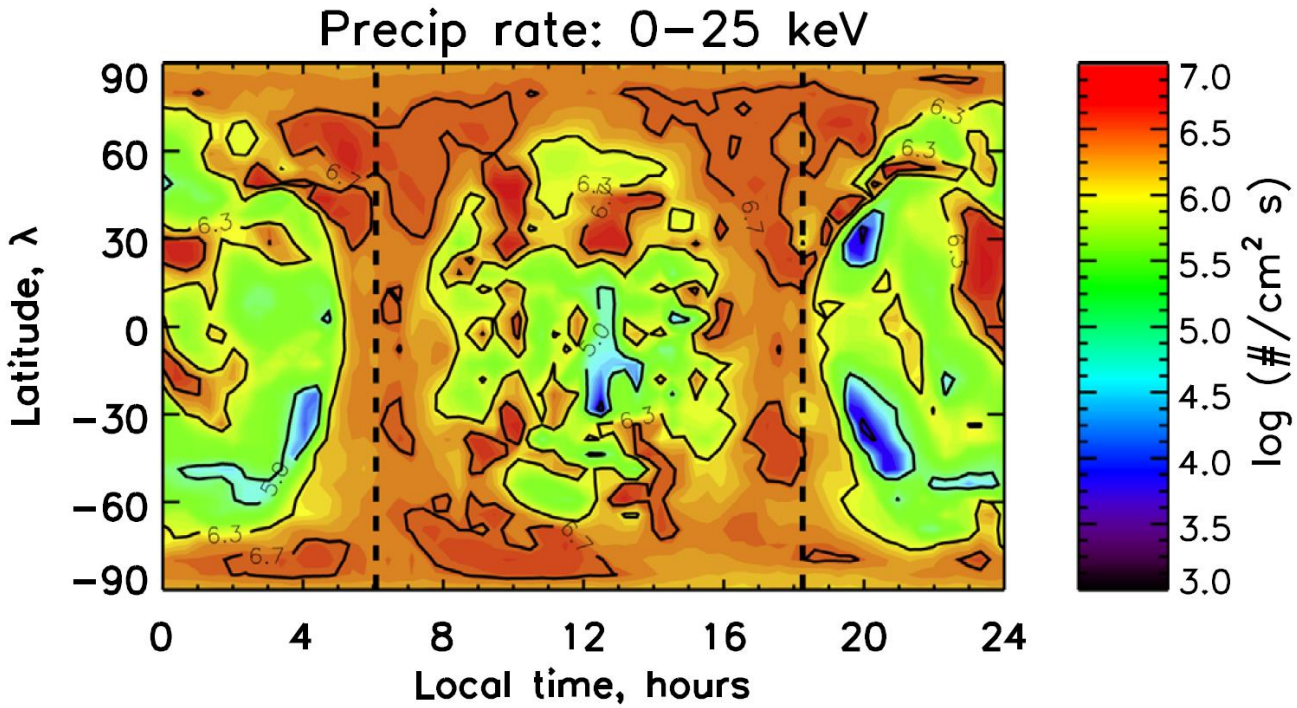


small-m protons return to Venus
1.7 times more often than oxygen

Physical driver: Full trajectories? Yes?



Curry et al., 2015

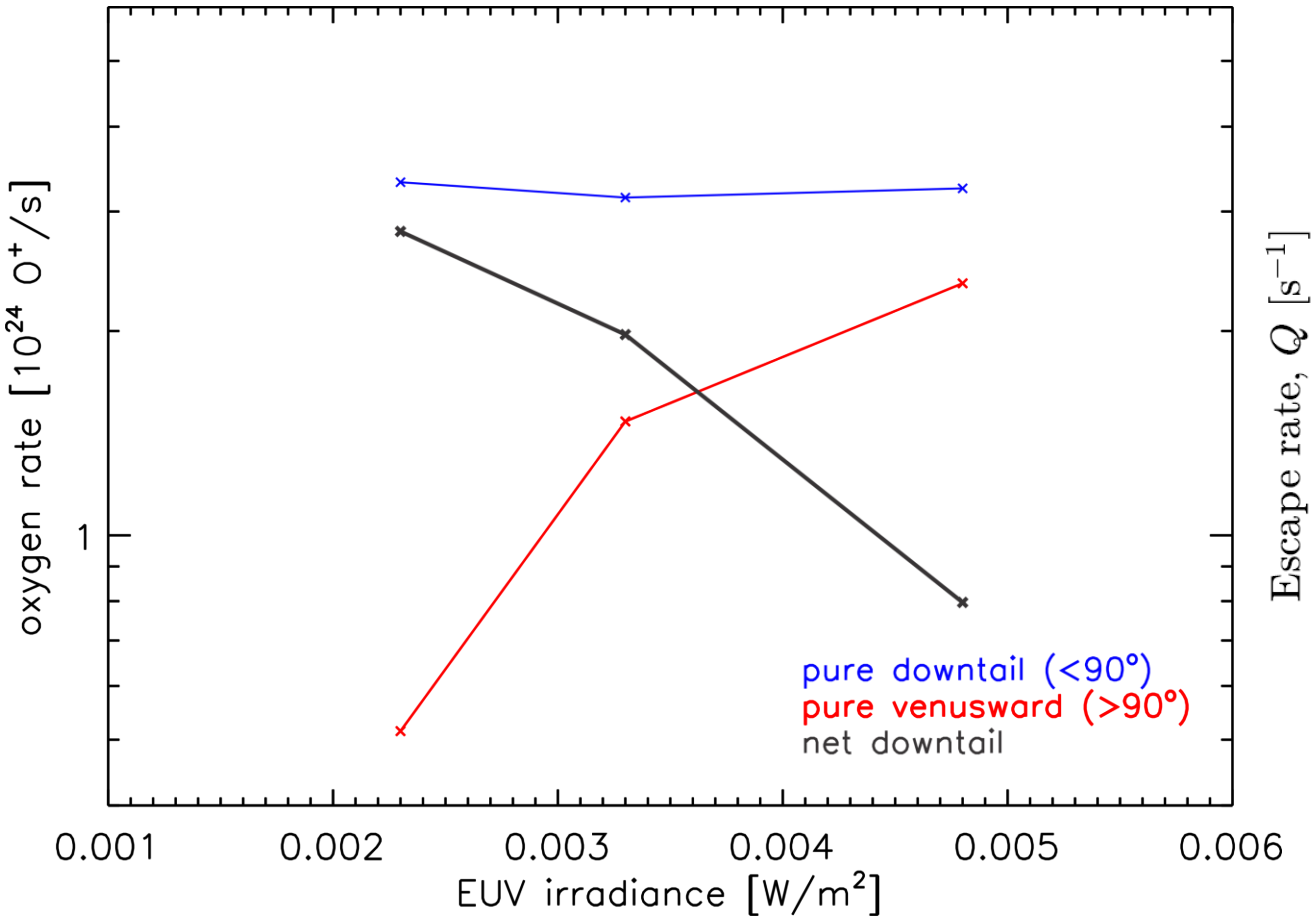


- Modeled precipitation flux similar observed linear average flux.

Curry et al., 2015; Luhmann et al. 1991

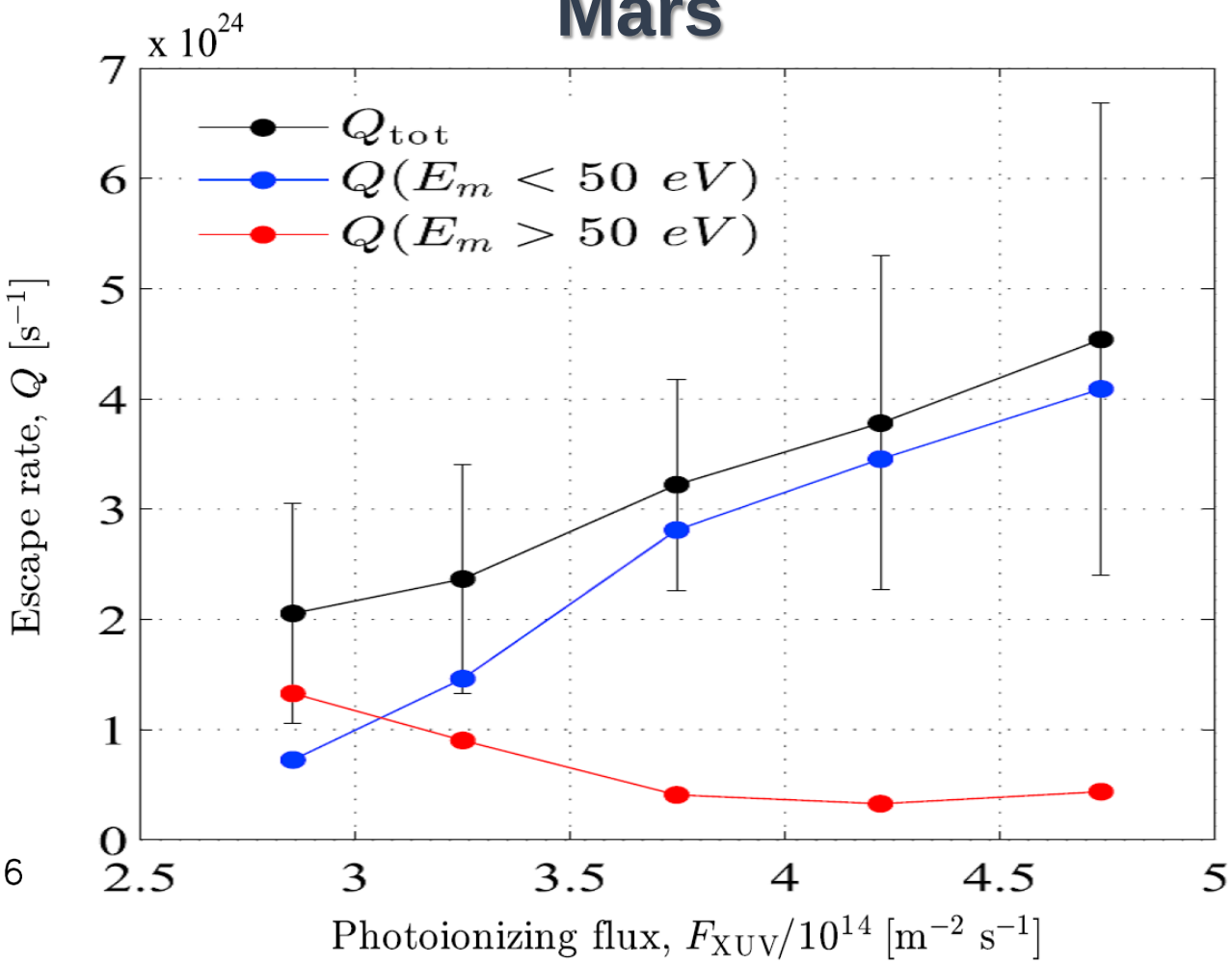
Venus vs. Mars: Rates

Venus



Kollmann et al., 2016

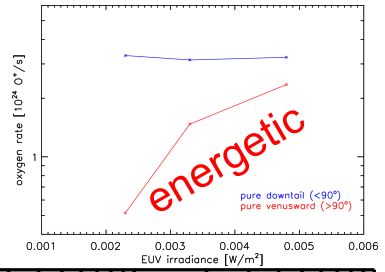
Mars

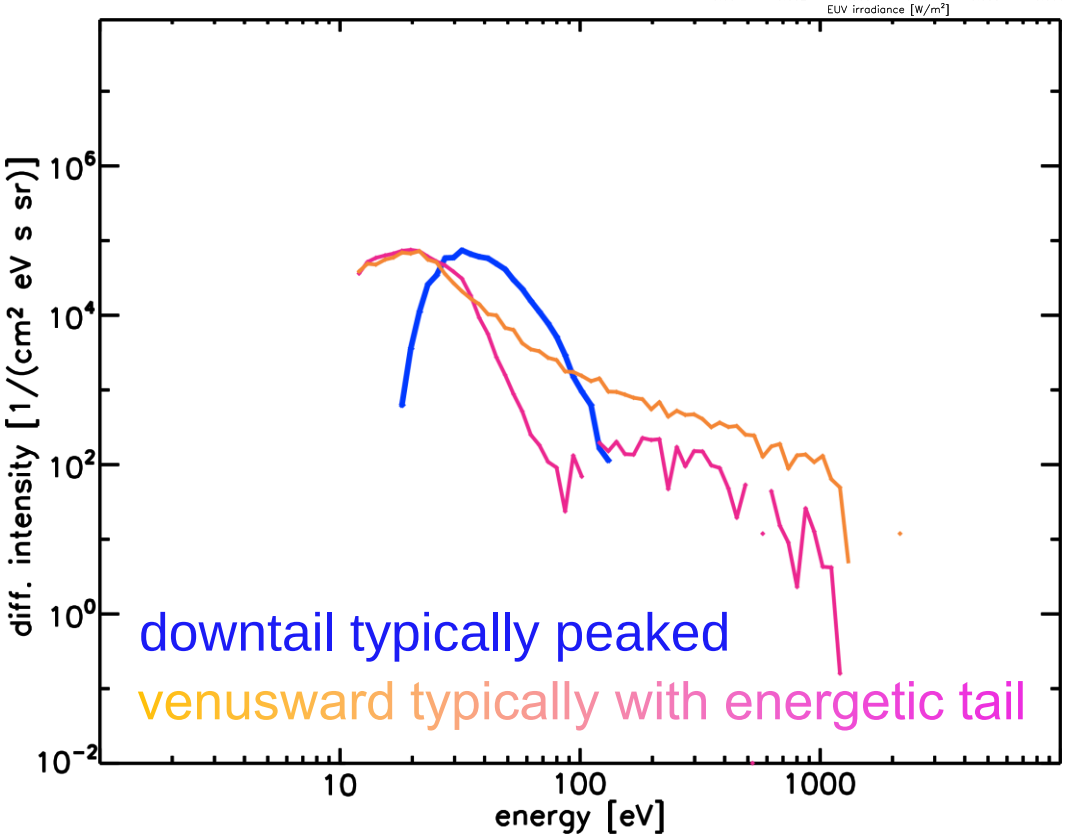


Ramstad et al., 2017

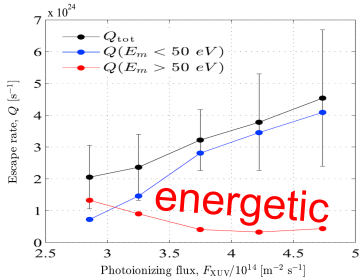
Venus vs. Mars: Spectra

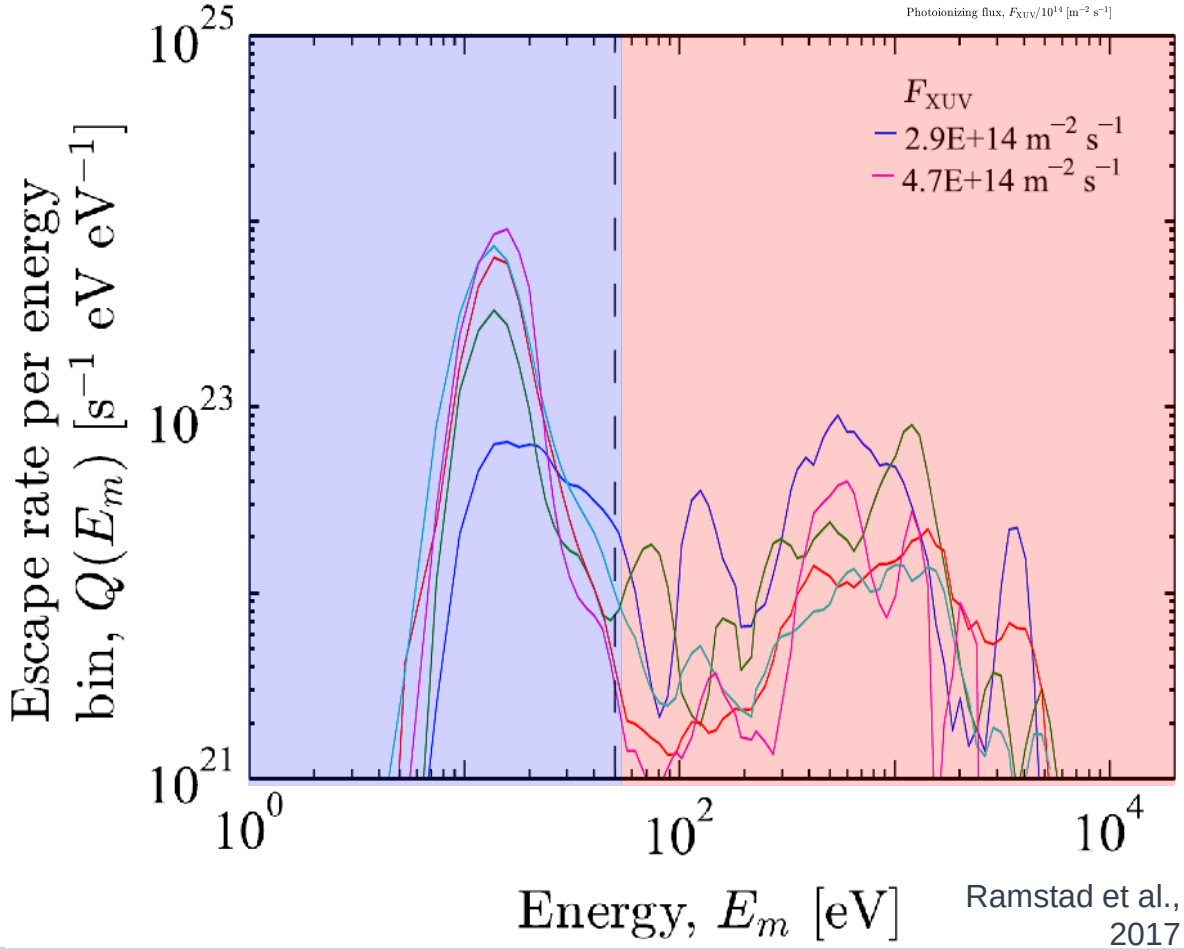
Venus





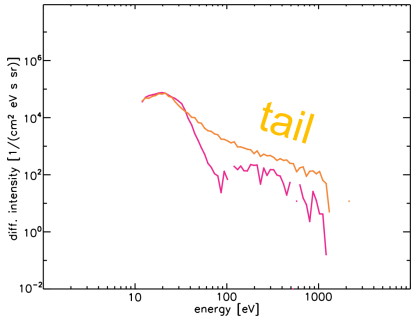
Mars



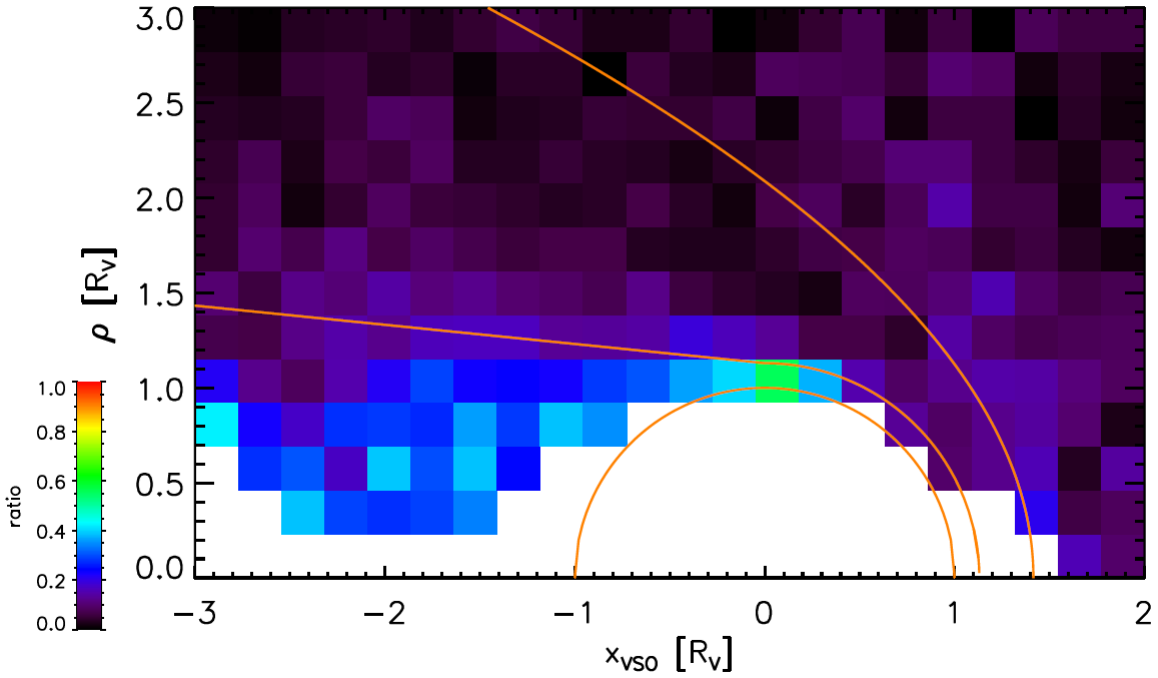


Ramstad et al., 2017

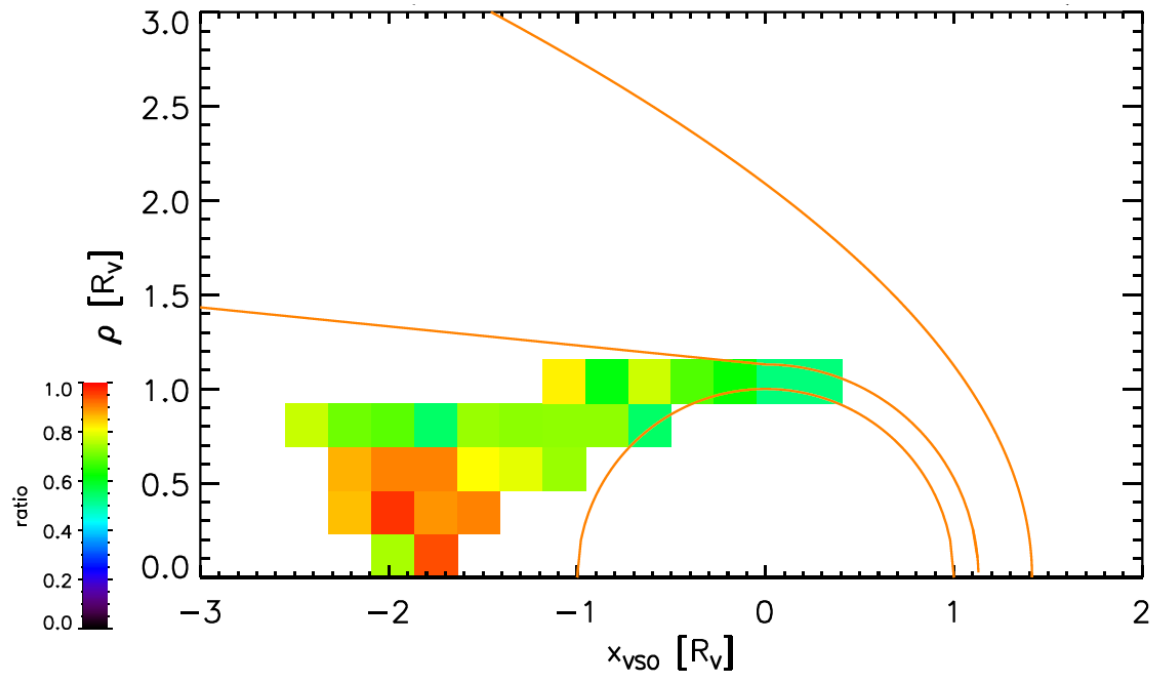
High-energy tail spectra



downtail



venusward

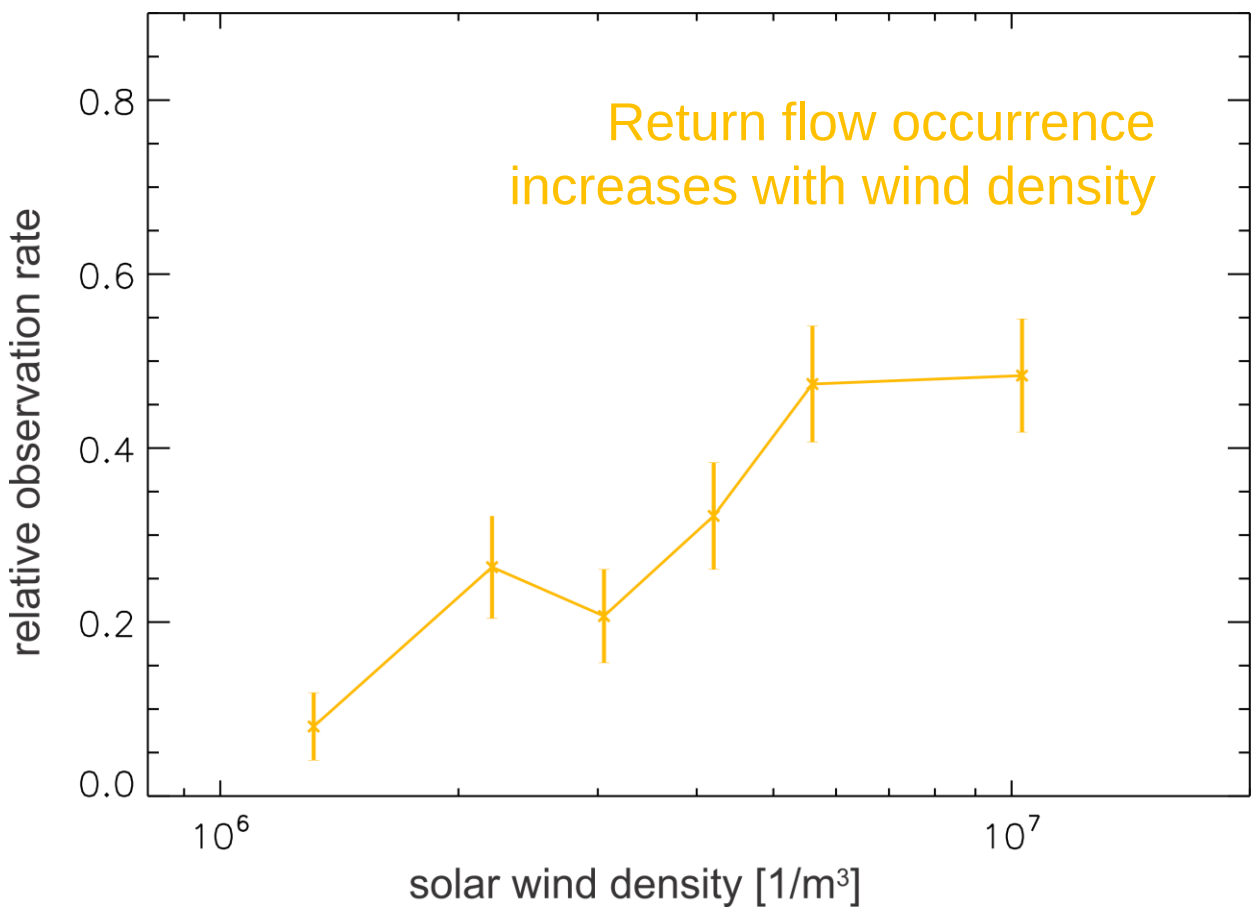


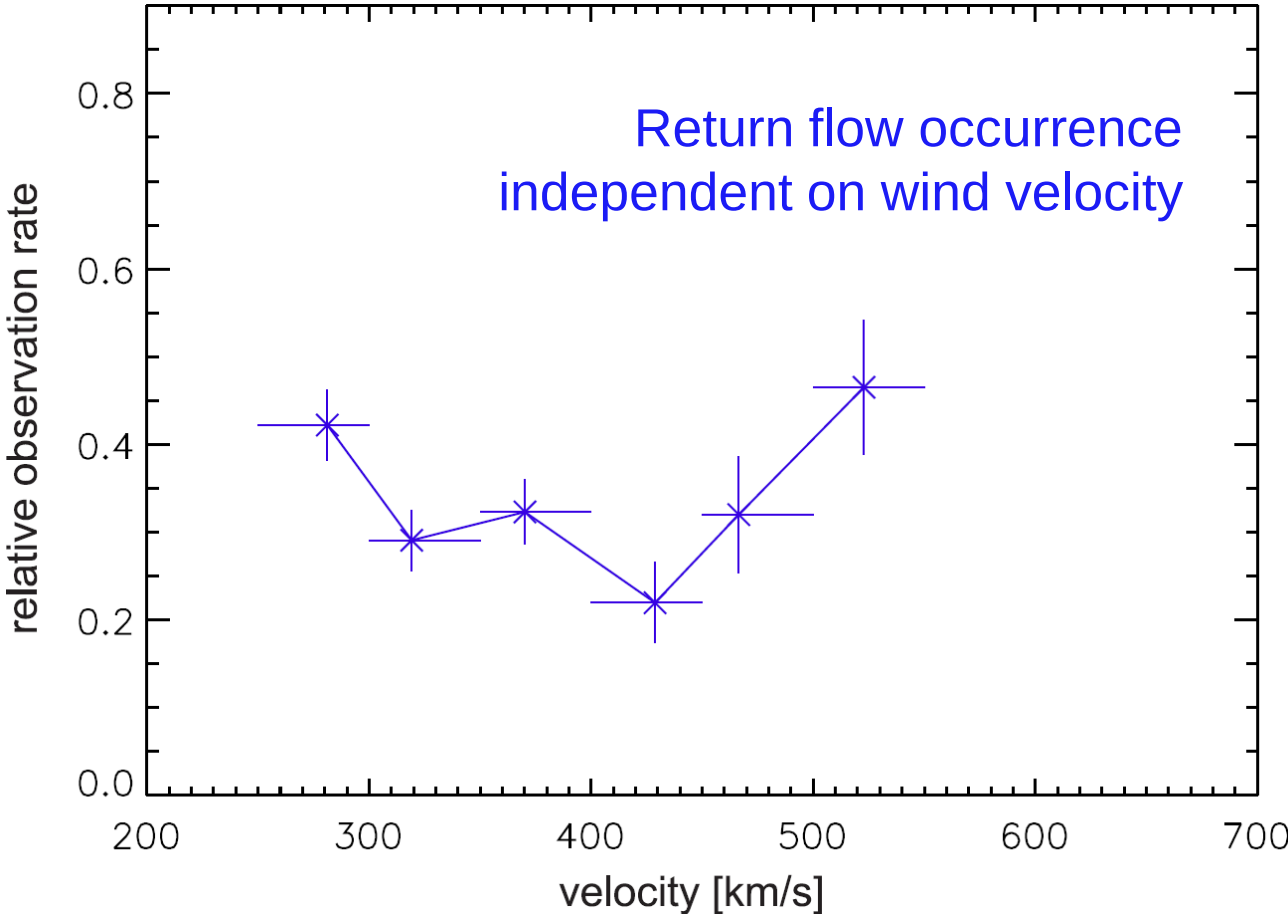
Color = Occurrence rate

<30% downtail spectra have high-energy tail

>60% venusward spectra have high-energy tail

Other correlations





For net *flux* correlations see poster by K. Masunaga, M. Persoon, et al.

Beyond atmosphere evolution

Venusward return flows...

- heat atmosphere with 70 MW.

  << hundreds GW from UV light

- excite atmosphere → tens of Rayleigh emission.
  << 30kR N+O nightglow

- support nightside ionosphere formation?

Summary

- Venusward flows modulate net escape rate.
  Downtail flows stay constant for different UV input.
- Venusward spectra have high-energy tails.
- Venusward flow origin
  - Not from reconnection?
  - Not from gravity?
  - Might emerge from single particle motion
- Venus and Mars escape rates
  scale oppositely with UV.

Thanks

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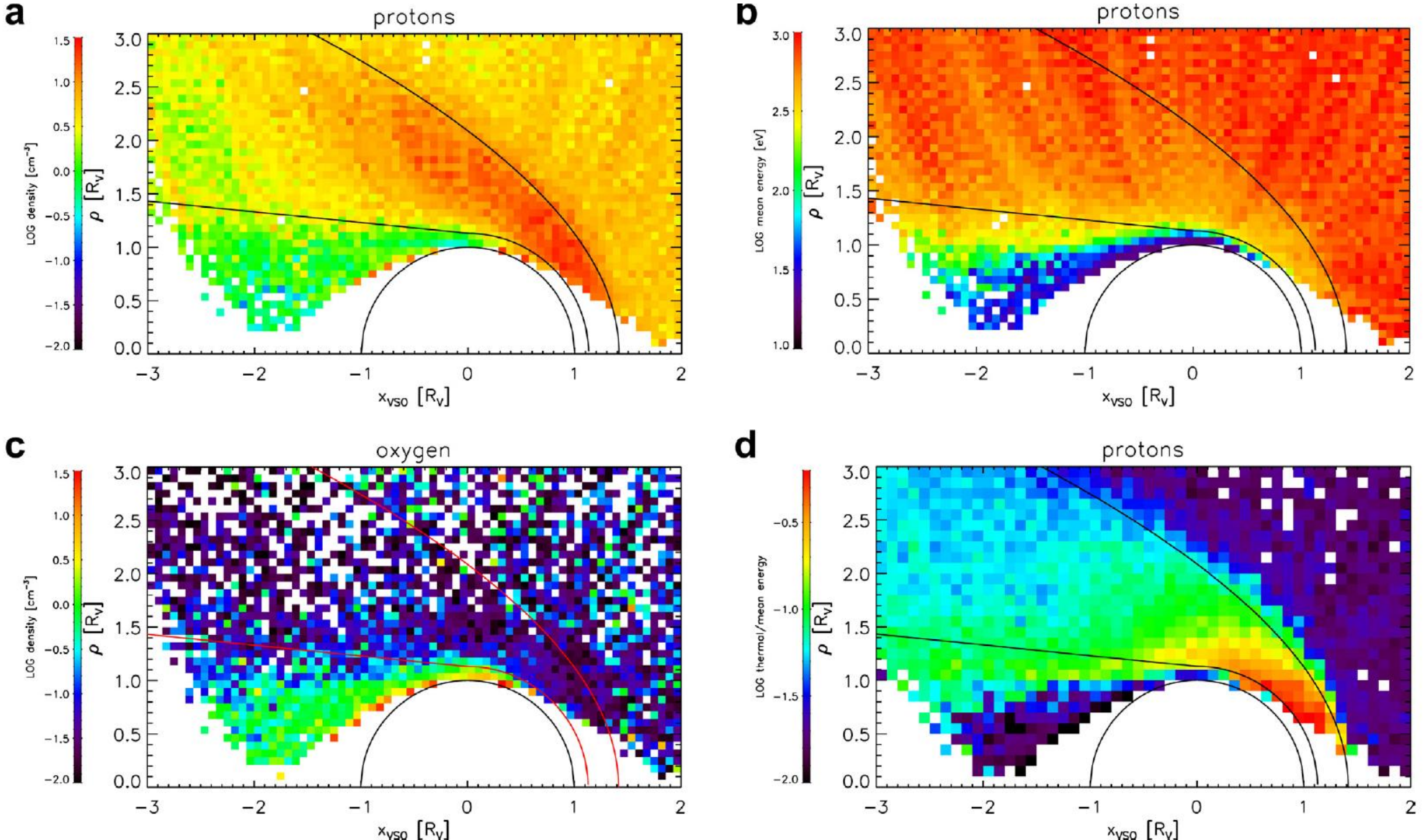
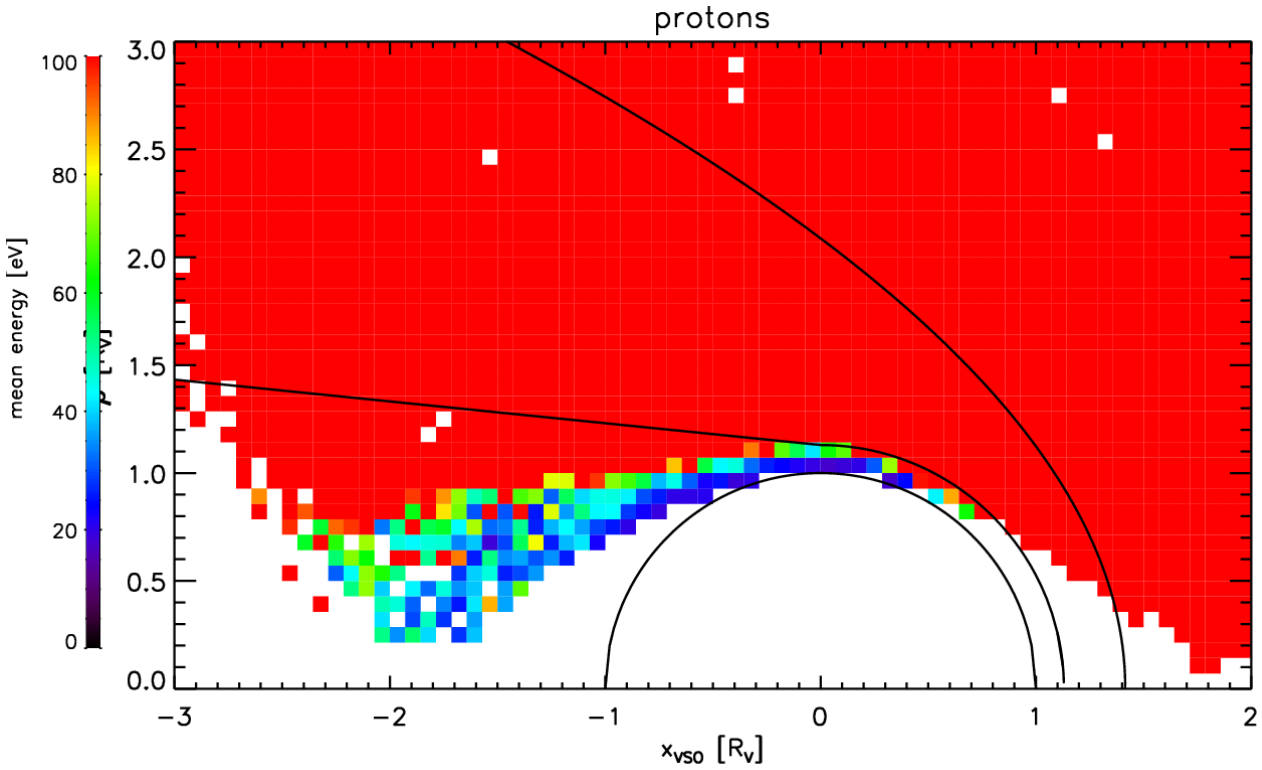
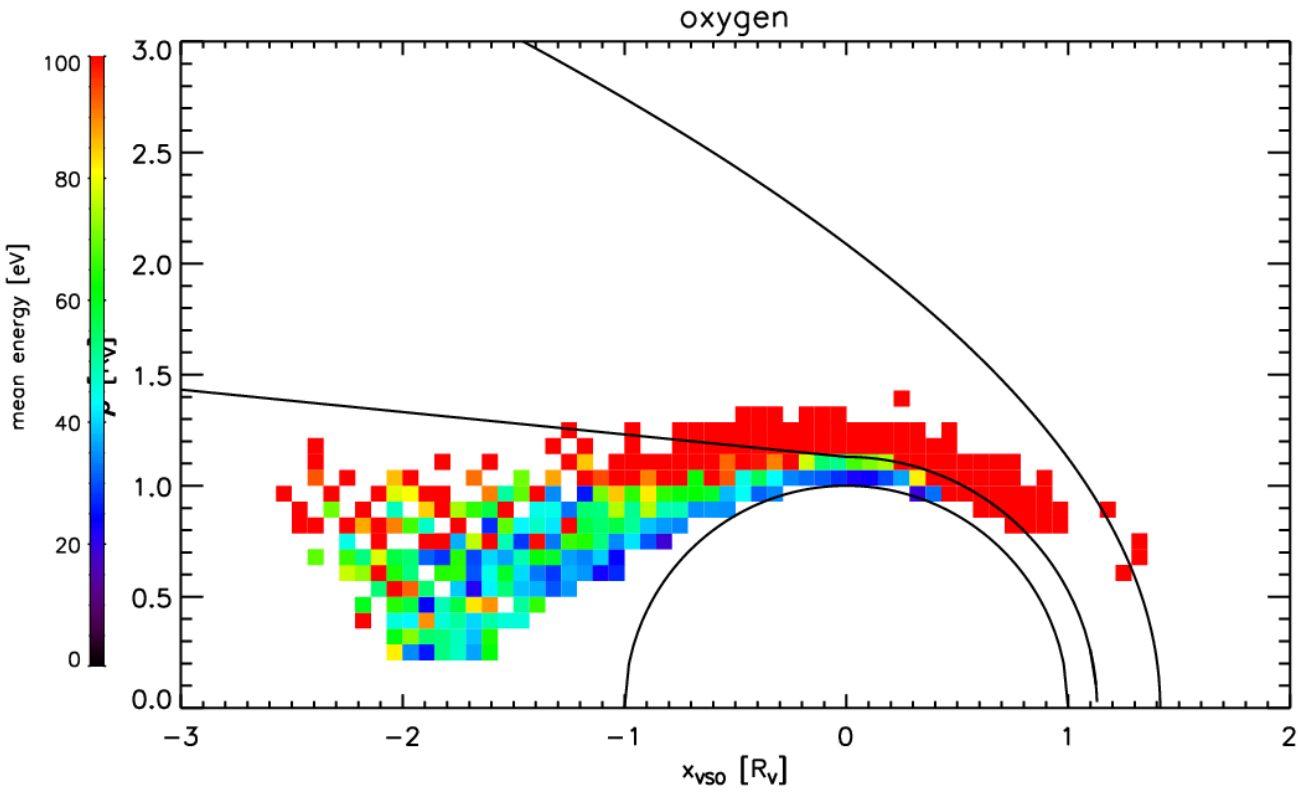

a
protons
LOG density [cm⁻³]
ρ [Rv]
xvso [Rv]
b
protons
LOG mean energy [eV]
ρ [Rv]
xvso [Rv]
c
oxygen
LOG density [cm⁻³]
ρ [Rv]
xvso [Rv]
d
protons
LOG thermal/mean energy
ρ [Rv]
xvso [Rv]

Mean energies

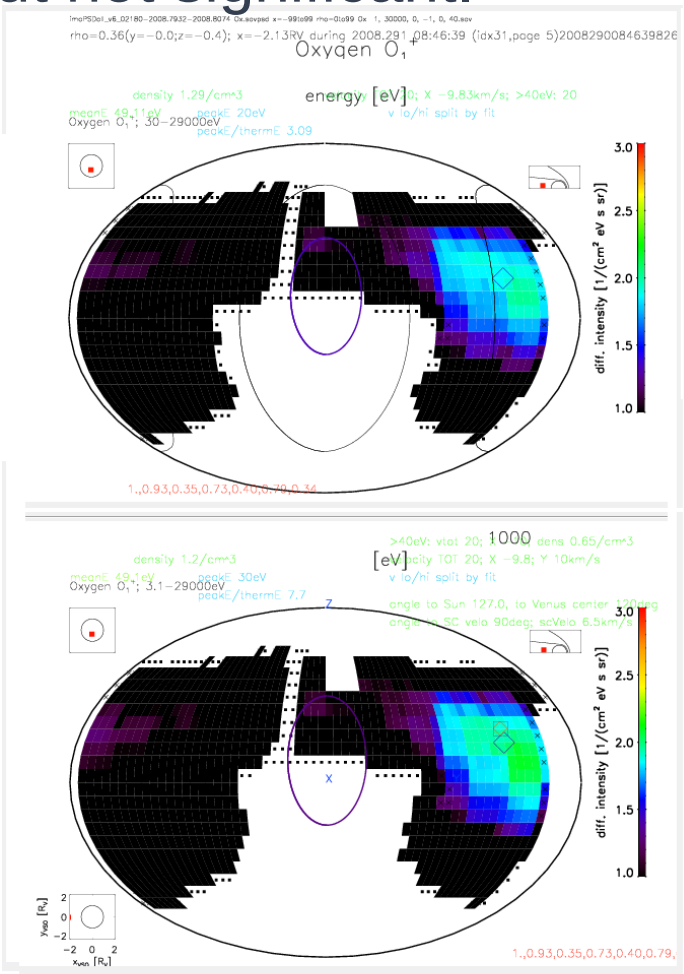




Difference does not follow mass ratio.
Protons are faster than one might expect.

Spacecraft electric field

Spherically symmetric:
change in bulk flow direction,
but not significant.



>30eV intensity

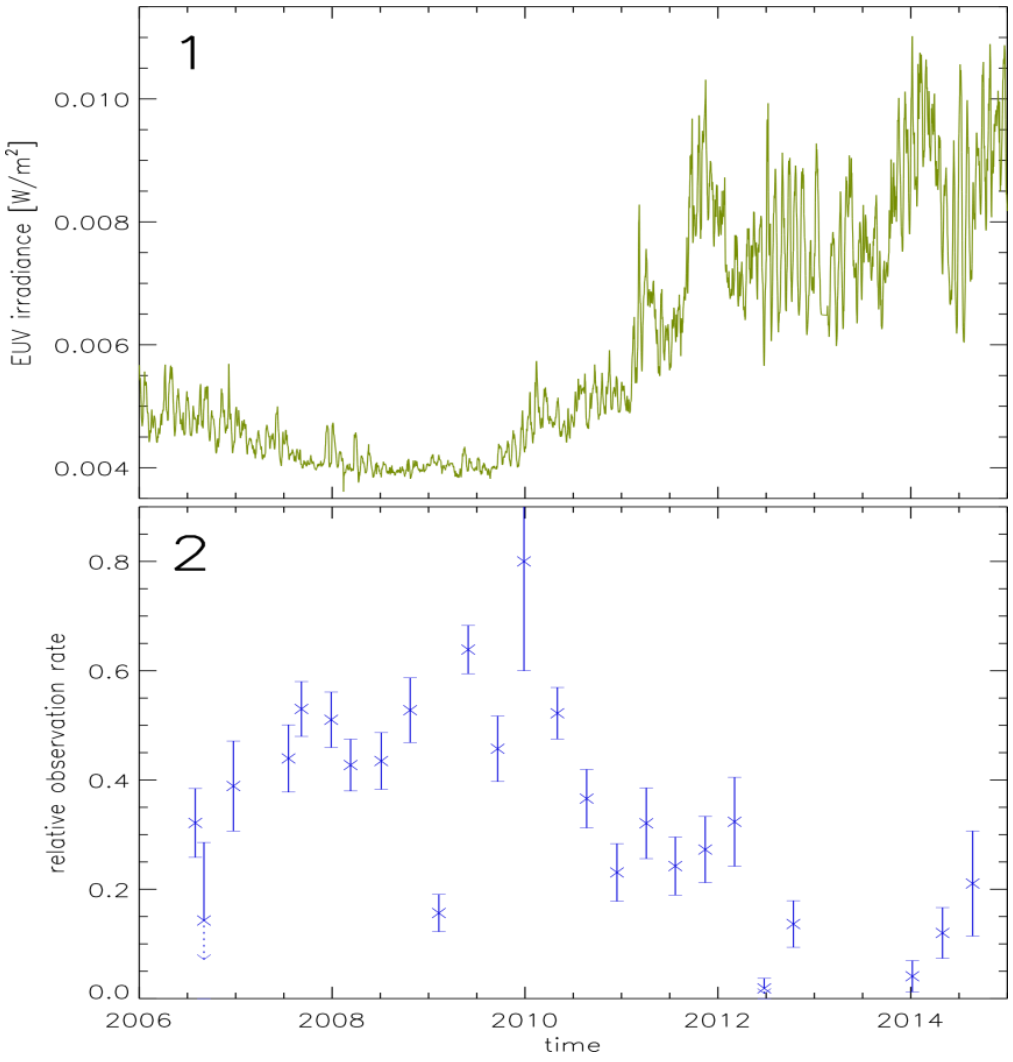
average intensity of full energy range

- blue diamond: bulk velocity when integrating over full energy range
- red diamond: when integrating from 40eV on

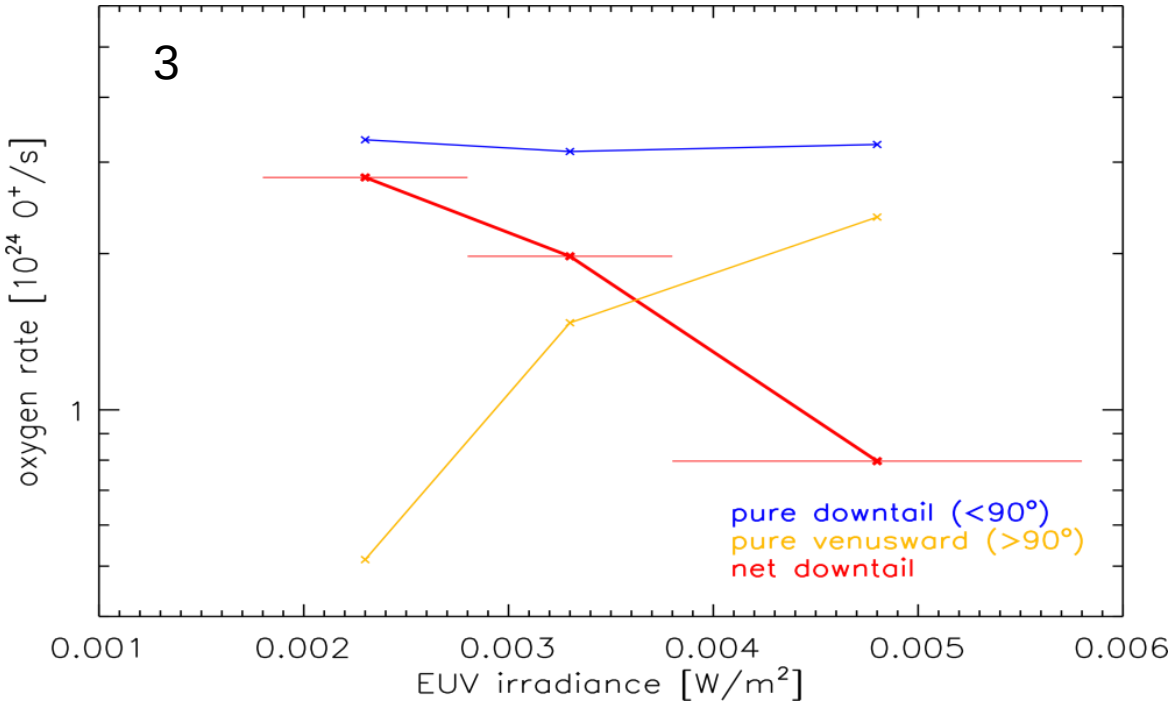
Asymmetric field:
Deflects particles in spacecraft frame, which might make flows come preferentially from a certain *direction* relative to the spacecraft.

Instead, flow direction organizes with the tail direction/VSE frame.

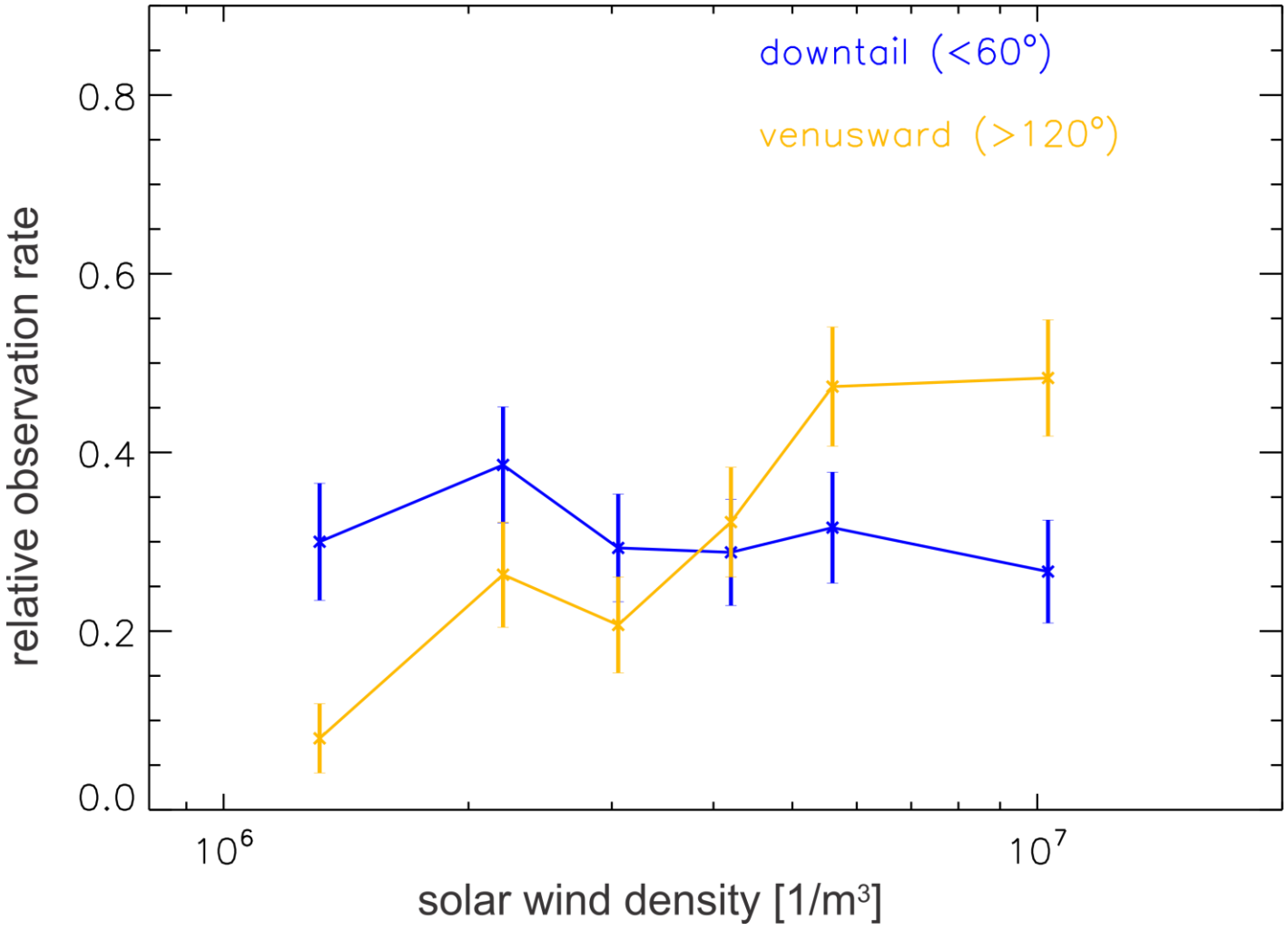
EUV correlation



- Venusward flows occur more frequently during strong EUV.
- **EUV affects precipitation rate and net-escape.**
- Solar wind moments do not affect precipitation rate.



Correlation with solar wind



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Motivation

- Understand planetary evolution
- Interpret potential data from exoplanets
- Find relevant physical drivers

→ Study present-day planets in our solar system

Context: Average escape rates

		H^+ (s^{-1})	O^+ (s^{-1})	O_2^+ (s^{-1})	CO_2^+ (s^{-1})	Total (kg/s)
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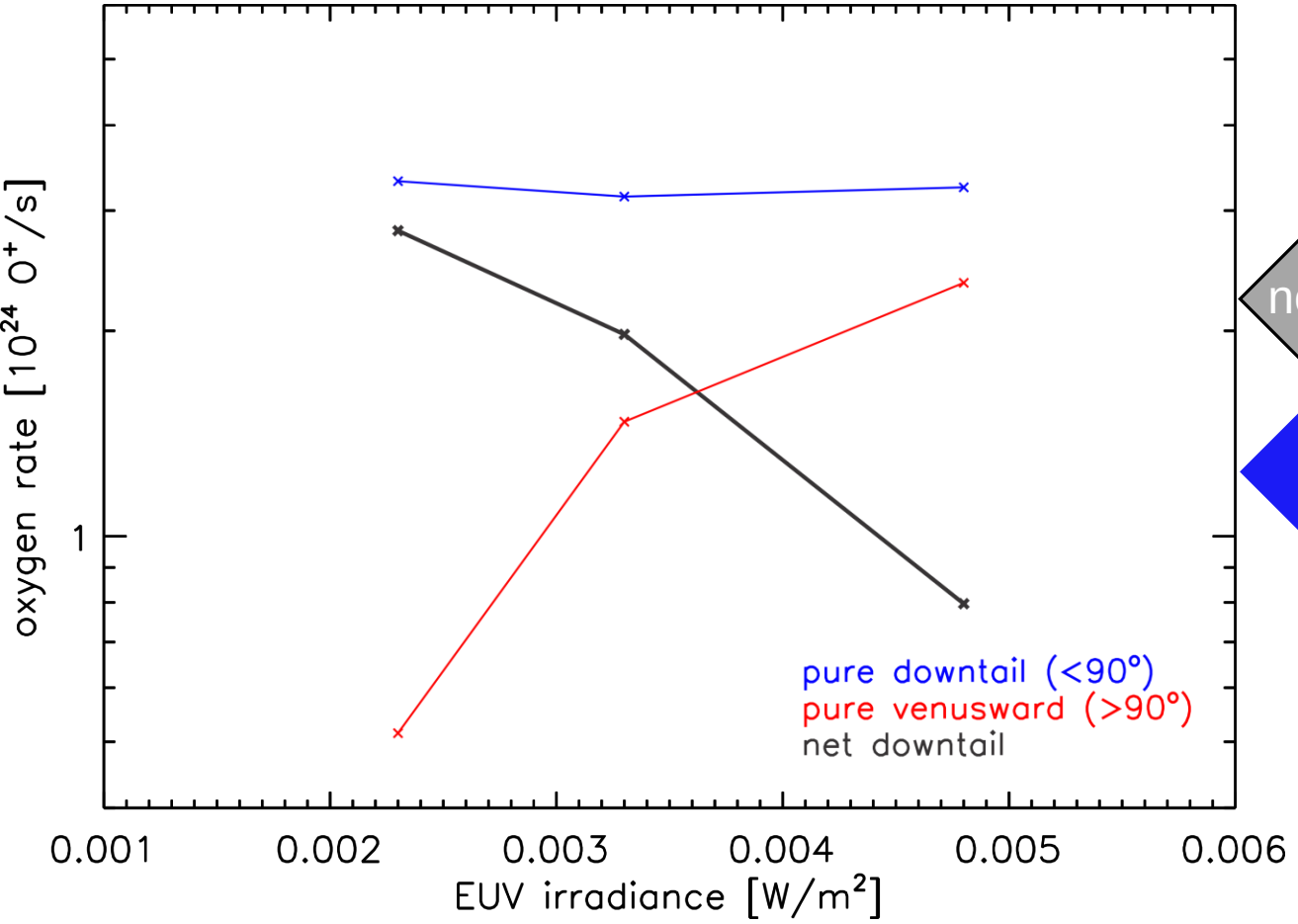
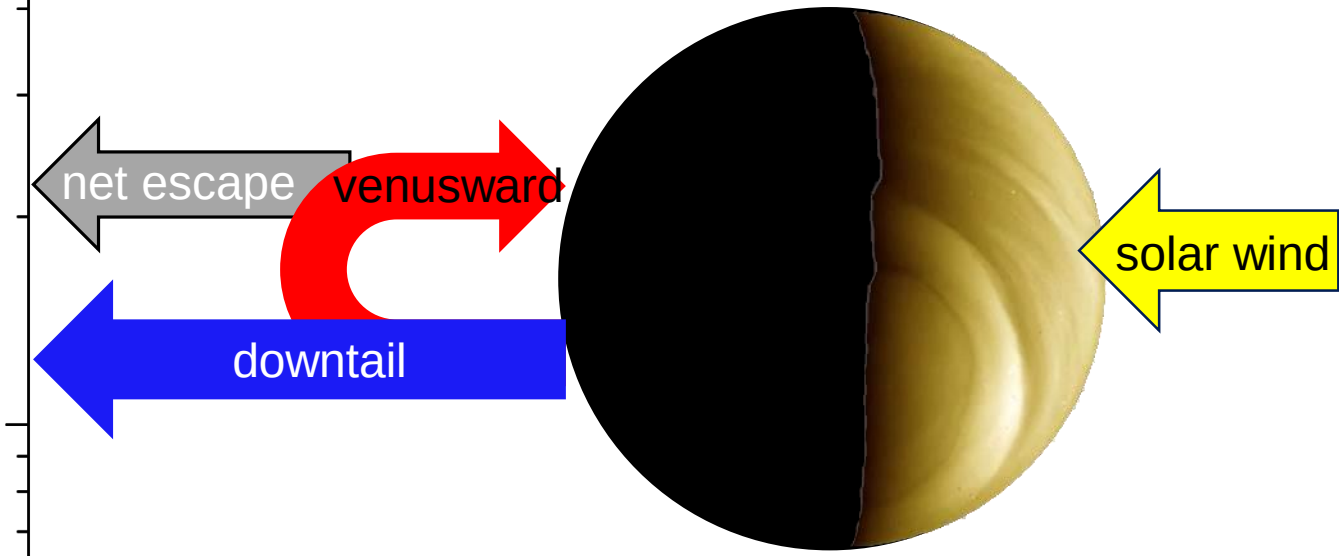
	Borovsky+2008	≤$2x10^{26}$	~$10x10^{24}$	-	-	**~0.5**

range of UV scaling, etc. on same order as uncertainties.

Flow components





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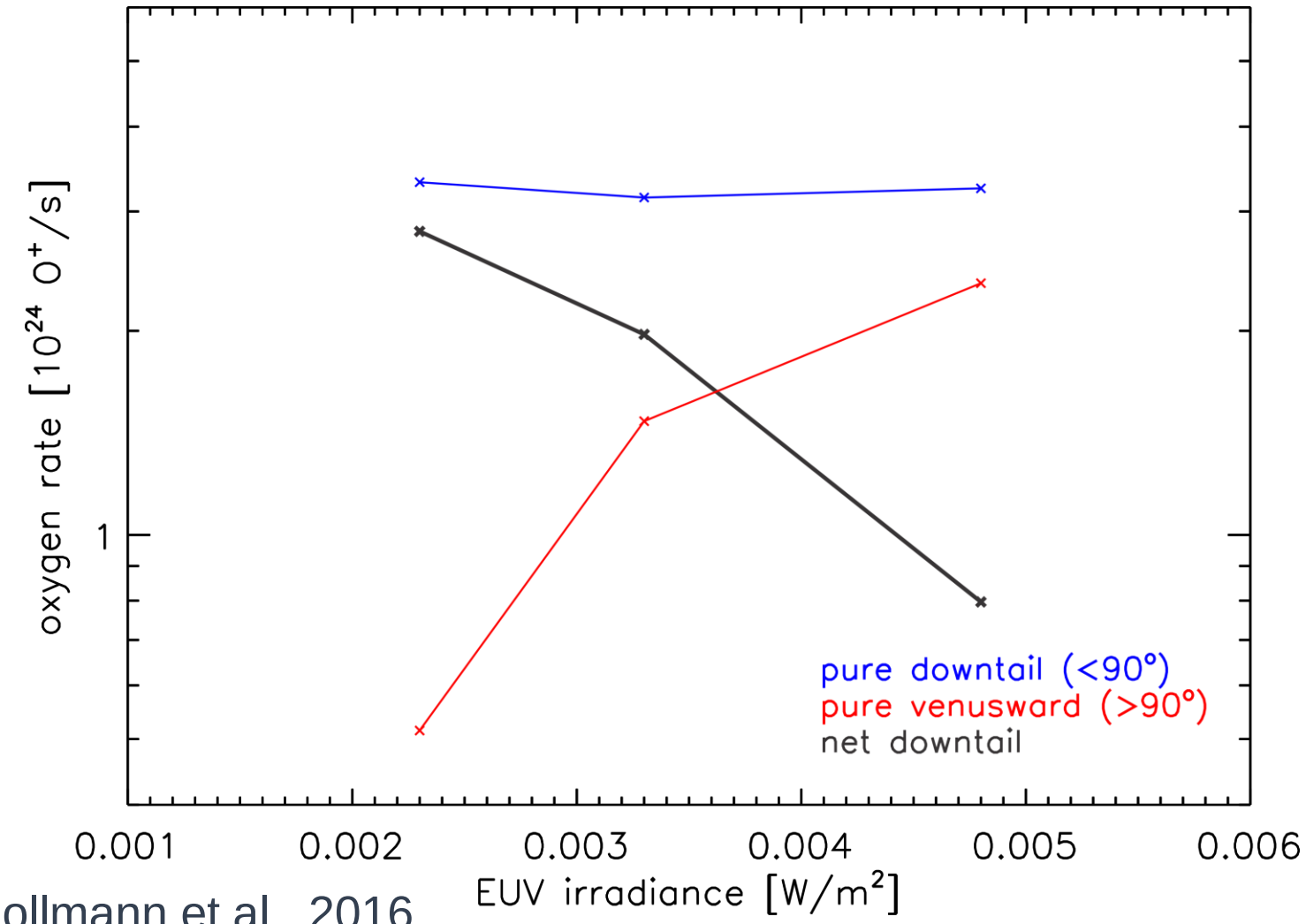
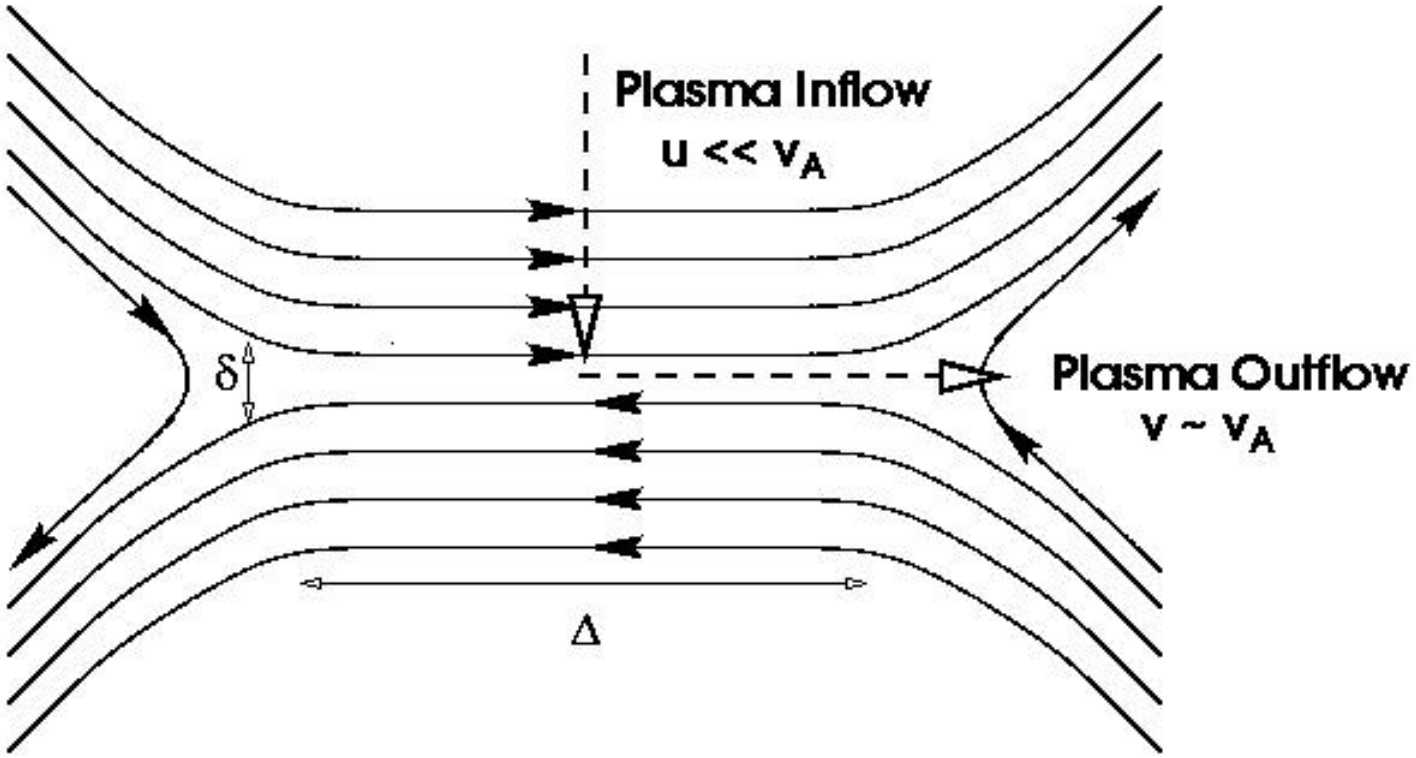


Kollmann et al., 2016

Net flow is
downtail / escaping
minus
venusward / precipitating.

Only venusward flow scales with UV.

Physical driver: Reconnection?



If venusward flows are from **reconnection** and analog to Earth,
then venusward flows should
occur **near the tail current sheet** and/or correlate with current sheet flapping.