Circulation and loss of cold plasma of ionospheric origin

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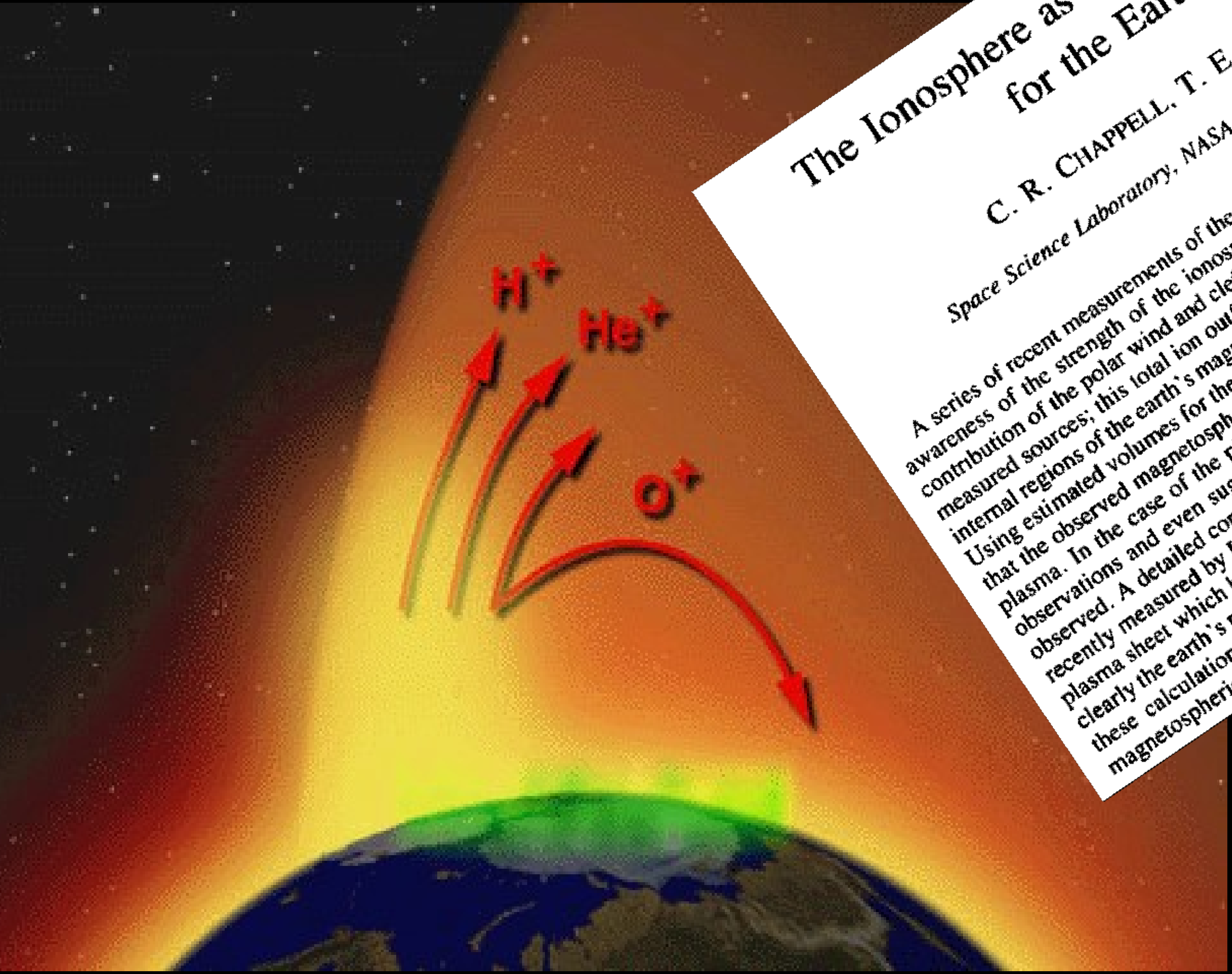

The Ionosphere as a Fully Adequate Source of Plasma for the Earth's Magnetosphere

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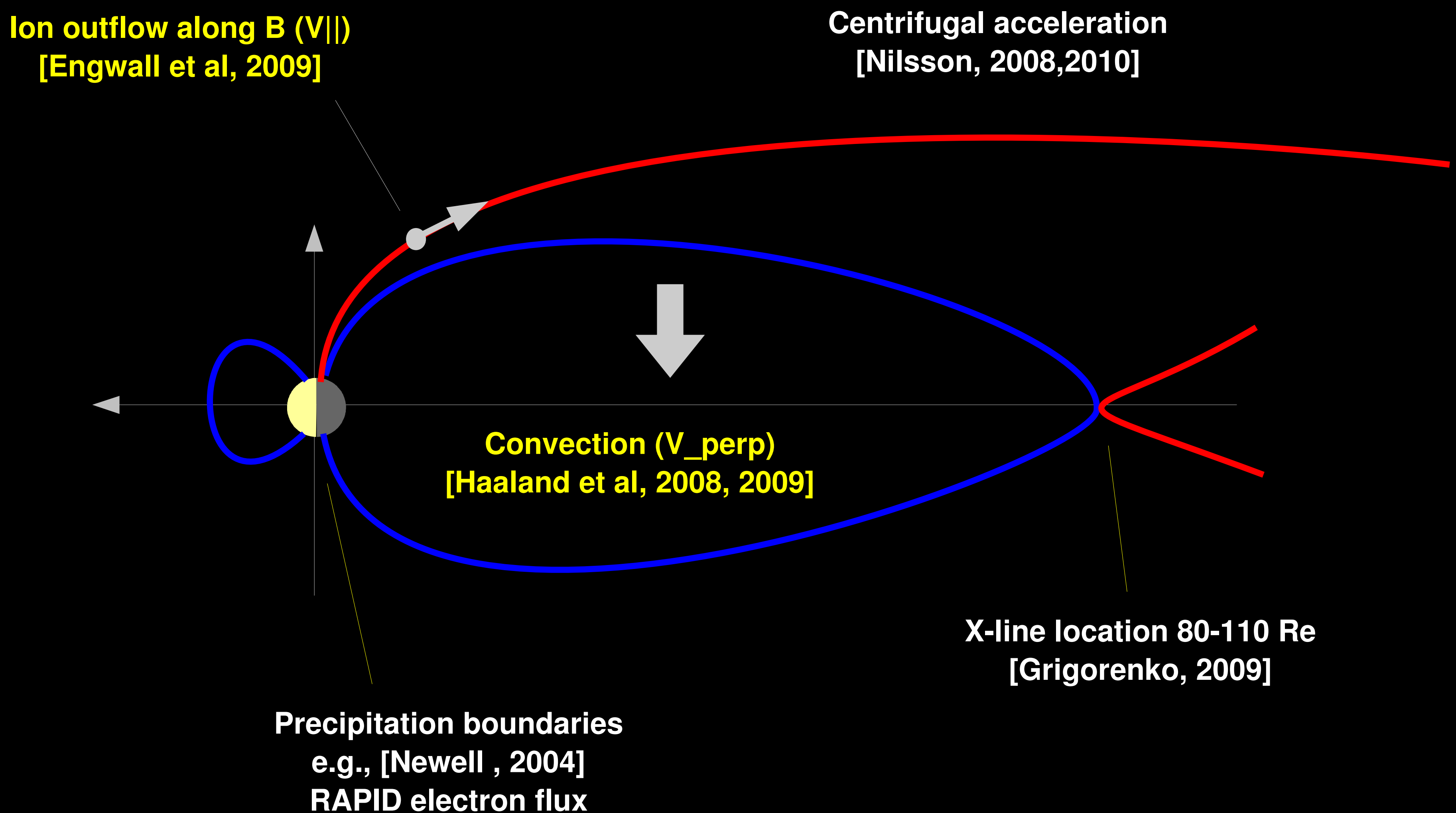
A series of recent measurements of the outflow of ionization from the ionosphere have further heightened our awareness of the strength of the ionospheric source of magnetospheric plasmas. In this paper the ionospheric contribution of the polar wind and cleft ion fountain at energies less than 10 eV has been added to the previously measured sources; this total ion outflow has then been used to calculate the resulting ion density in the different internal regions of the earth's magnetosphere: plasmasphere, plasma trough, plasma sheet, and magnetotail lobes. Using estimated volumes for these regions and an ion residence time characteristic of each region, we have found that the observed magnetospheric densities can be attained in all cases with no contribution from the solar wind plasma. In the case of the plasma sheet the ionospherically supplied density is more than enough to match the observations and even suggests an invisible component of low-energy plasma (<10 eV) which has never been observed. A detailed comparison between the calculated ionospheric source effects in the plasma sheet and those recently measured by ISEE shows excellent agreement and suggests a direct polar low-energy ion source for the plasma sheet which has remained unmeasured because of spacecraft potential effects. Although the solar wind clearly the earth's magnetospheric energy source and energetic solar wind ions are observed in the magnetosphe these calculations suggest the possibility that the ionospheric source alone is sufficient to supply the magnetospheric plasma content under all geomagnetic conditions.

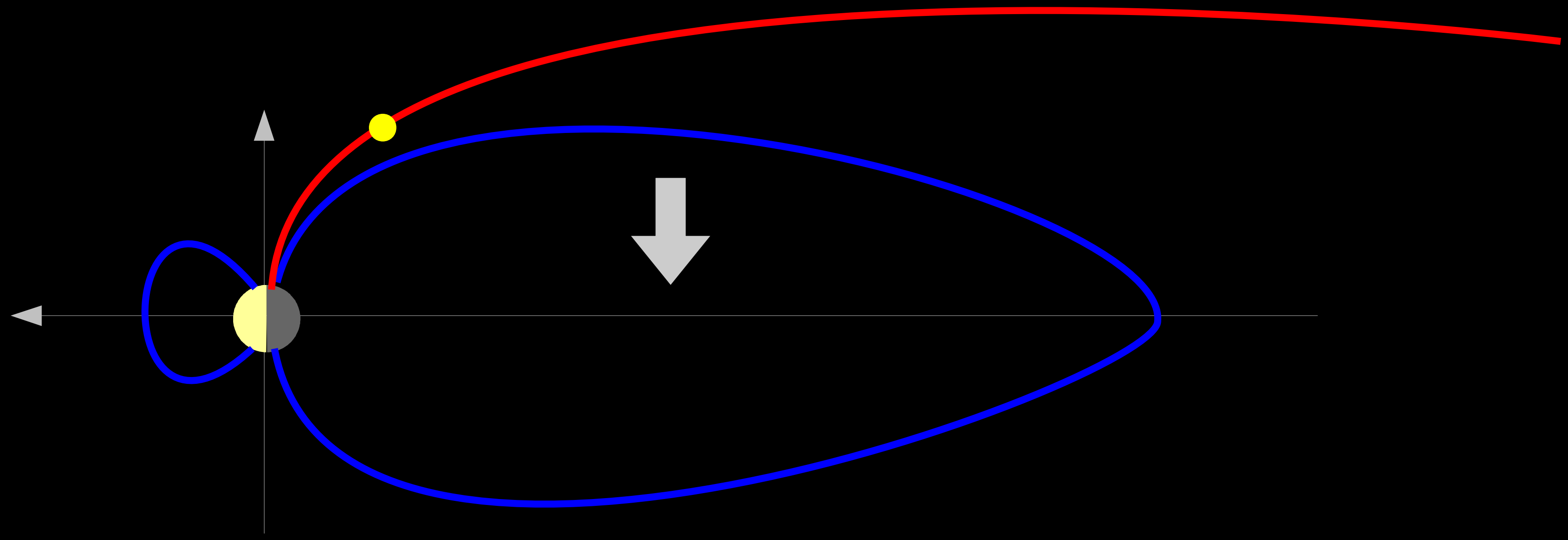
Motivation / Background

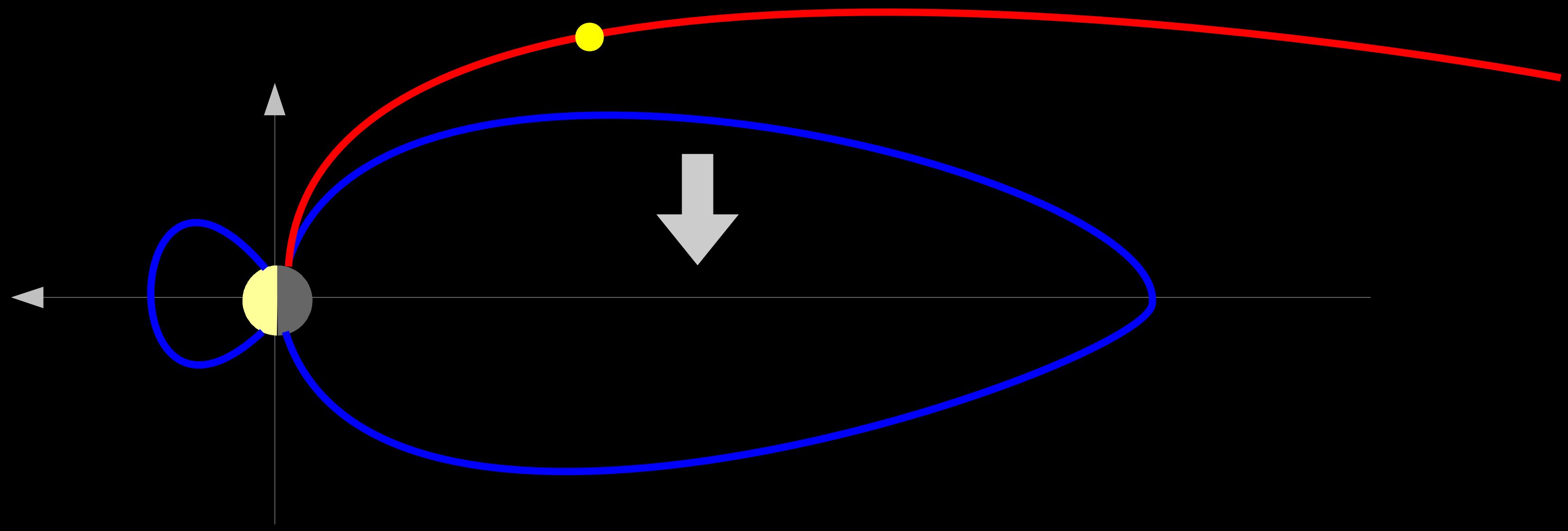
- Facts (*)
  - Ion outflow ca 1e26 ions/s (23000 t/y, 20% O+)
  - Escape energy H^+ : ~0.61 eV, O^+ ~9.7 eV
  - Similar observations from Mars, Venus
- Questions
  - Mars, Venus : role for life : **O + H = water**
  - Earth : magnetosphere shielding
  - **Net loss = outflow - return feed**

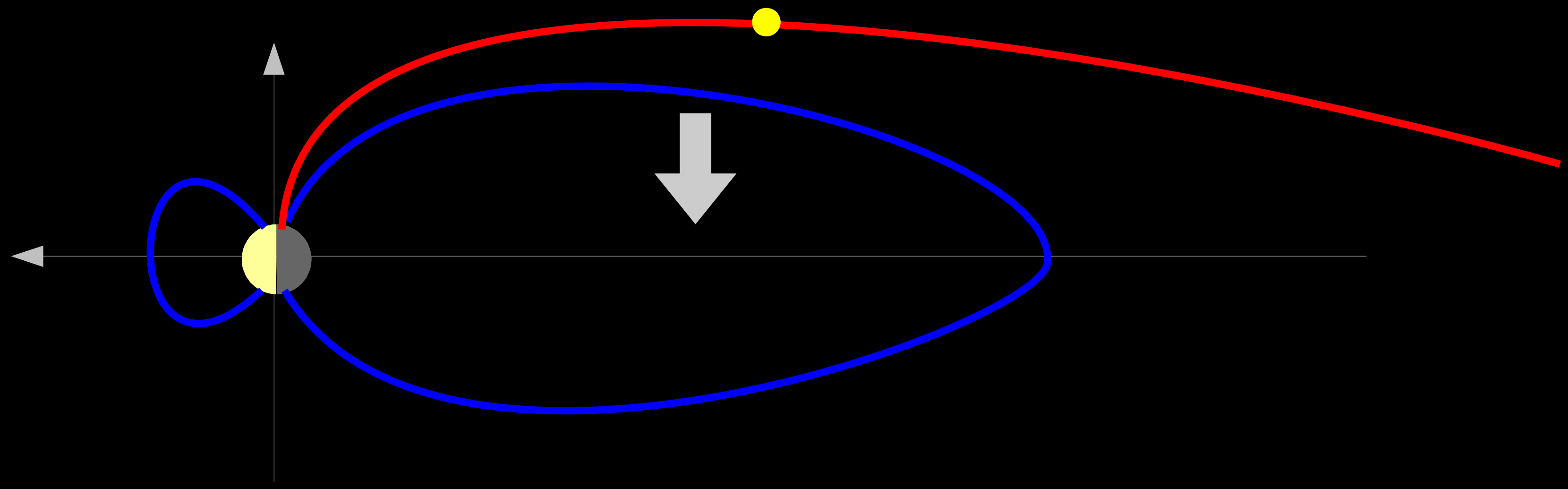
* Engwall et al, 2007,2008,2009, Andre & Yau 1995 , Moore 2007, Bouhram 2004.....

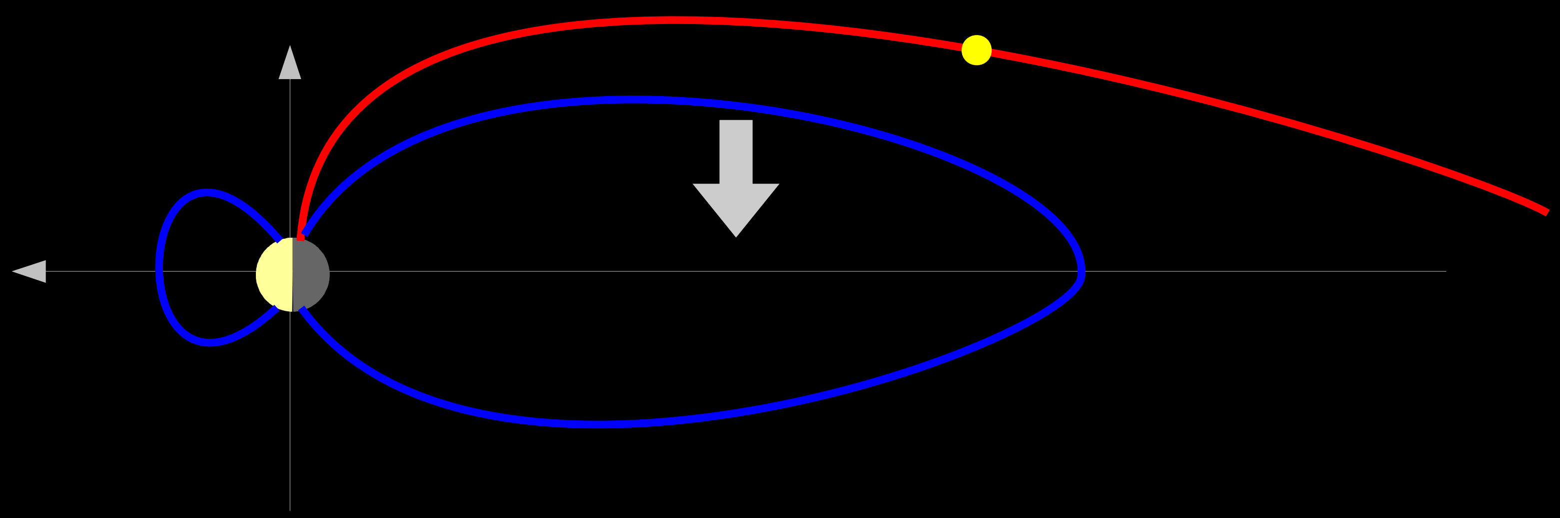
Tailward loss vs circulation

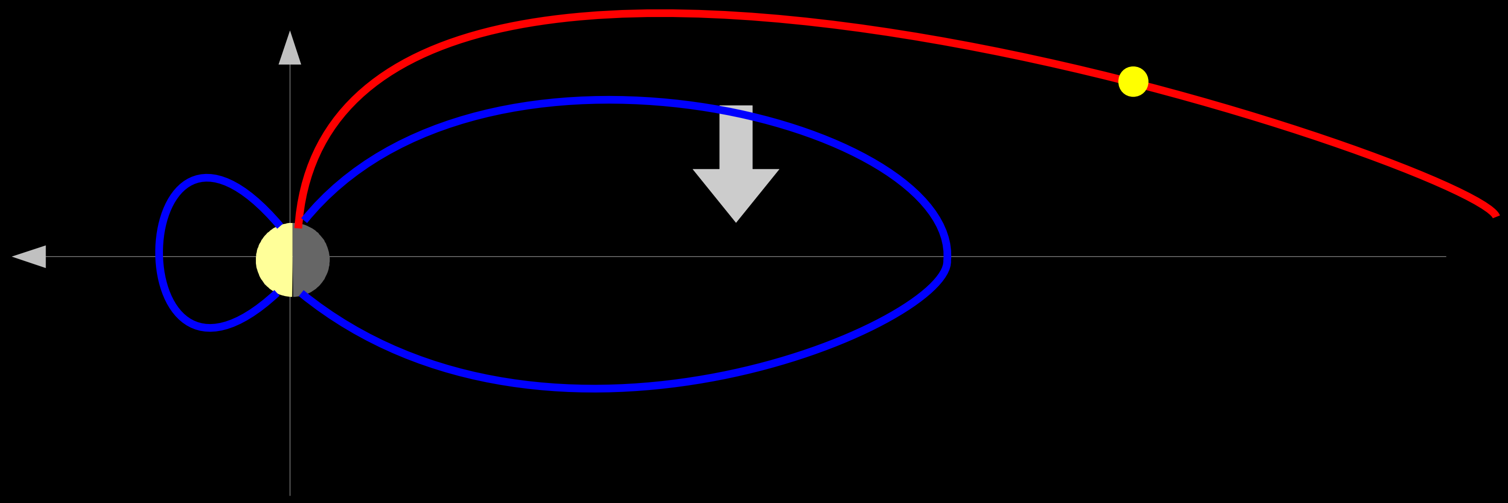


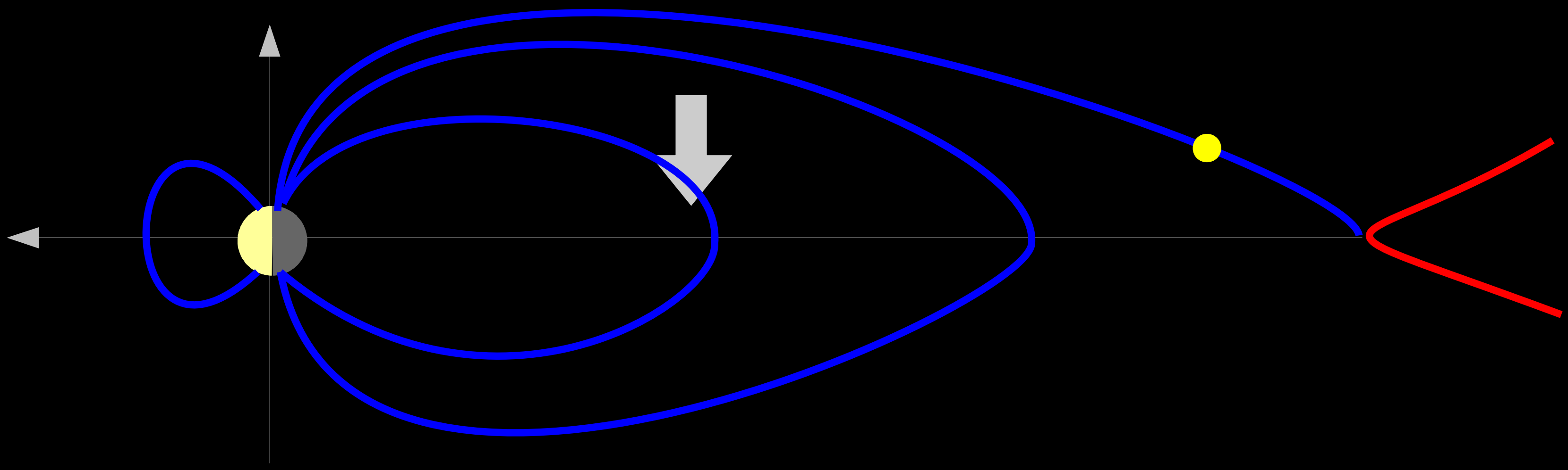


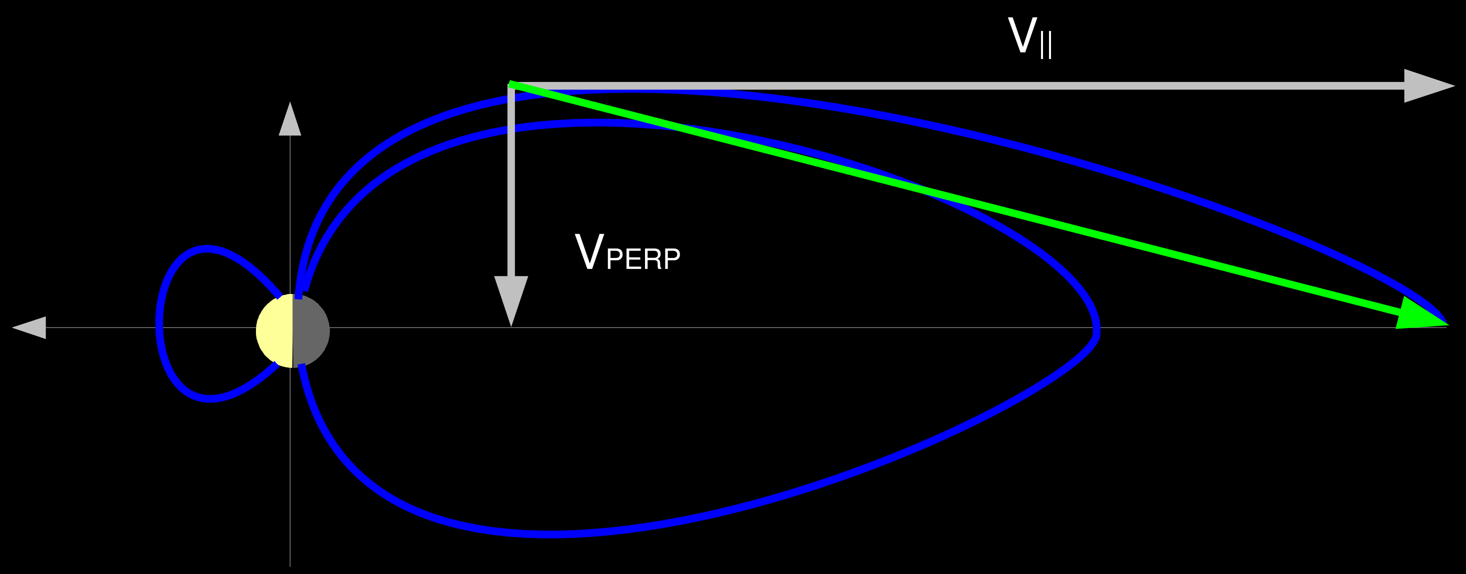




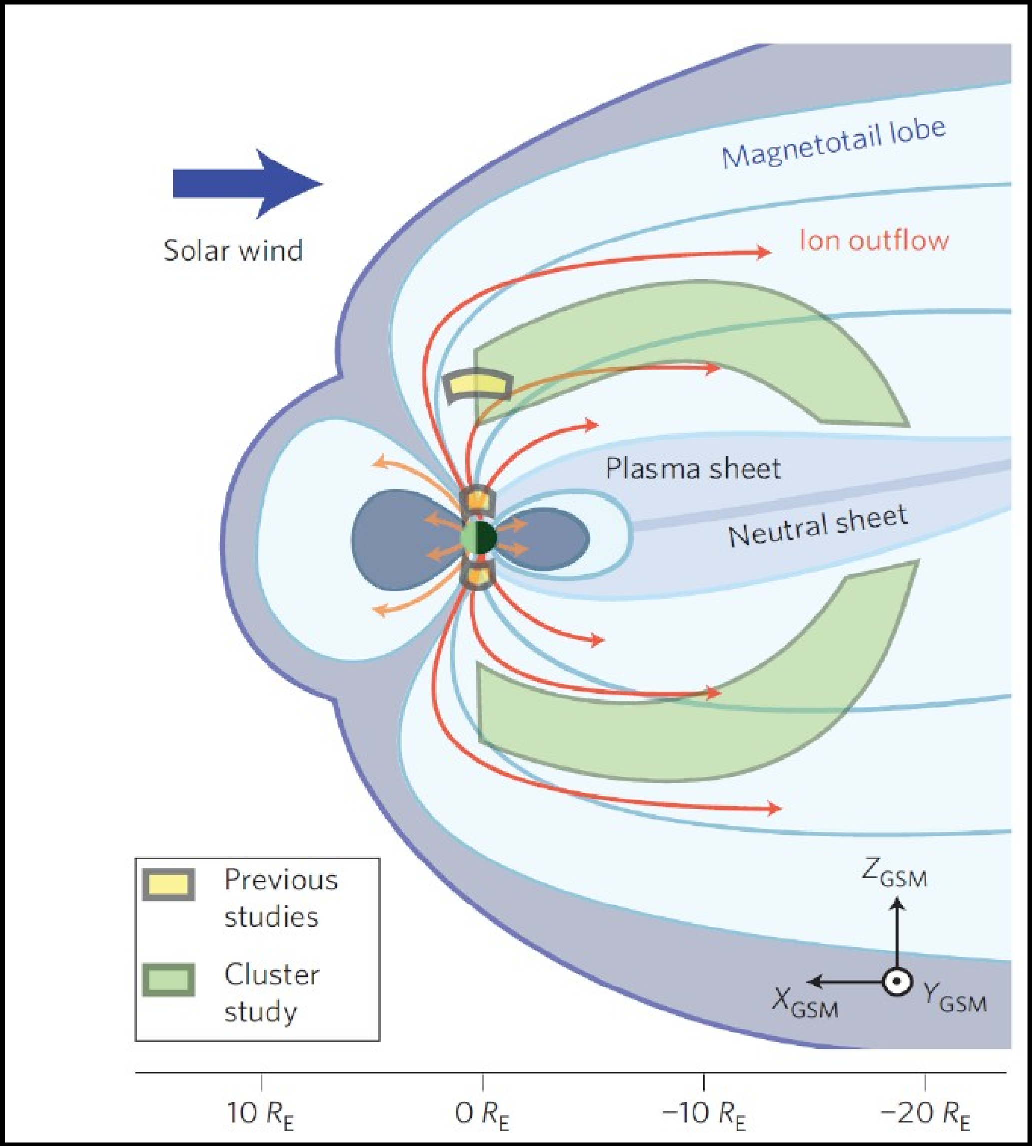







$V_{||}$
V_{PERP}

$V_{||}$ [Engwall et al 2009 data set]

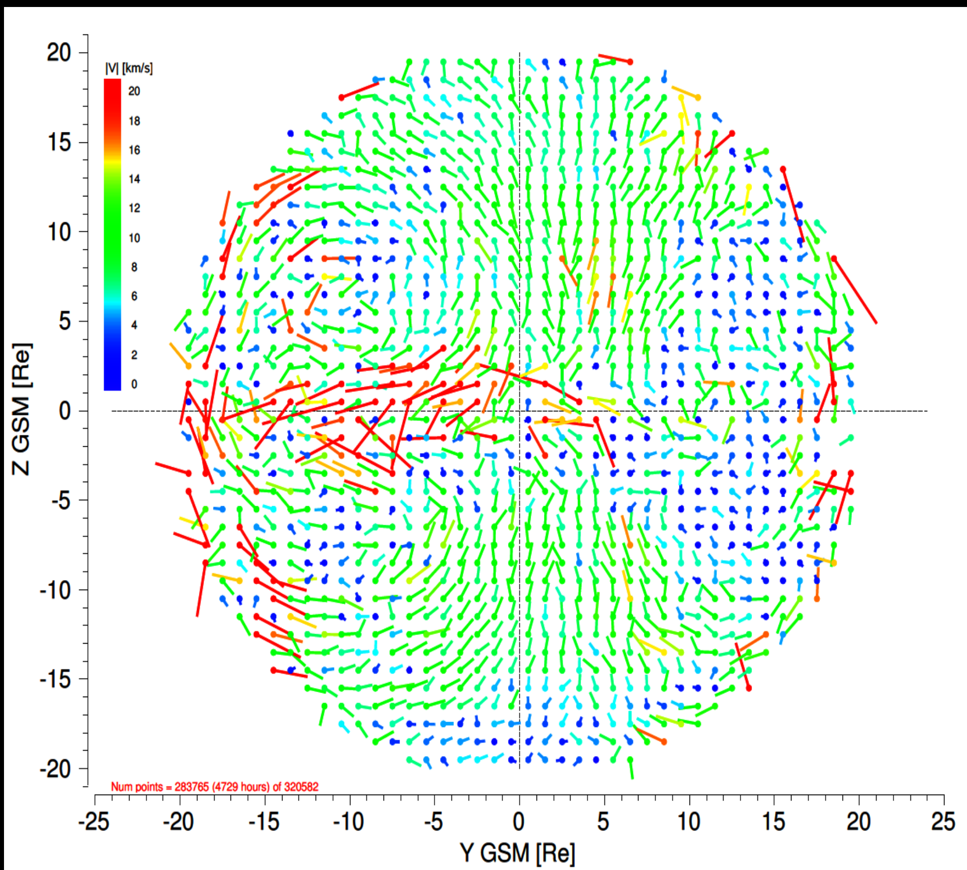


[From Engwall et al, Nature, 2008]

- ~178000 records
- 0.5 - 60 eV
- $V_{||}$ and n_e
- Ave $V_{||}$ = 26 km/s
- Ave n_e = 0.18 cm^{-3}
- Outflow =

  $0.74\ 10^{26}$ ions s^{-1}

V_{conv} [Haaland et al 2008 data set]

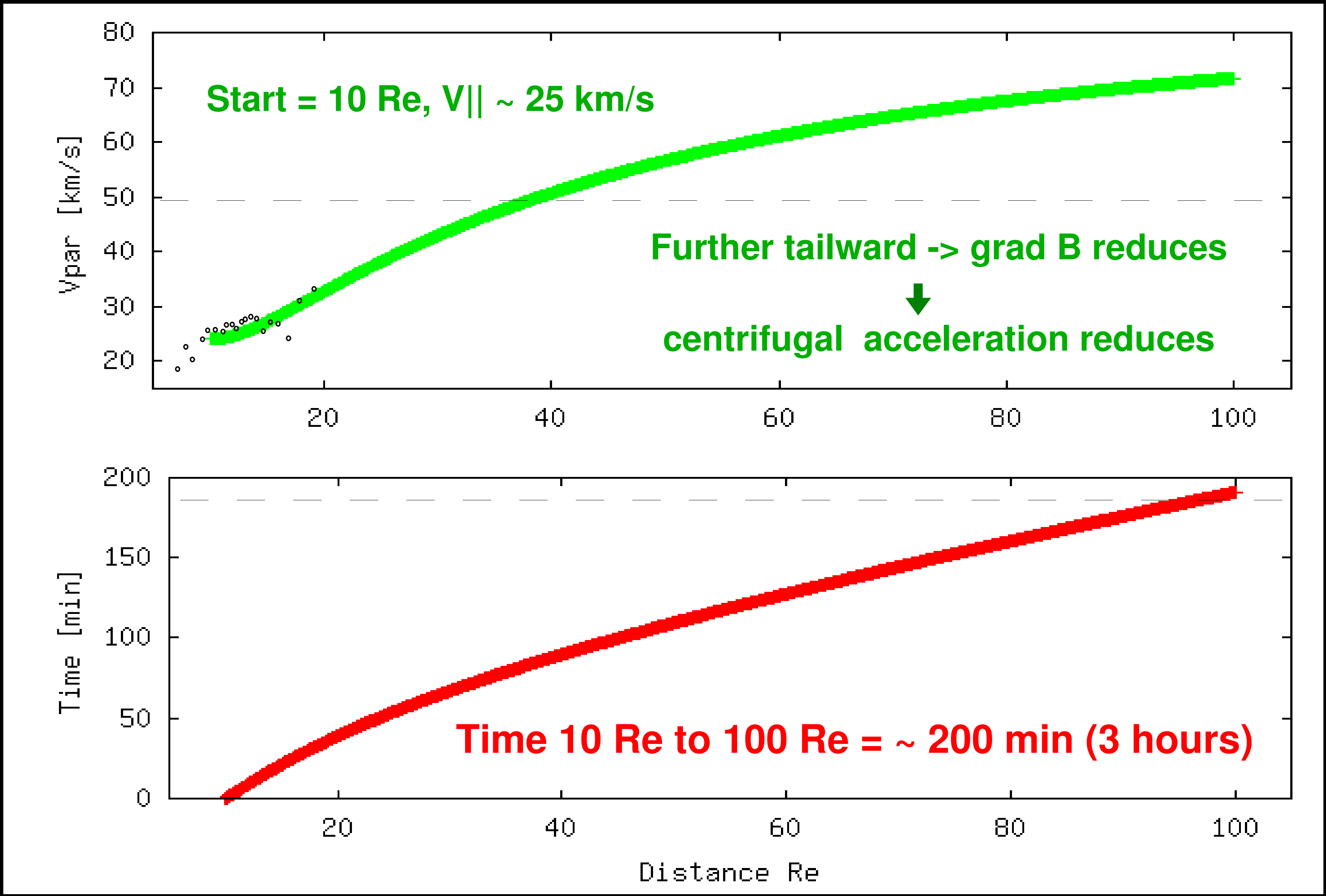


- ~320'000 records EDI
- <Vperp> = 7 km/s
- strong IMF control

Northern lobe	Bz+	By+	Bz-	By-	All
Num records	13985	29832	18120	32249	94186
Vz [$\mathrm{km\,s^{-1}}$]	-2.0	-7.2	-10.2	-7.3	-7.0
Vy [$\mathrm{km\,s^{-1}}$]	0.2	6.5	0.0	-7.7	-0.5
U_{CT} [kV]	21.4	41.6	61.6	42.2	41.2

Results

- Grand averages (i.e, no sorting after Dst, Ae..)


Start = 10 Re, V|| ~ 25 km/s
Further tailward -> grad B reduces
centrifugal acceleration reduces
Vpar [km/s]
Time [min]
Time 10 Re to 100 Re = ~ 200 min (3 hours)
Distance Re

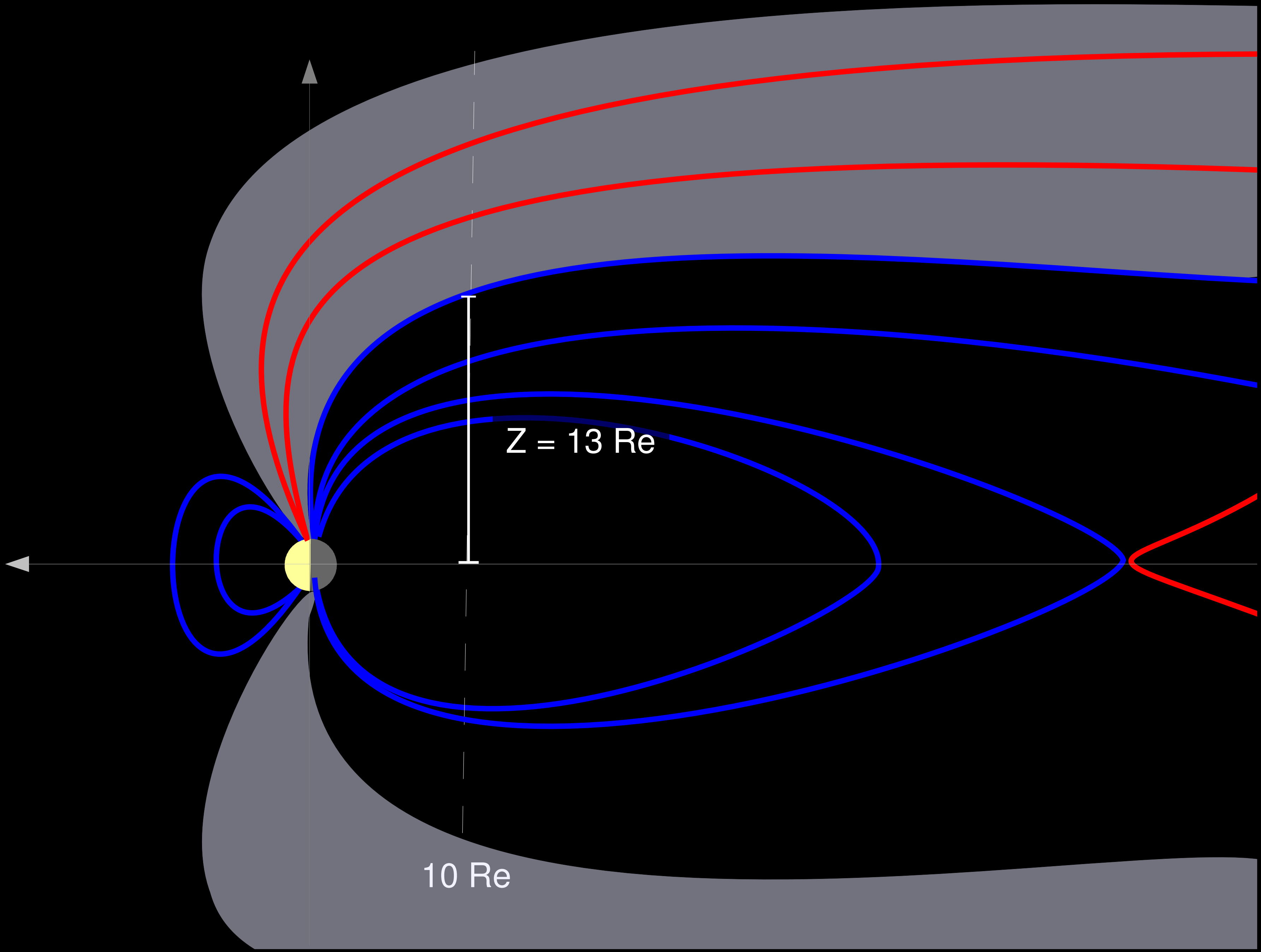
How far do the ions convect in 200 min ?

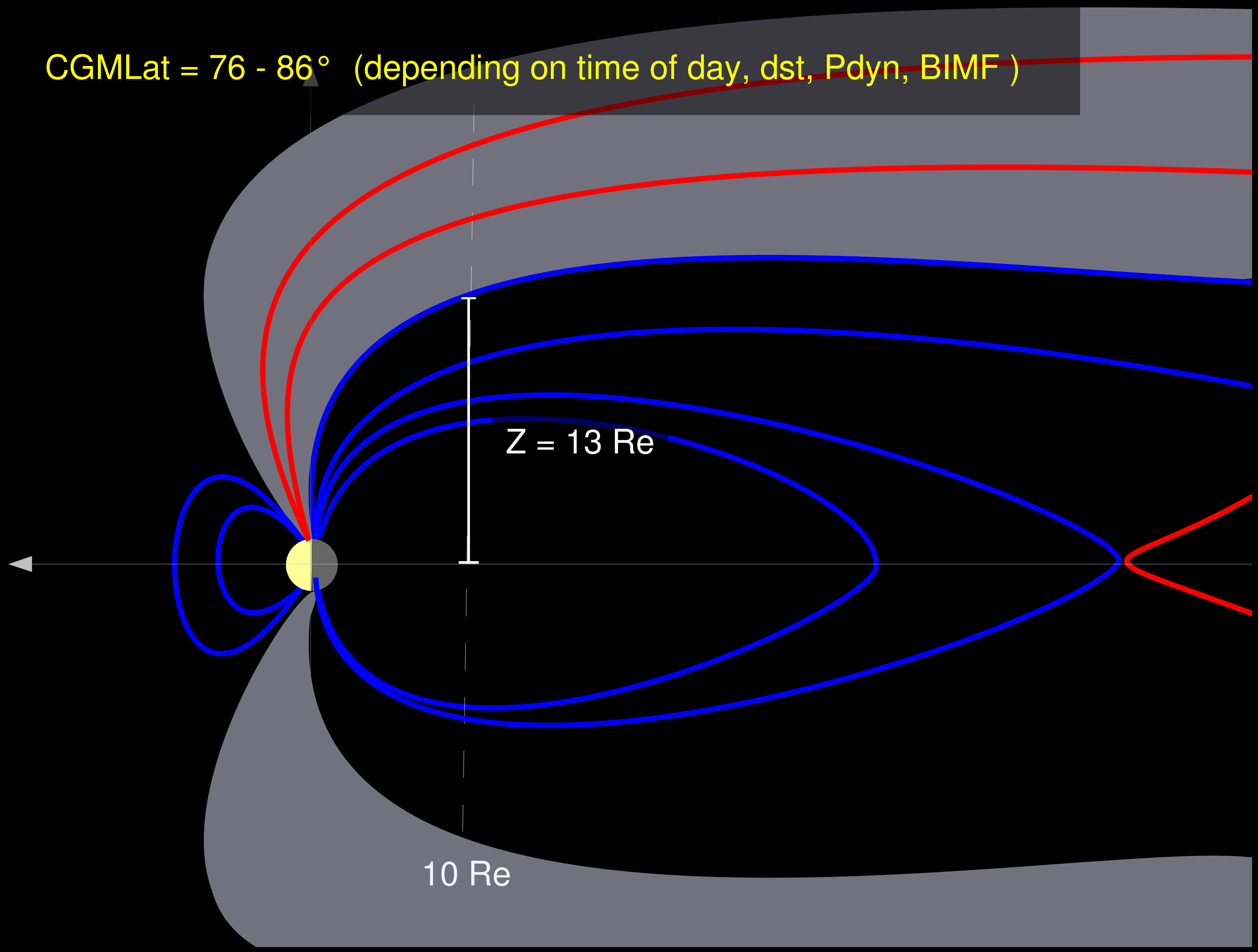
$V_{\perp}$ (X= -10 Re) = 7 km/s = ~ 420 km/min

200 min -> 85000 km ~ 13 Re

Ions on field lines with |Z| >13 Re are lost

(will be able to travel beyond distant X-line before reaching PS)


Z = 13 Re
10 Re


CGMLat = 76 - 86° (depending on time of day, dst, Pdyn, BIMF)
Z = 13 Re
10 Re

Total flux :

- Flux ~ $n_e * V_{||}$
- MappedFlux = Flux * (B_ion/B_msp)
- Total flux = PolarCapArea * MappedFlux

- Engwall et al., 2009 cold plasma:
  - PolarCap = > 70° MagLat = $41.5 \cdot 10^6$ km^2
  - MappedFlux = $1.8 \cdot 10^8$ [ions cm^{-2} s^{-1}]
  - TotalFlux = $0.74 \cdot 10^{26}$ ions/s (17000 tons/y)

Flux on $|Z_{GSM}|$ > 13 Re:

- Flux ~ $n_e * V_{||}$
- MappedFlux = <Flux> * (B_ion/B_msp)
- LostFlux = PolarCapArea * MappedFlux

- Results :
  - PolarCap = > 81° CGMLat = $8.4 \cdot 10^6$ km^2
  - MappedFlux = $8.2 \cdot 10^7$ [ions cm^{-2} s^{-1}]
  - LostFlux = $6.9 \cdot 10^{24}$ (1600 tons/y)

Result : grand average

- Total outflow = $0.74 \cdot 10^{26}$ ions/s
  - ~17 000 tons/year (20% O^+, 80 % H^+)

- Lost outflow = $0.69 \cdot 10^{25}$ ions/s
  - ~1600 tons/year

- 90 % circulation, 10 % tailward loss

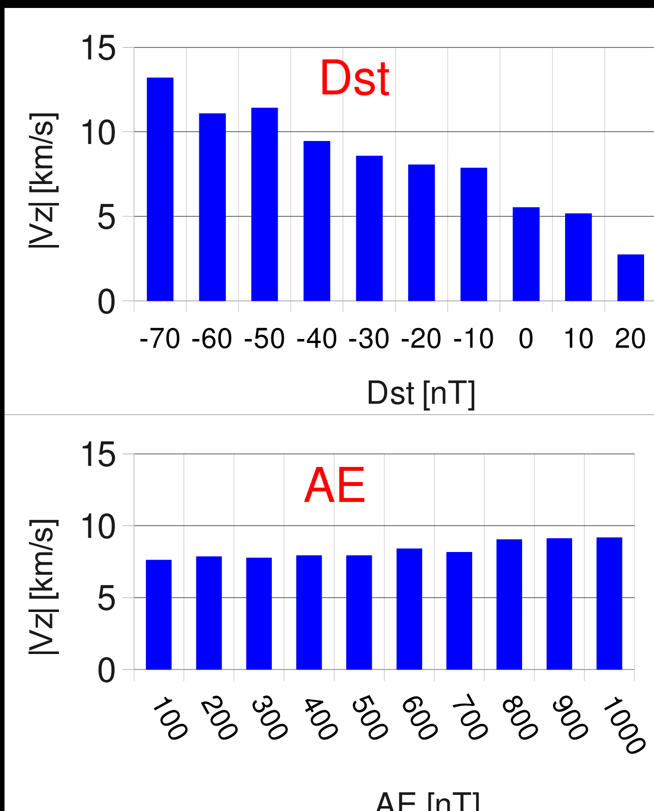
Activity dependence

- Assumptions :
  - Keep distant X-line at 100 Re
  - No change in field aligned acceleration
  - Mass calc : [O+] / [H+] does not change

- $V_{||}$, density, $V_{\perp}$ change
- Travel time + convection distance change
  - Mapping changes (Magnetic field model)
  - Footpoint in ionosphere + PC area

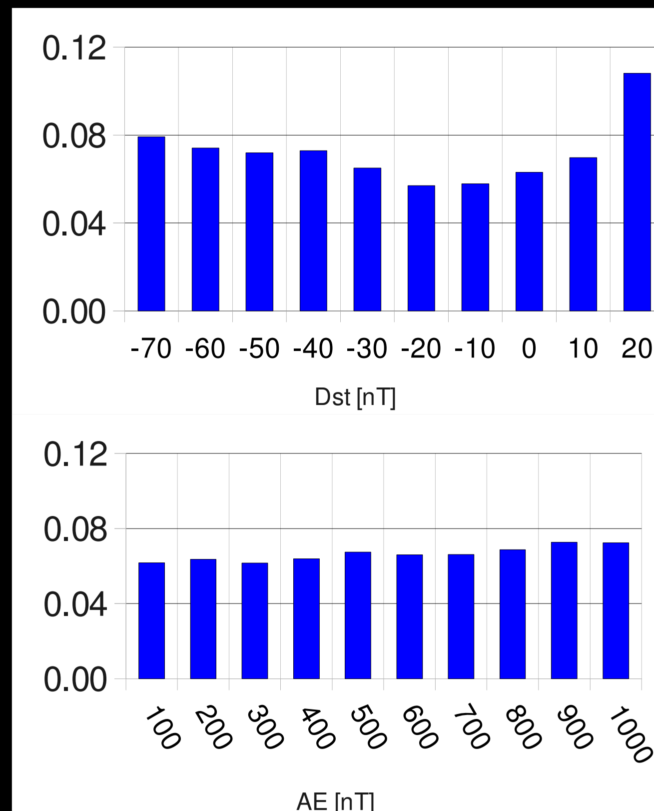
Activity dependence

Convection



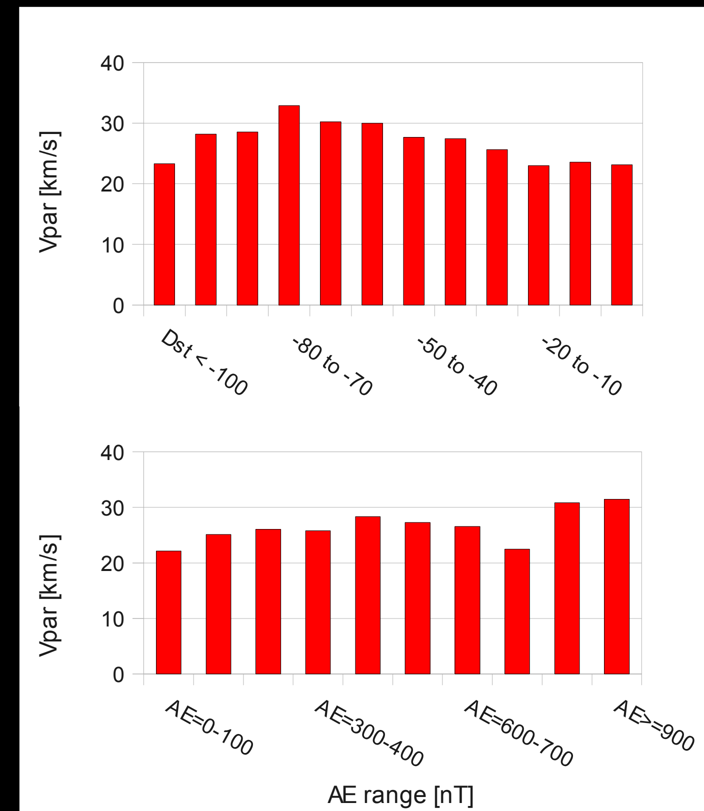
Convection: strong Dst dependency, ca factor 3

Density



Density : little or no dependency

Outflow (|| B)



Parallel velocity : Little or no activity dependency

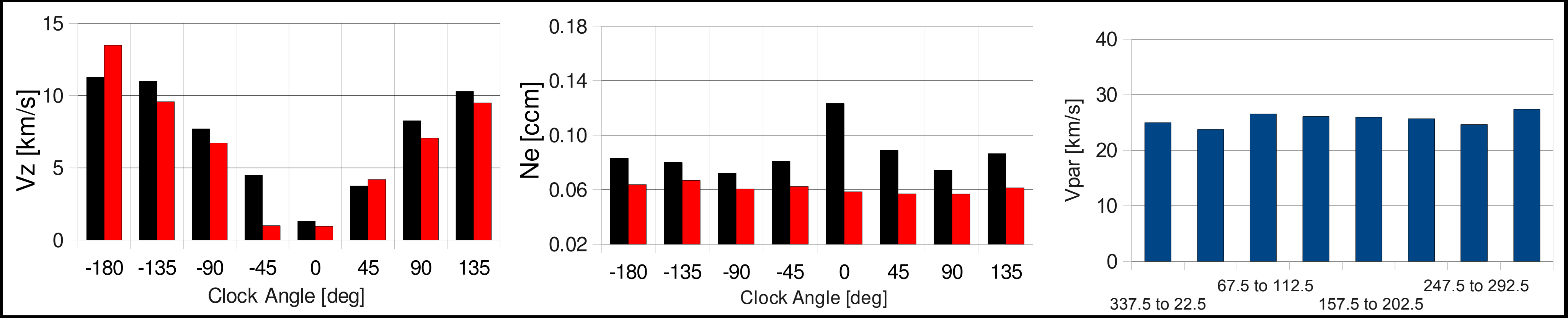
Activity dependence

- Dst <= -20 nT (storm time)
  - $V_\perp \sim 11$ km/s , $V_{||} \sim 30$ km/s, t = 150min
  - Loss above 12.7 Re (maps 77-87° Lat)
  - Lost flux = (0.01 - 1.3) • 10^{25} = 0-17 % of total

- Dst > -10 (quiet time)
  - $V_\perp \sim 5$ km/s , $V_{||} \sim 23$ km/s, t = 220 min
  - Loss above 10.5 Re (maps 73-83° Lat)
  - Lost flux = (0.16 - 1.5) • 10^{25} = 3-20 % of total

Activity dependence

- IMF dependency



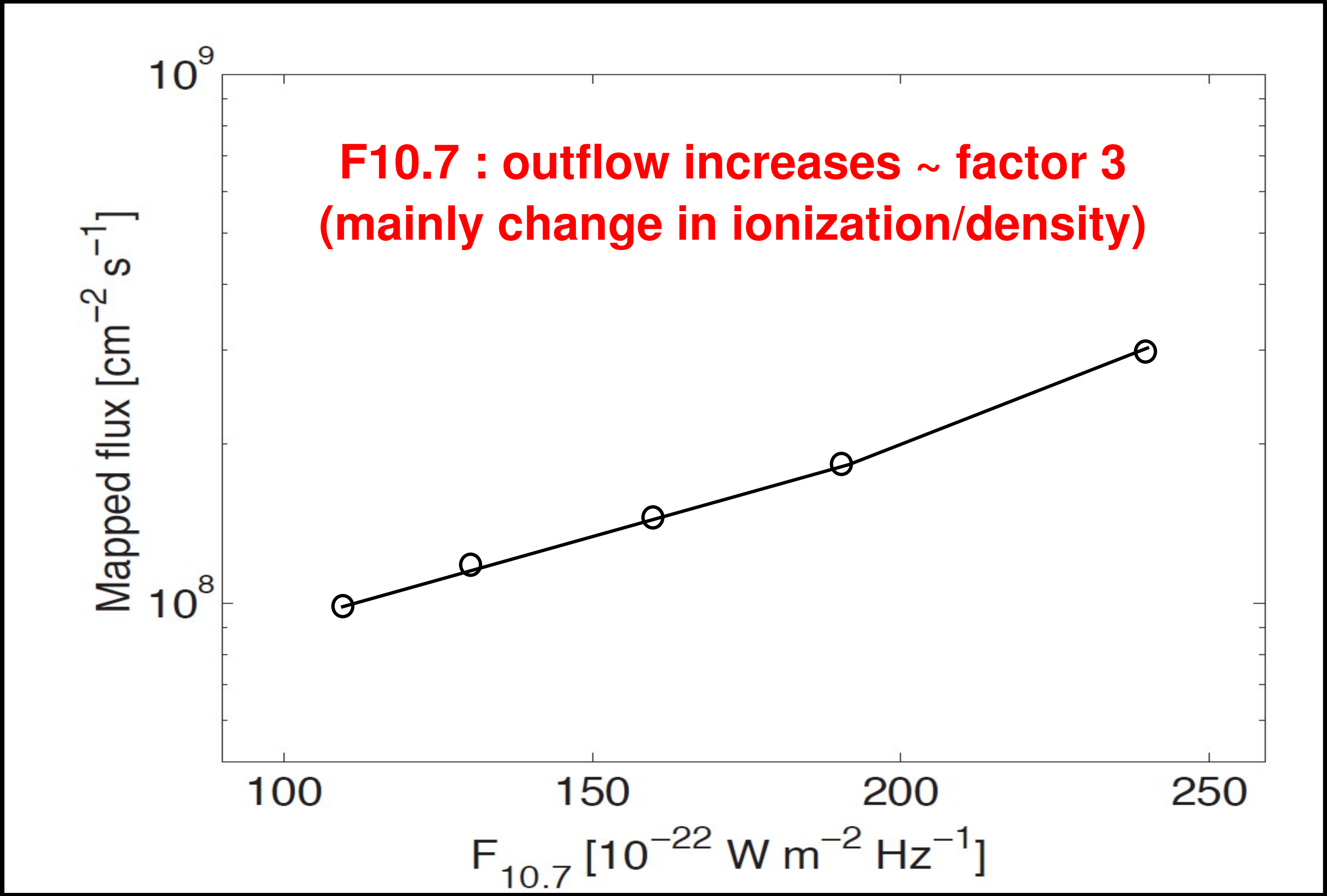
- Strong influence only on V⊥

Activity dependence

- **Northward IMF : 90° sector** 
  - $V_\perp \sim 2$ km/s , $V_{||} \sim 23$ km/s, t = 220min
  - Loss above 4.7 Re
  - Lost flux = All

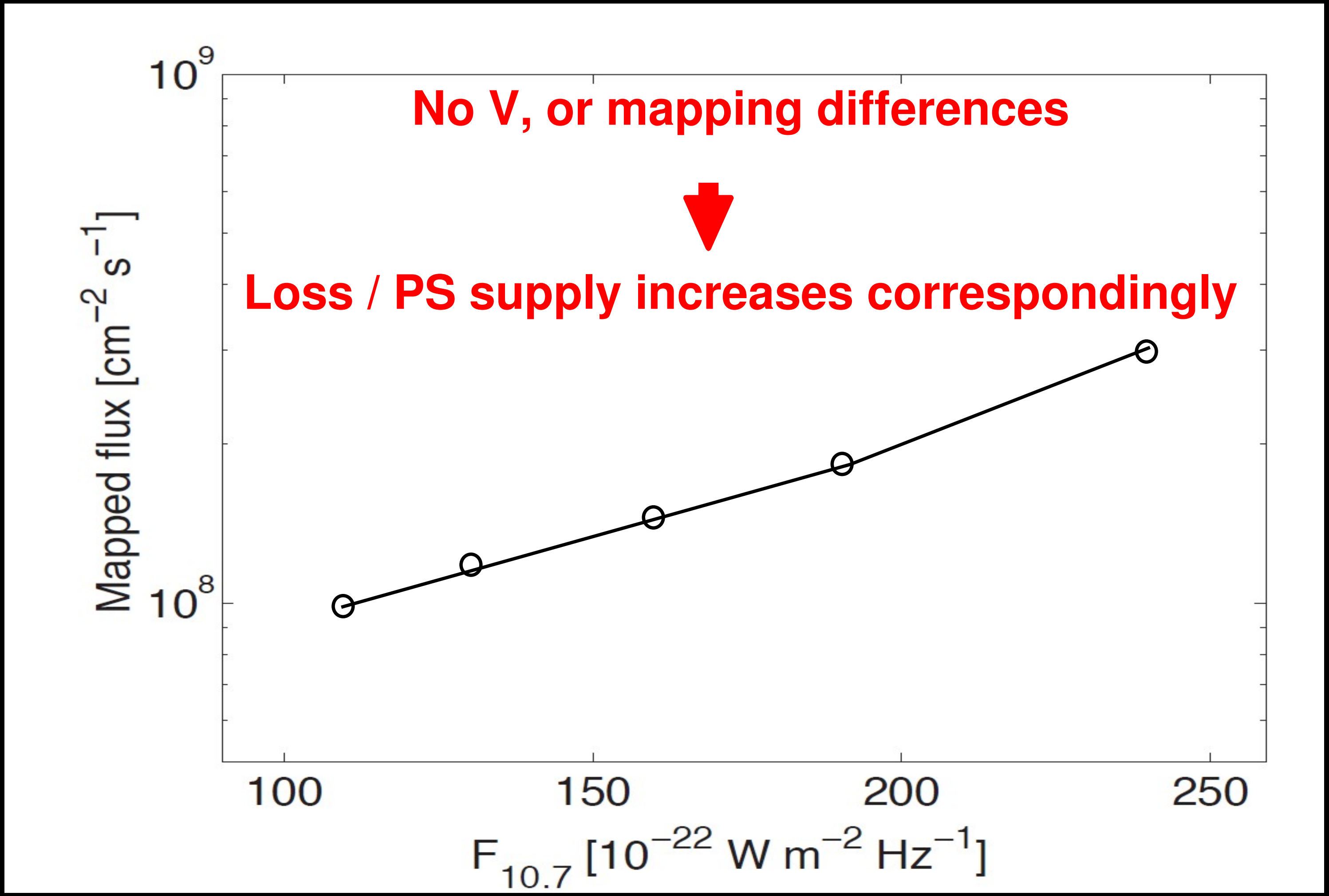
- **Southward IMF** 
  - $V_\perp \sim 12$ km/s , $V_{||} \sim 27$ km/s, t = 200 min
  - Outflow convected to PS

Solar activity dependence



Engwall et al, 2009, fig 9

Solar activity dependence



Engwall et al, 2009, fig 9

Summary and Conclusion

- On average :
  - Most of the outflowing ions are convected to PS
  - up to ~ 20% loss
- Geomagnetic activity
  - higher activity -> larger supply to PS
- Solar irradiance (F10.7)
  - higher irradiance -> larger supply to PS