MAX-PLANCK-GESELLSCHAFT

MPS

The effect of solar illumination on ionospheric outflow

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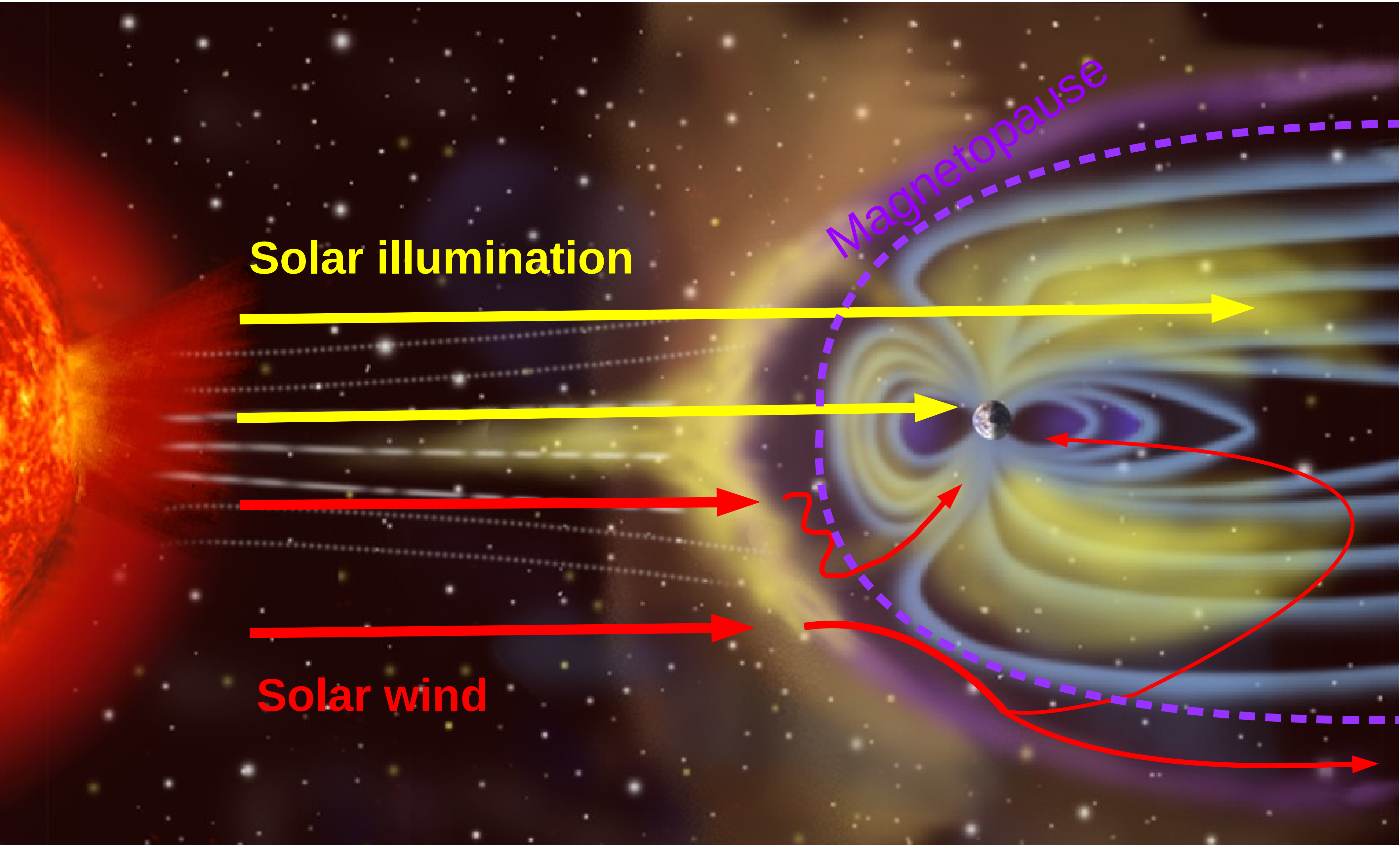
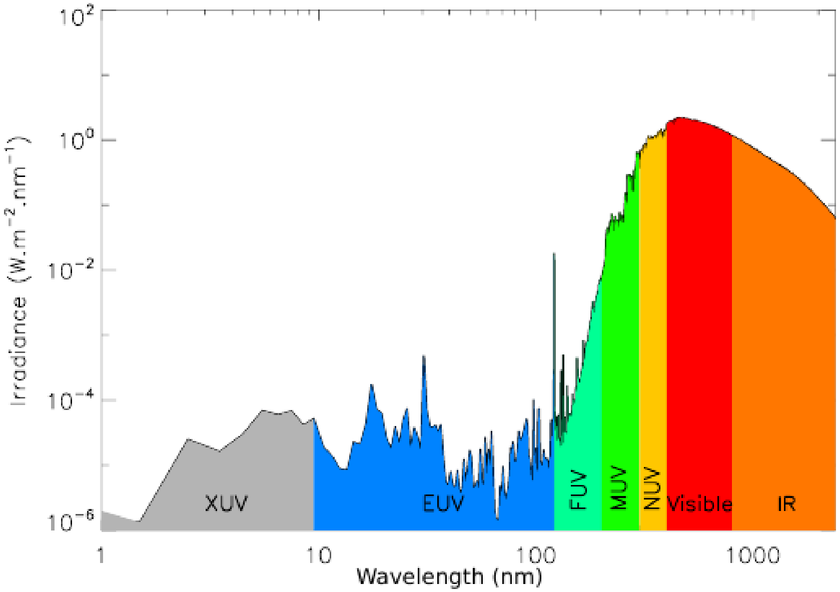
Solar energy input



Solar illumination

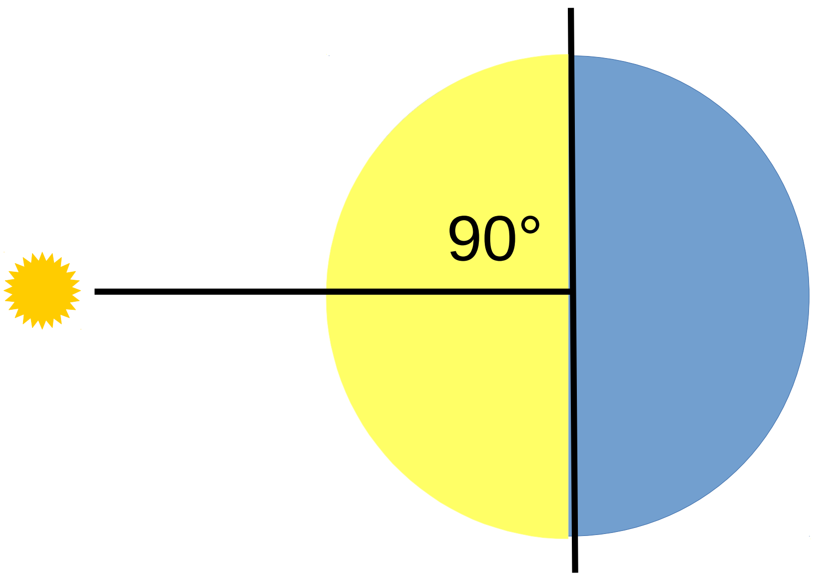


Intensity variation
F10.7 for EUV (and radio)

More energy in longer wavelengths

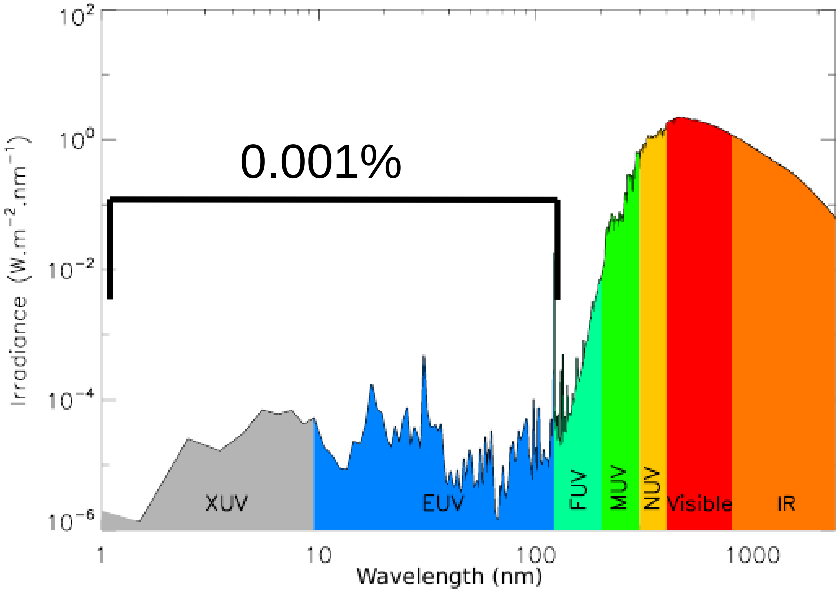
Illuminated or not

Solar zenith angle (SZA)



terminator

Solar illumination



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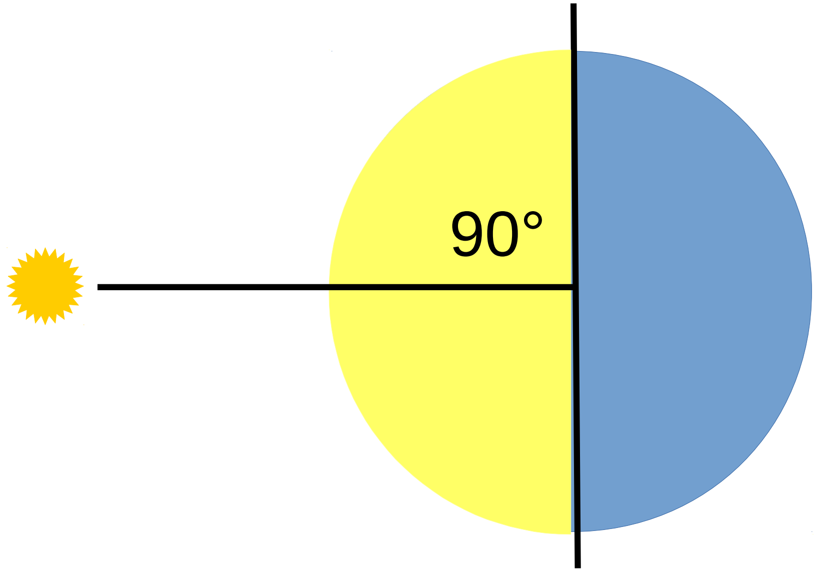

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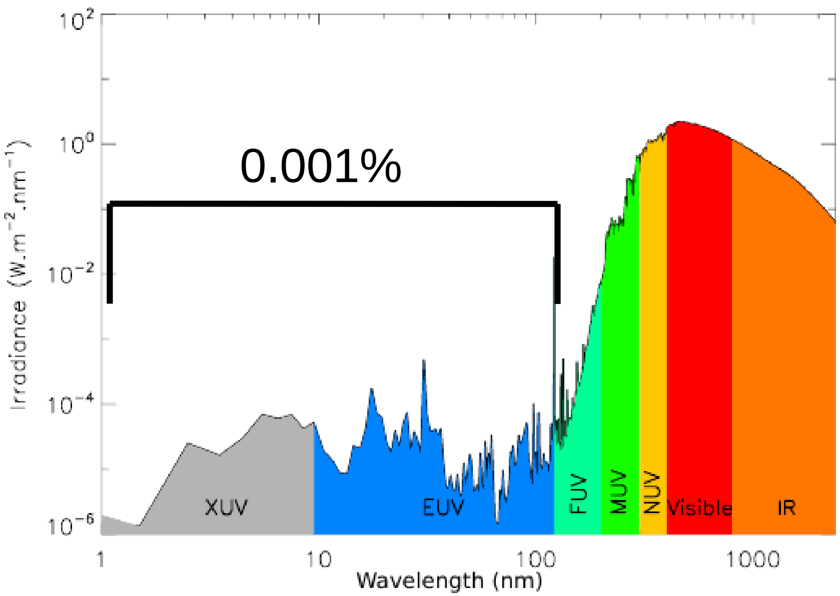

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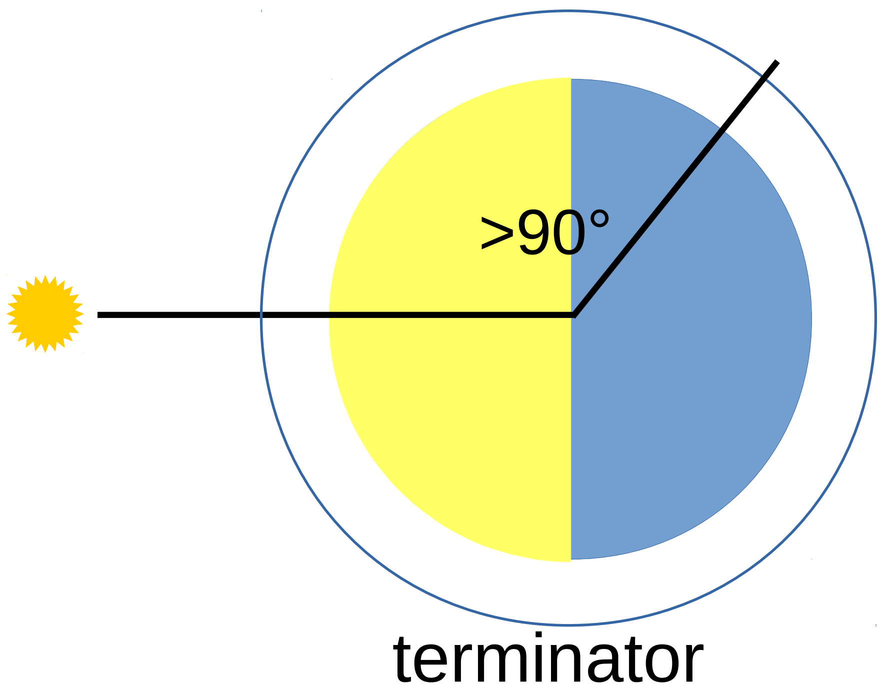
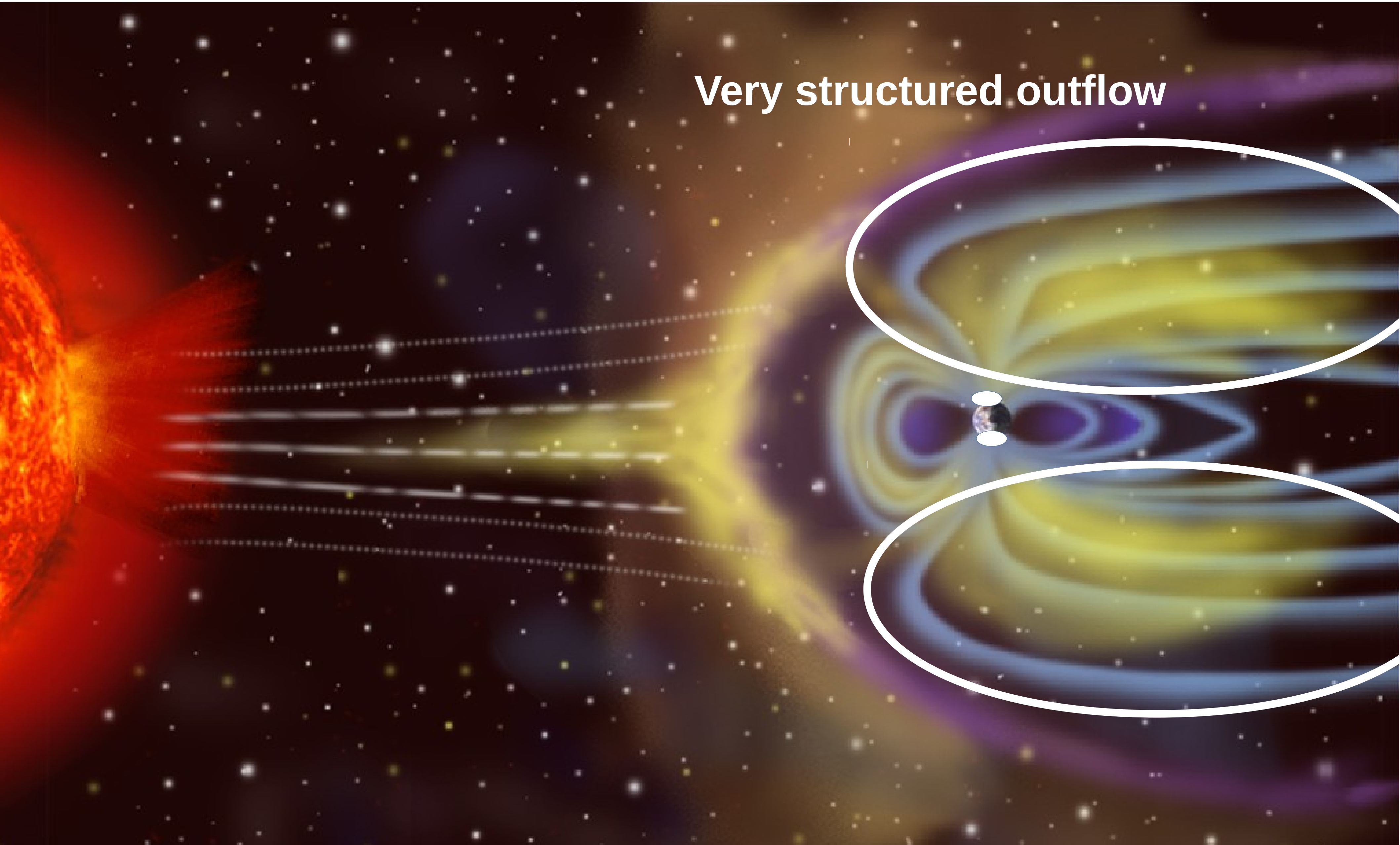
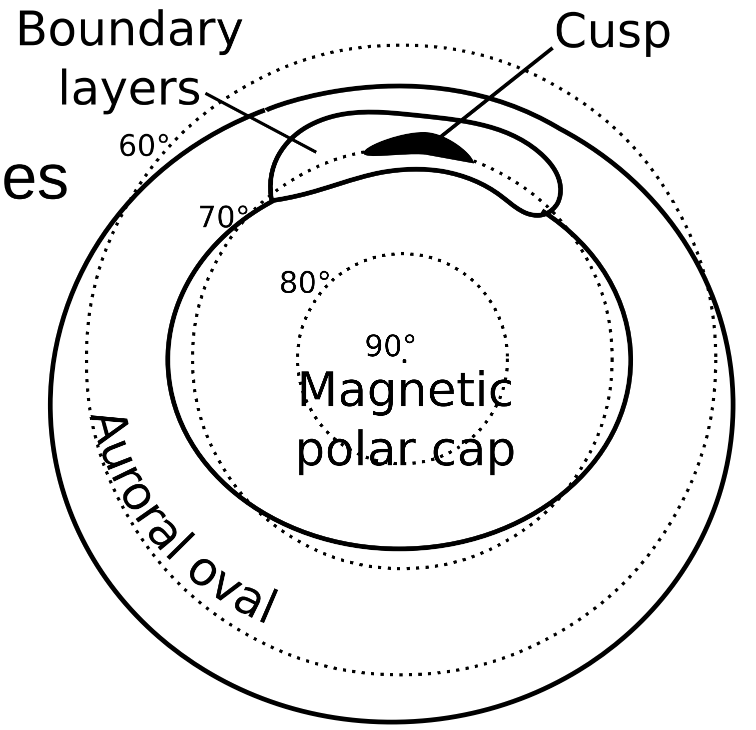


High-latitude magnetosphere



High-latitude ionosphere

- Cusp
  - Connected to open field lines
  - Large energy input: Particle precipitation, waves
  - Small spatial extent
- Magnetic polar cap
  - Connected to lobes, open field lines
  - Less energy input
  - ~<70°> MLAT, ~60°-80°
- Auroral oval
  - Connected plasma sheet, closed
  - Large energy input
  - Larger spatial extent



Polar wind

Gravitational separation of electrons and ions

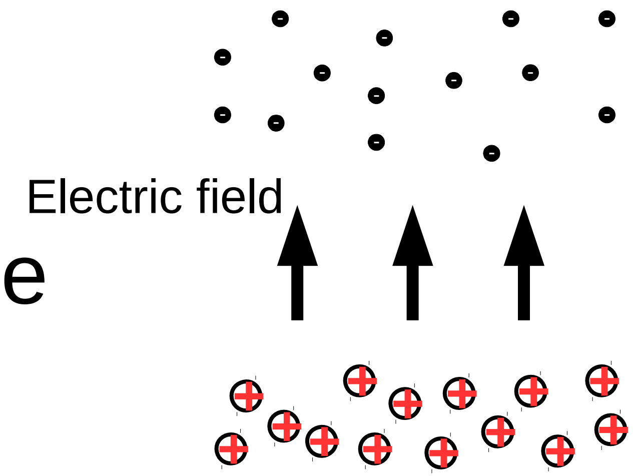
⇩

Ambipolar electric field

On open field lines, no pressure from above

⇩

Low-energetic and cold outflow



“Thermal expansion/escape of a plasma”

O(10^{25}-10^{26} s^{-1}) ⇨ Much more efficient than neutral thermal escape (Jean’s escape)

6×10^{24} s^{-1} for same area

Plasmasphere

- Filled by ionospheric upflow similar to polar wind, until pressure balance

- Despite closed field lines outflow also possible:
  - Plasmaspheric **erosion**
  - Plasmaspheric **plumes**
  - Plasmaspheric **wind**

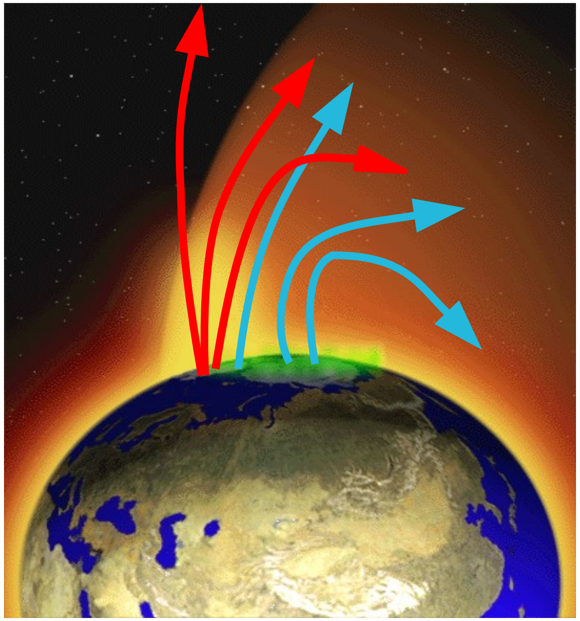
    Imbalance between gravity, pressure gradient and centrifugal force

    ⮡ Transmitted by magnetic field

Difficult to measure

- Contamination by cusp outflow

  Low-energy cusp outflow convected over polar cap, difficult to differentiate from polar wind



- Spacecraft charging

  Spacecraft potential repels ions
  Typically higher than energy of polar wind ions

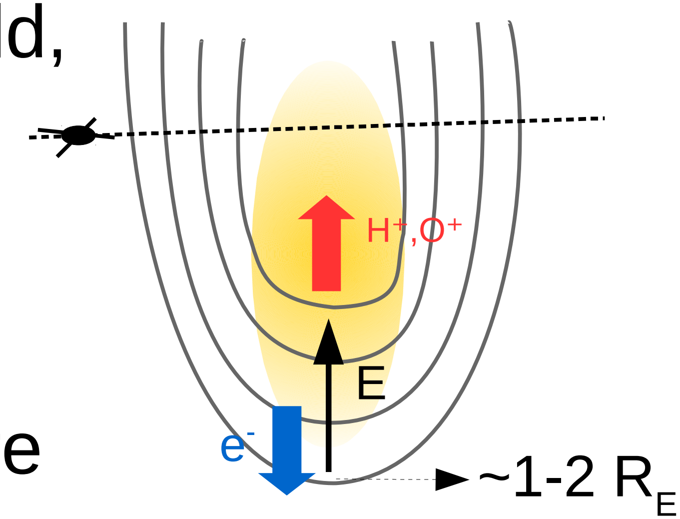
  Become invisible to detectors

Outflow above polar cap arcs

- Large scale ⟺ Small scale

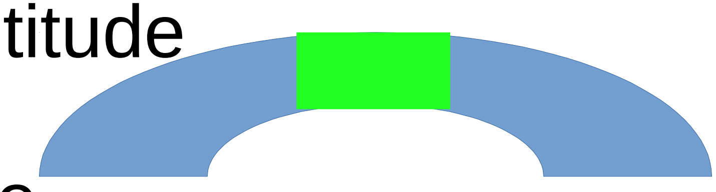
- Similar to auroral arcs,
  Across polar cap, **less energetic**

- Quasi-static field-aligned electric field,
  U-shaped potential, current system

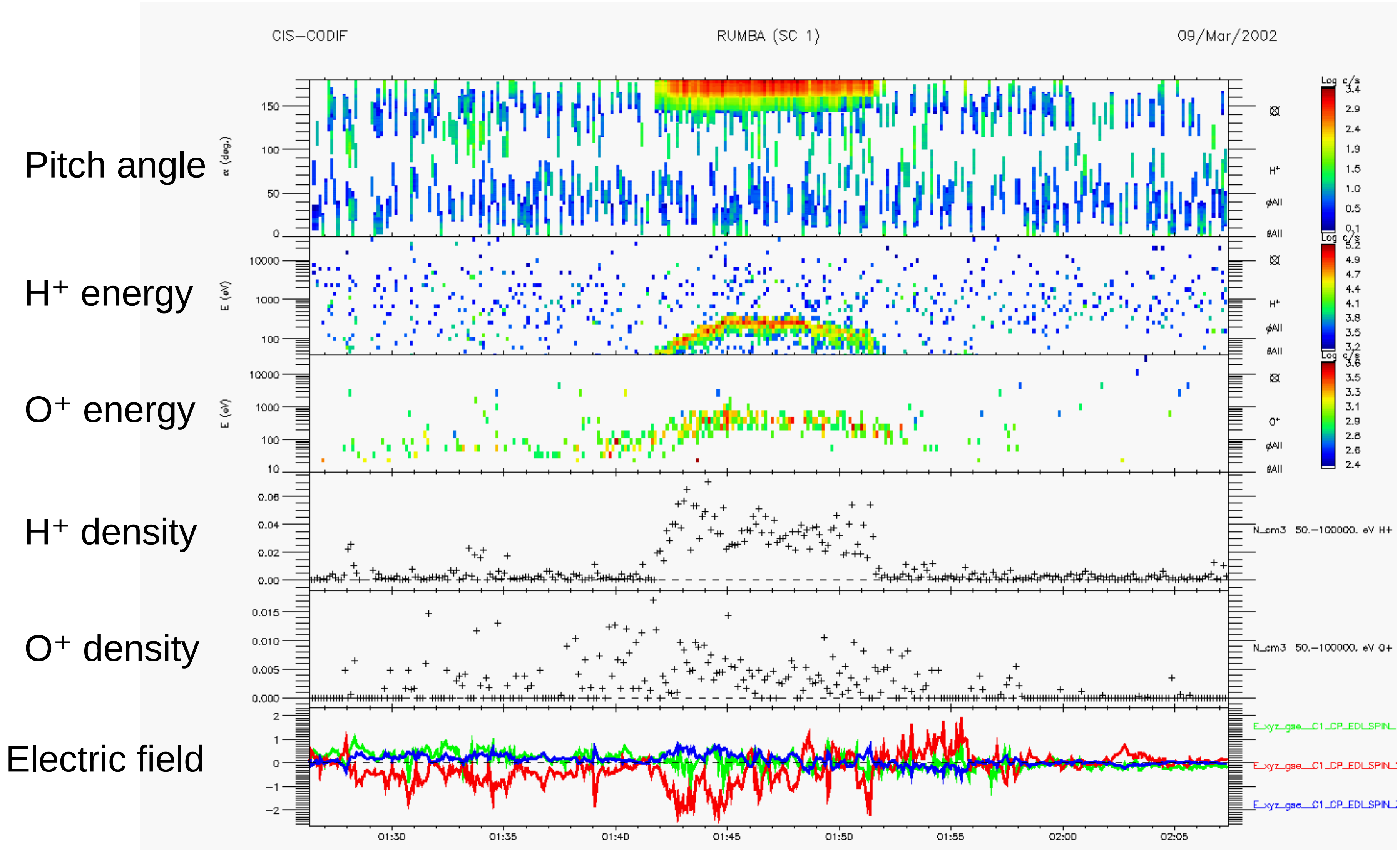


- Electrons accelerated downwards
  Ions accelerated upwards
- Current system closing in ionosphere

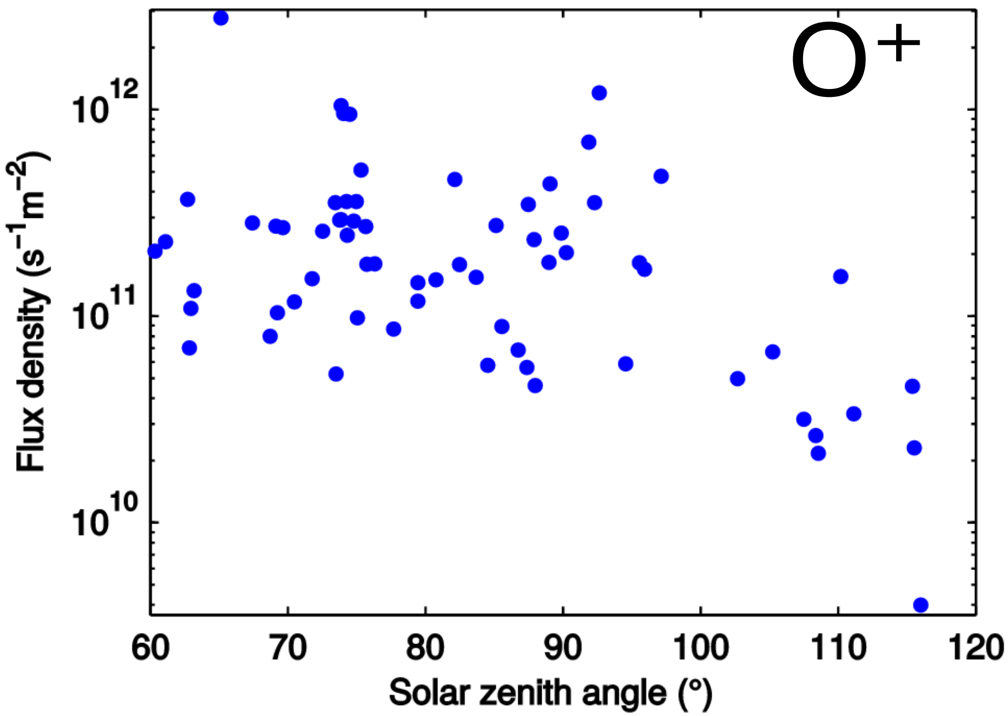
- Observed by Cluster at ~ 5-8 R_E altitude
  [Magiollo et al., 2006; 2011; 2012]
  Accelerated ions better measurable



Ion beams above polar cap arcs



Above polar cap arcs: SZA



[Maes et al., 2015]

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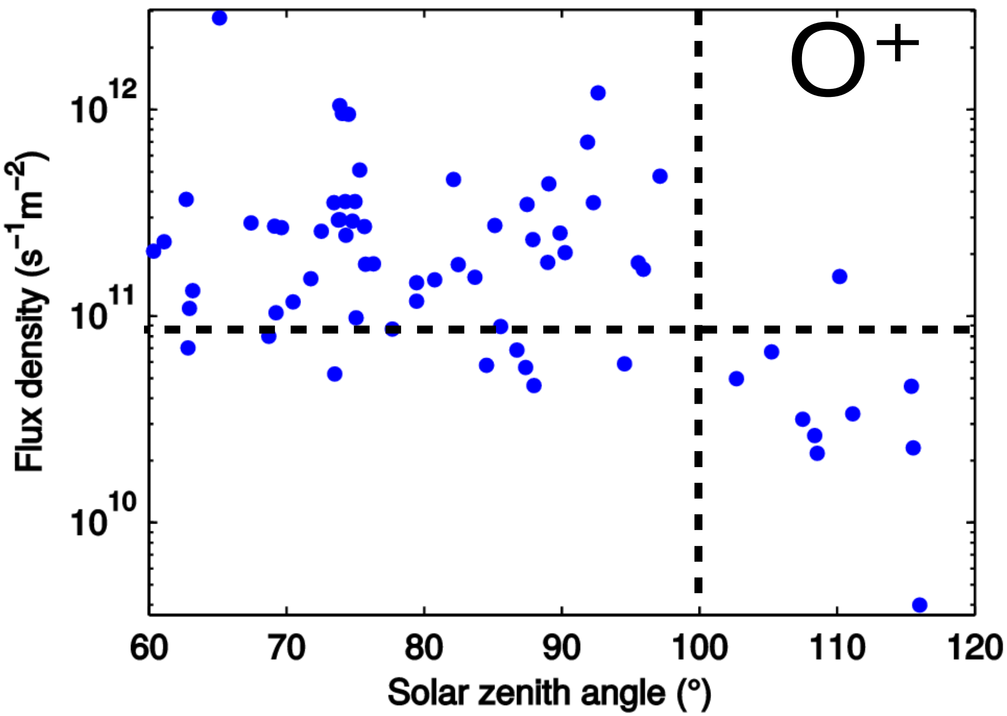

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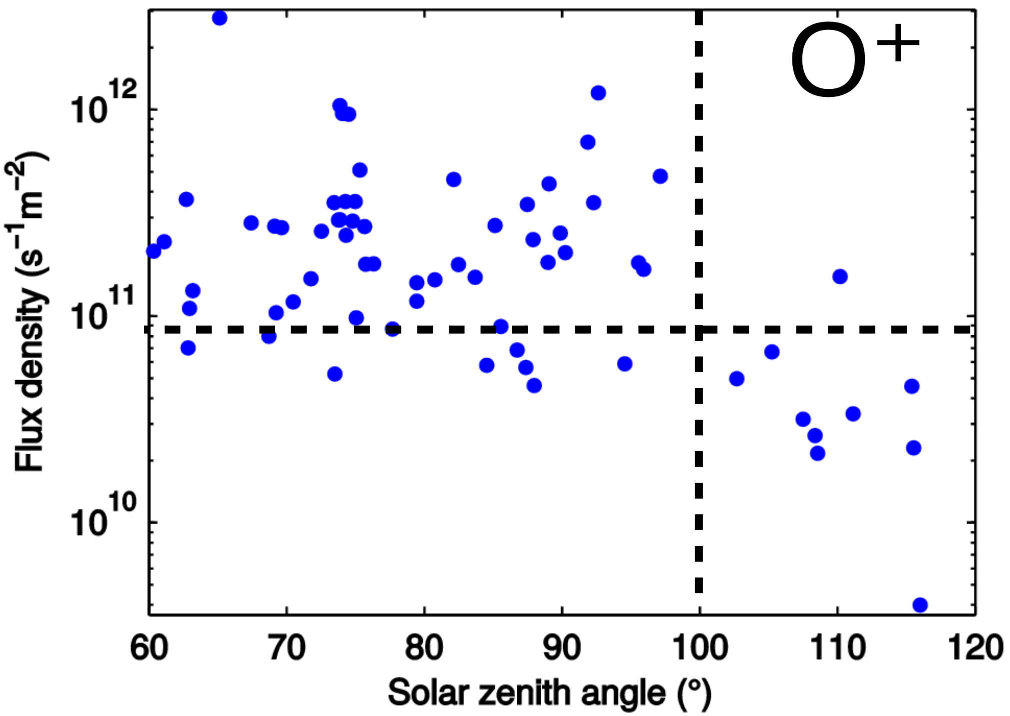

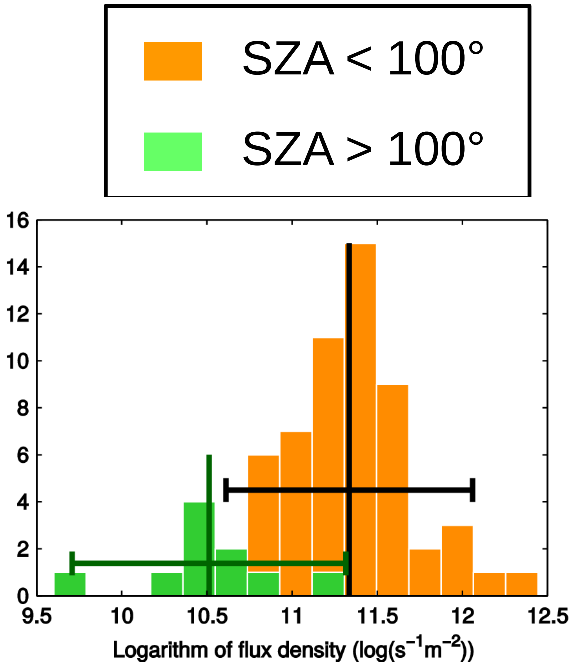

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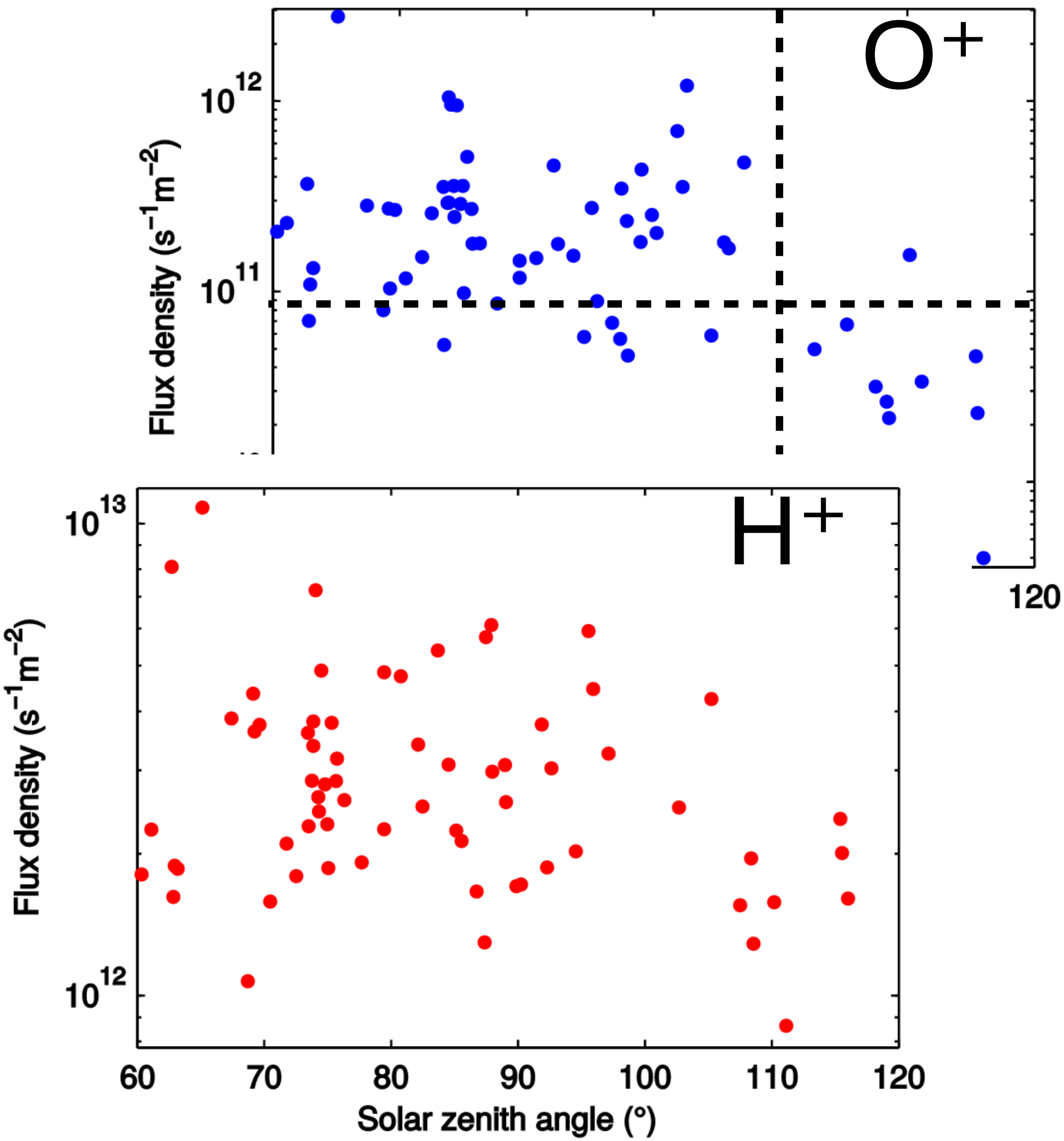

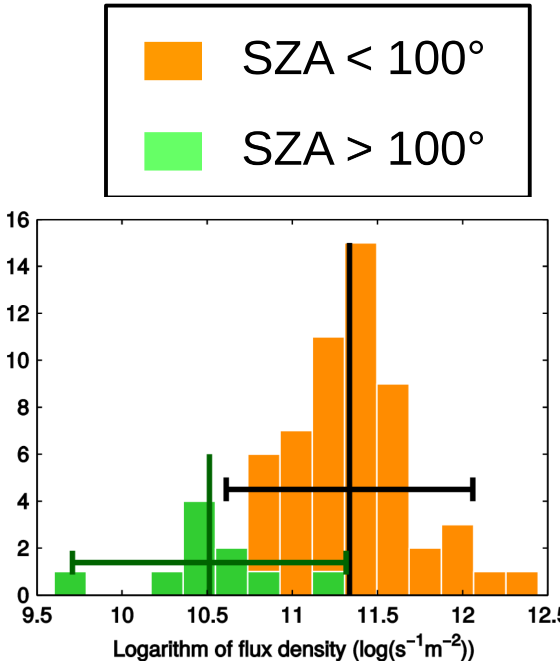

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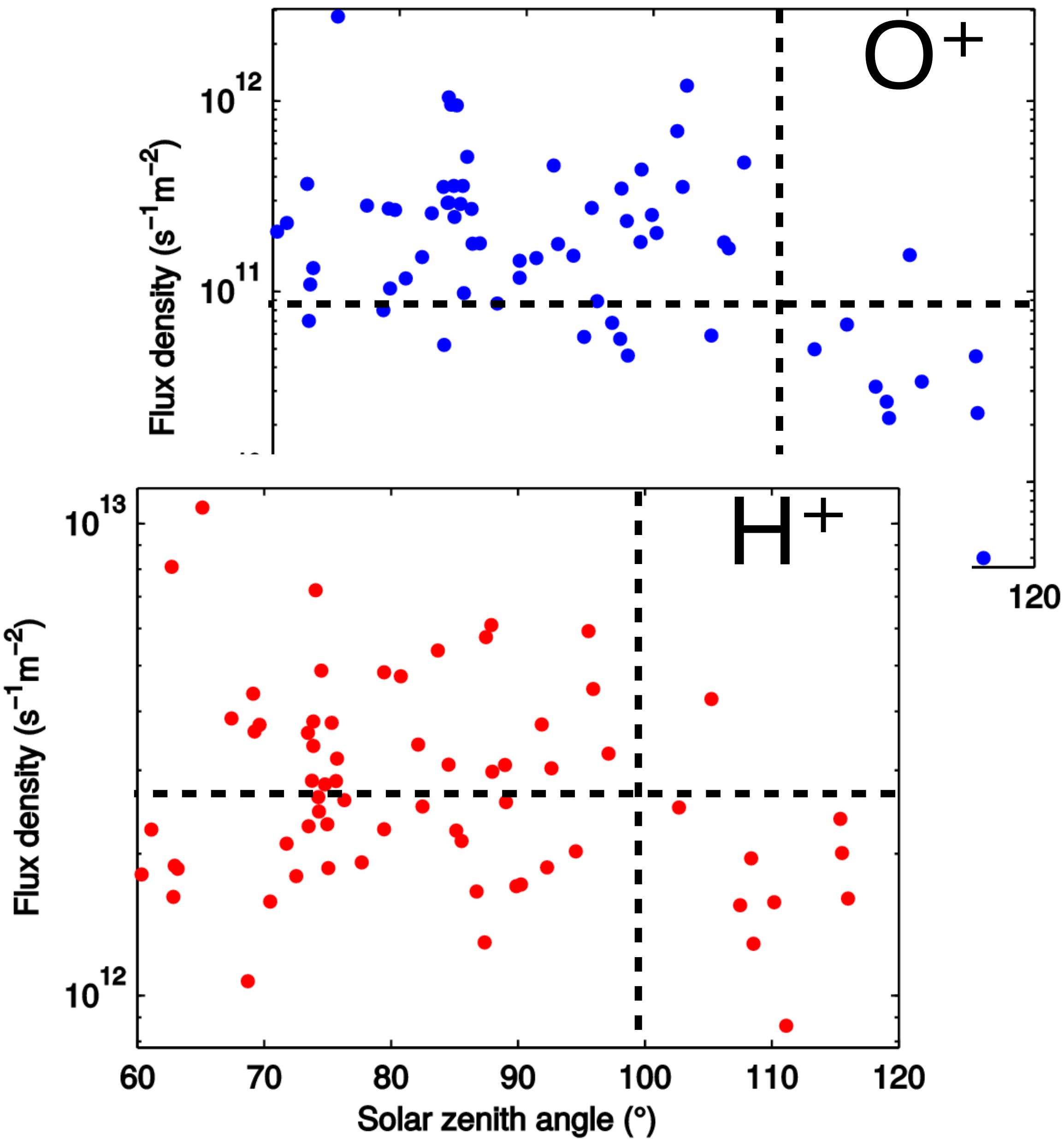

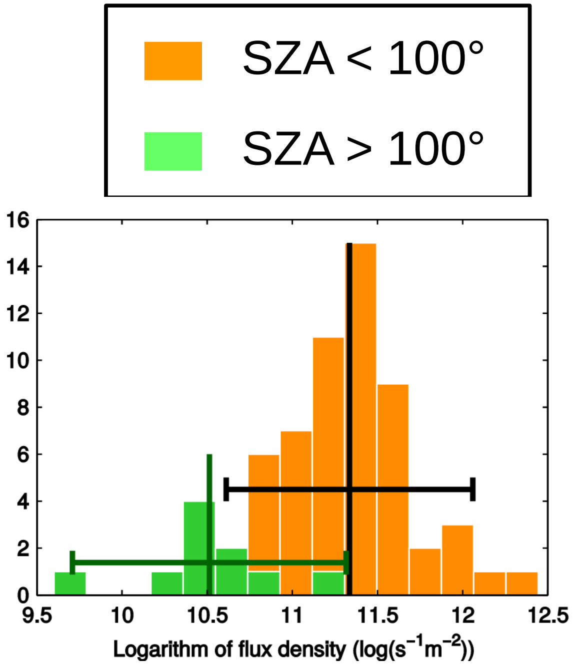

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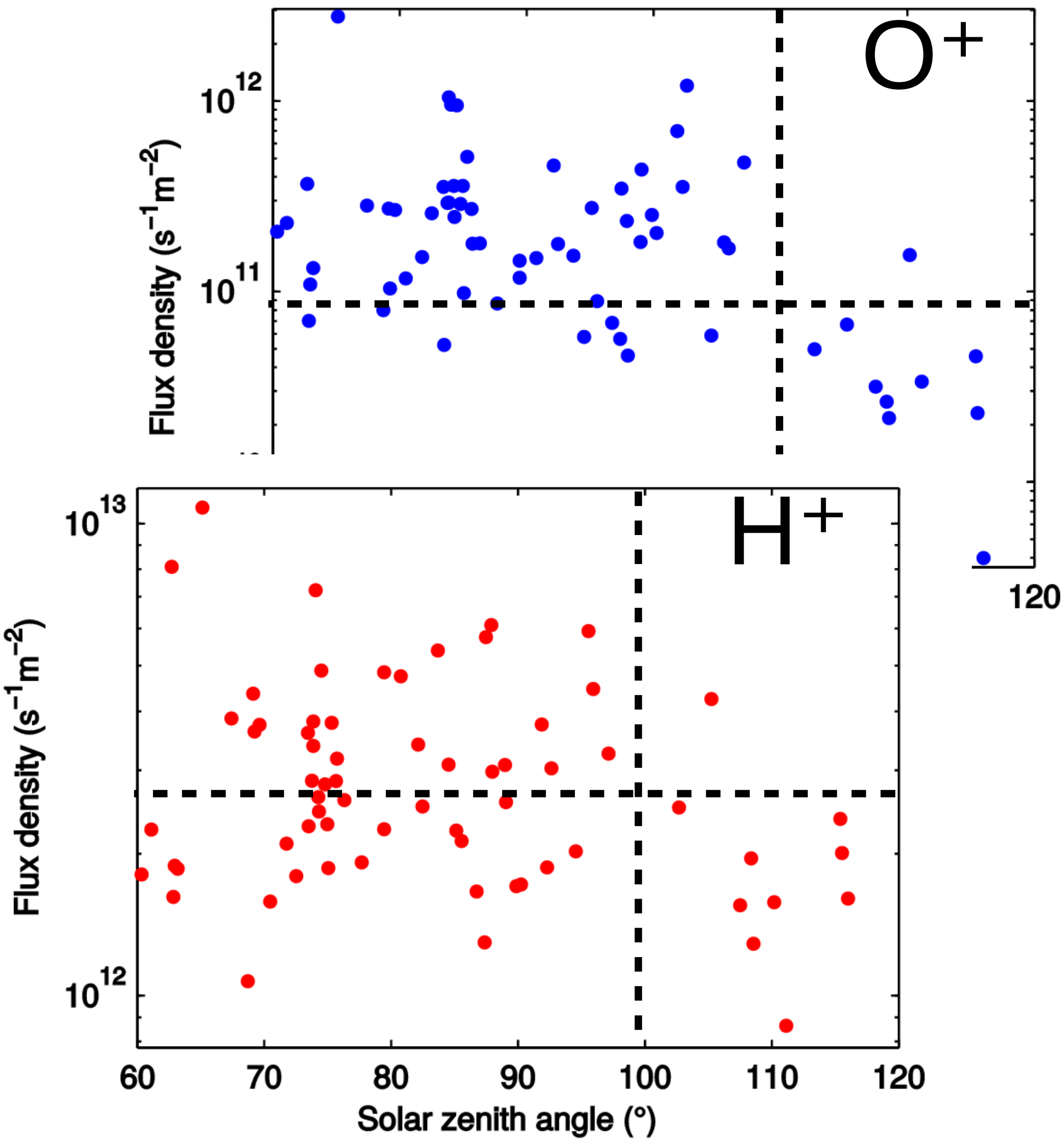

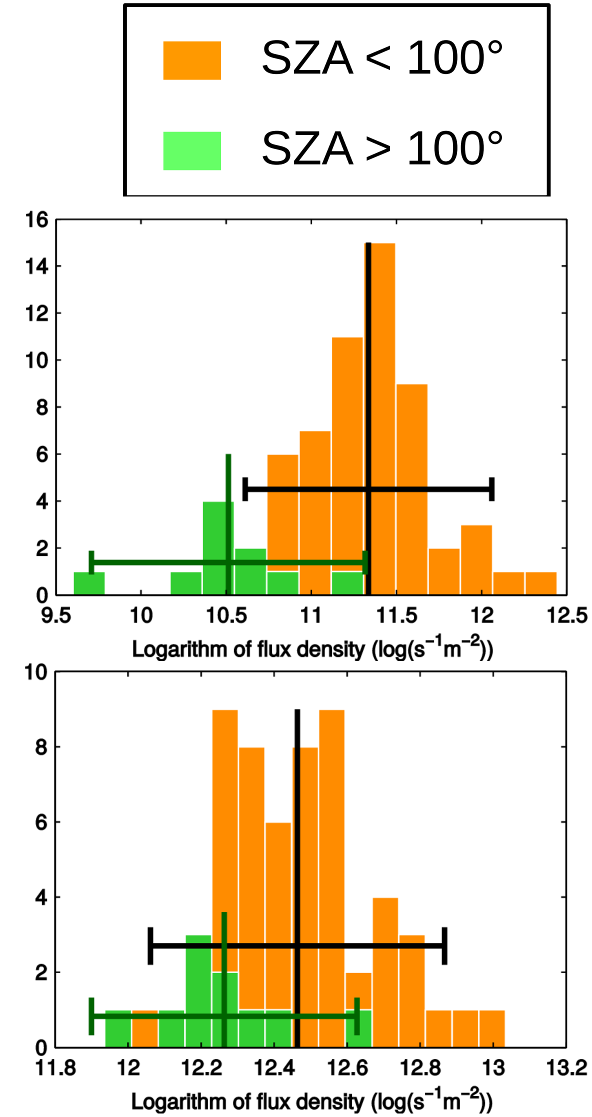

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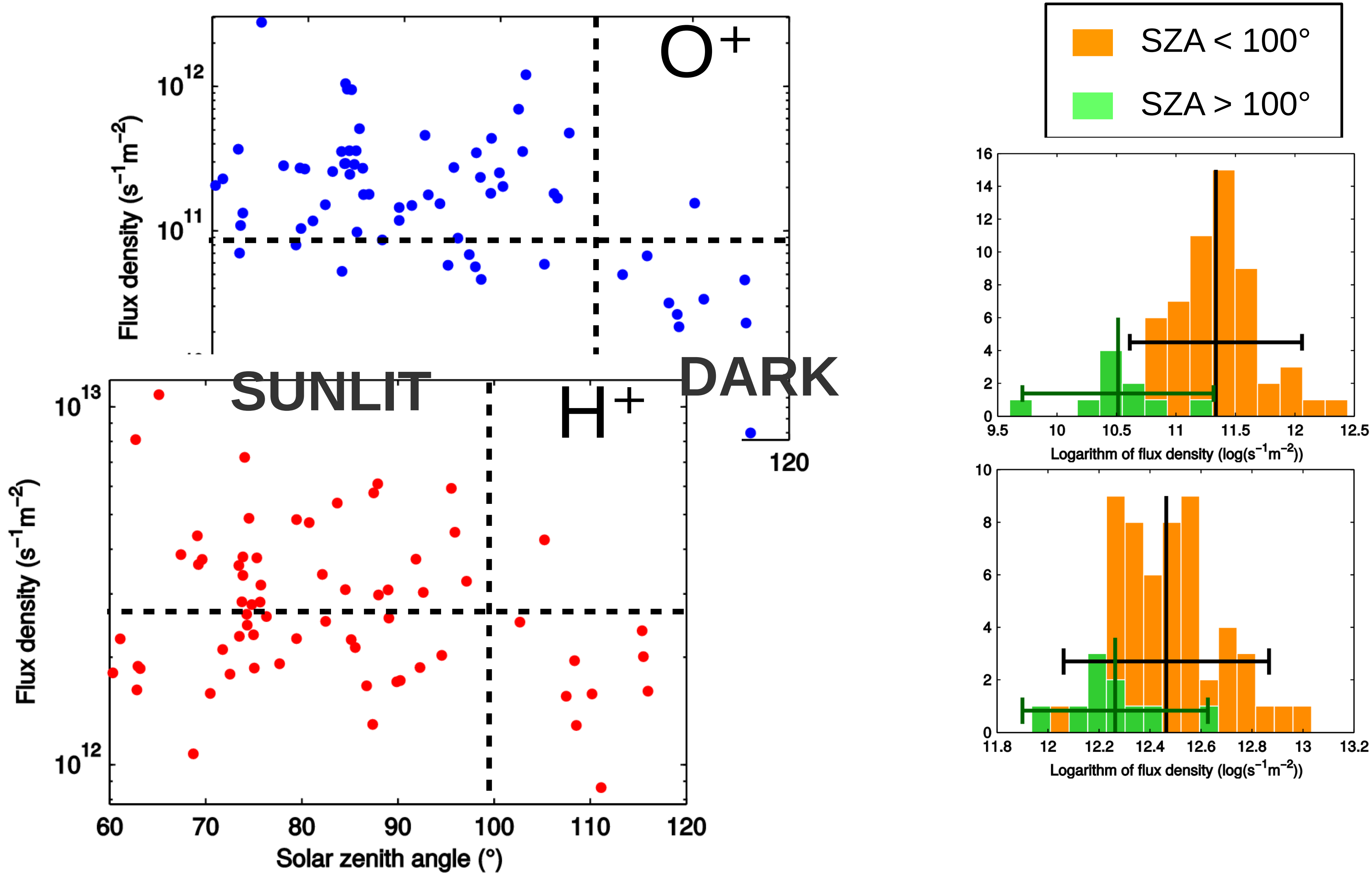

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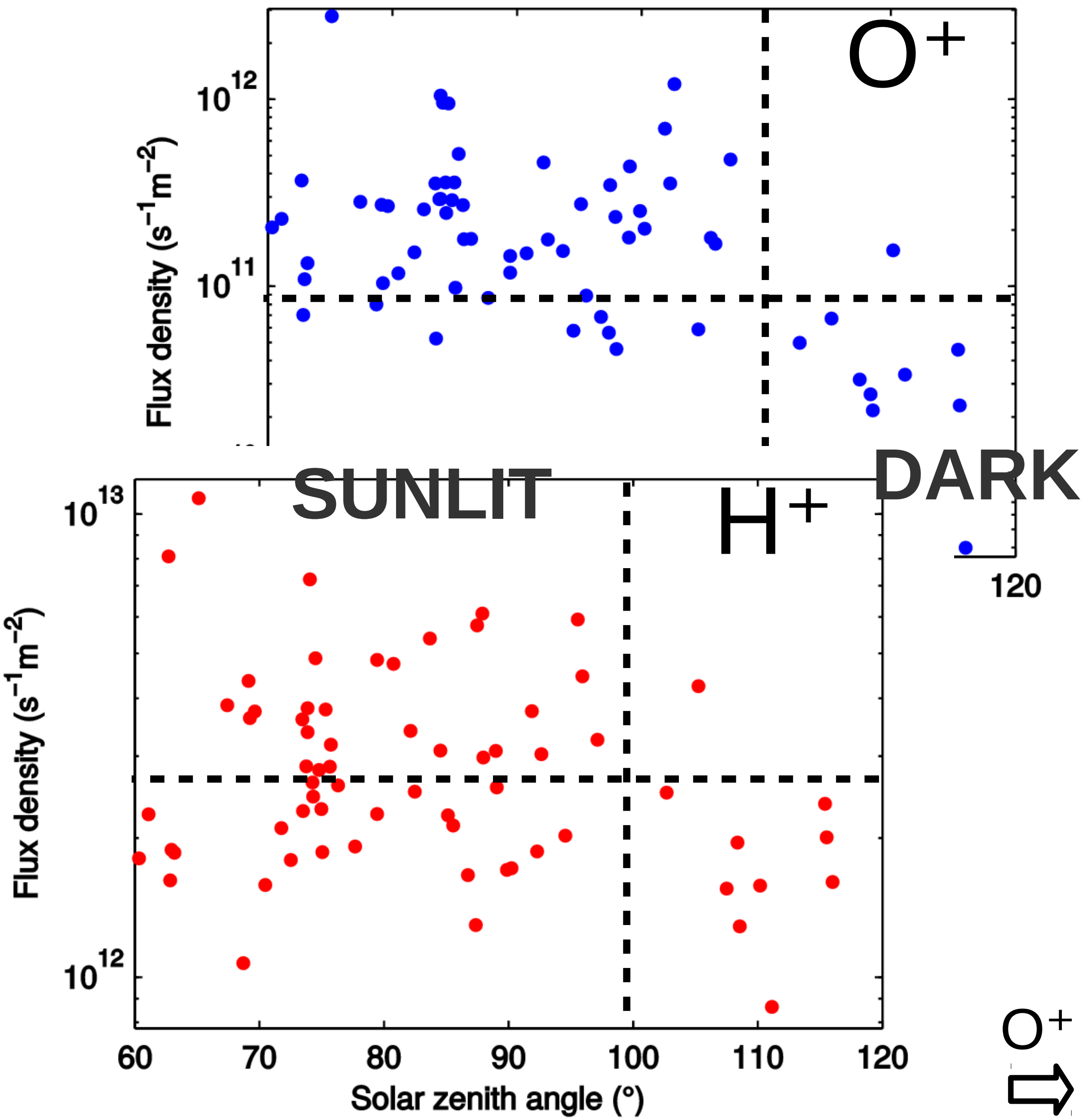

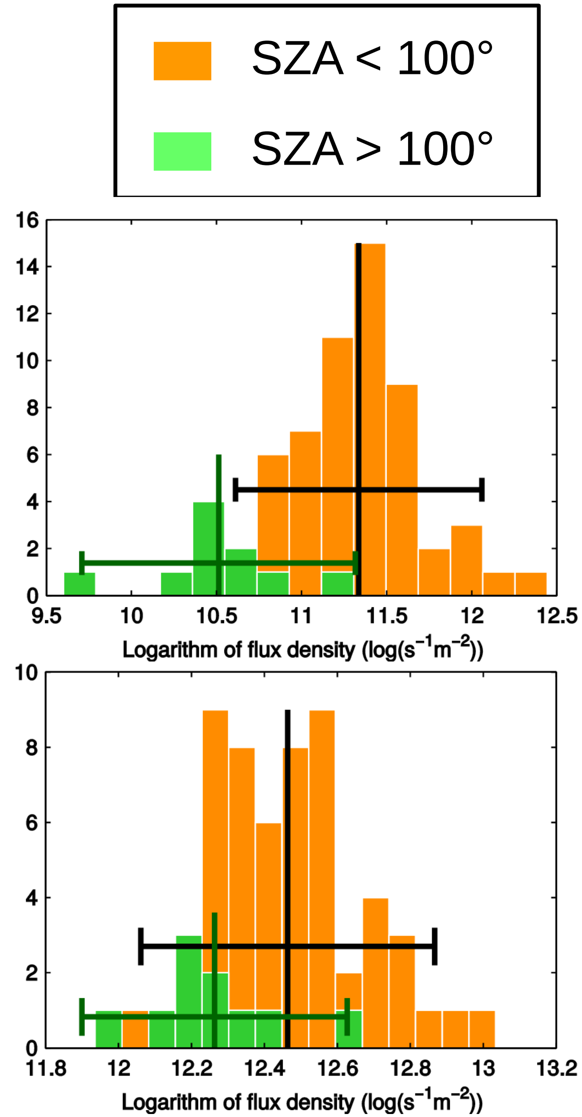

O^+ more strongly affected

⇨ O^+/H^+ ratio also affected

O^+ in polar wind?

- H^+ flux similar to polar wind
  (~10^{25}-10^{26} s^{-1} if integrated over whole polar cap)
- Electron precipitation no effect on flux

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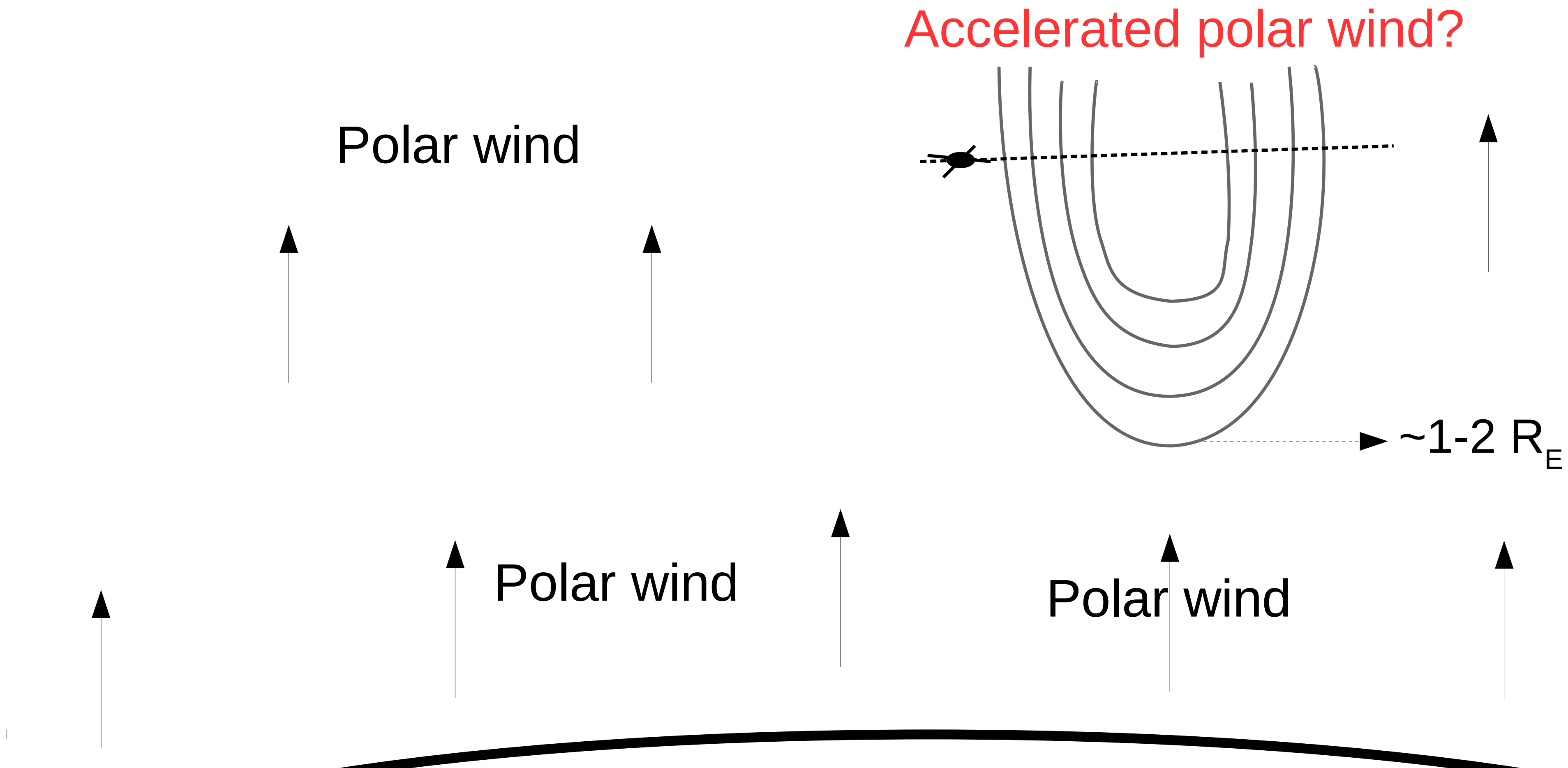

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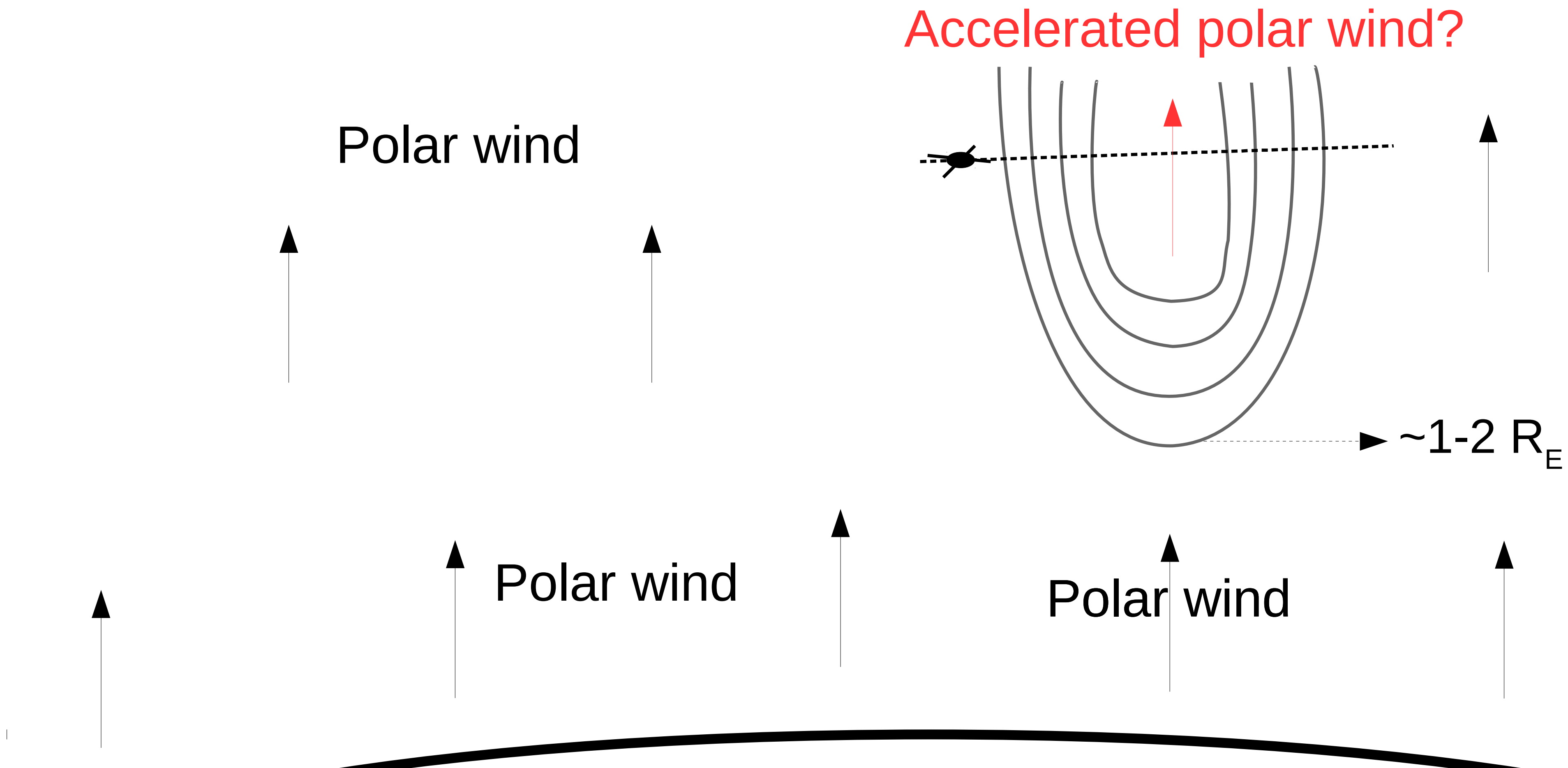

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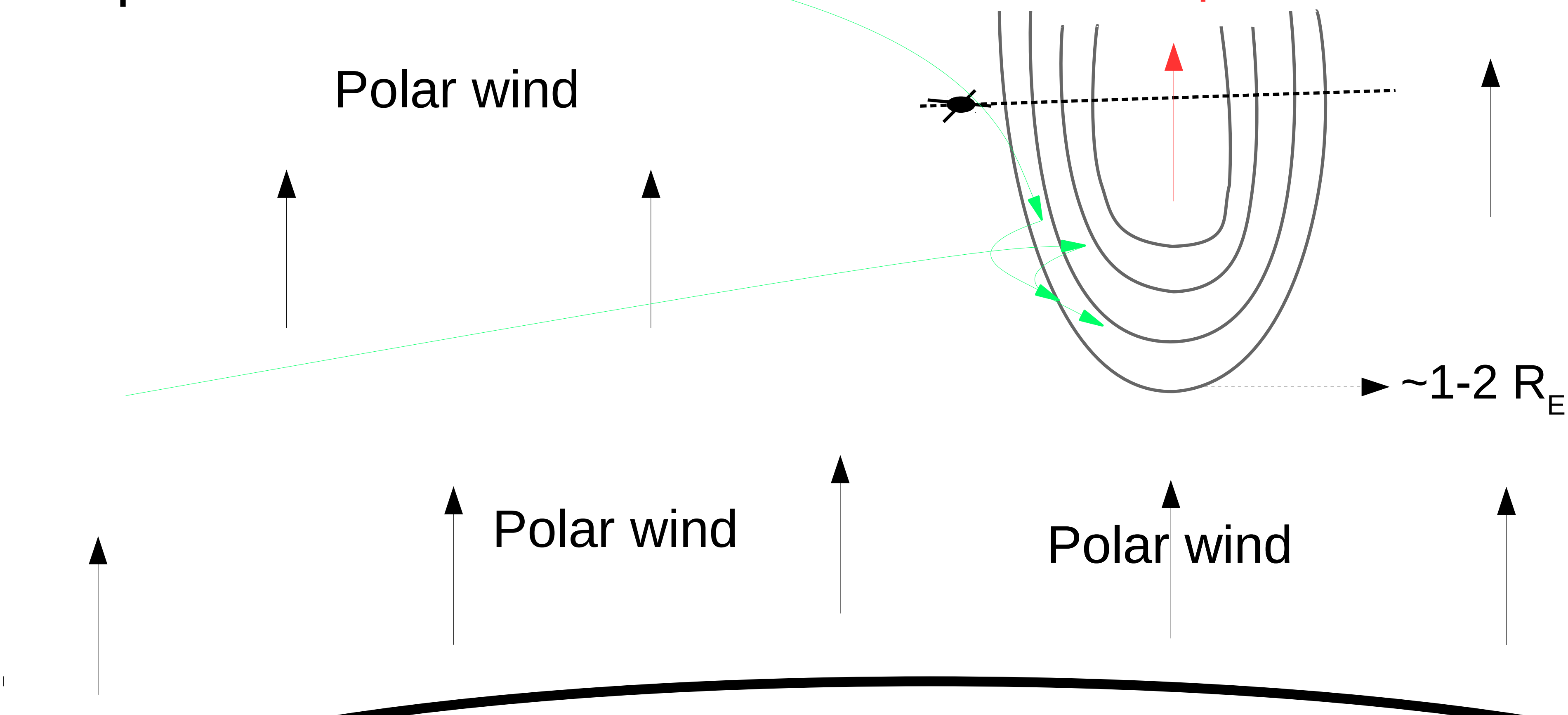

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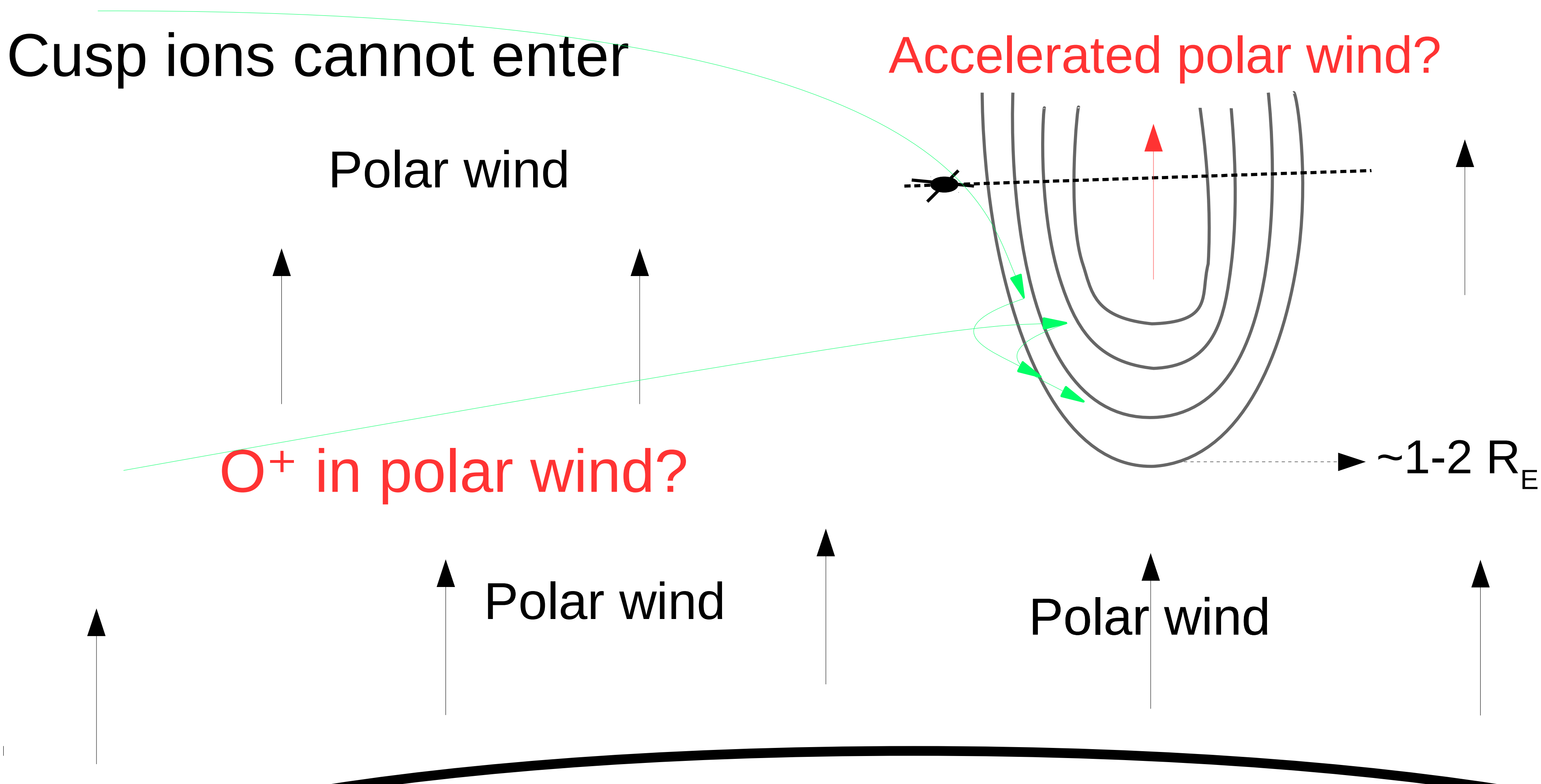
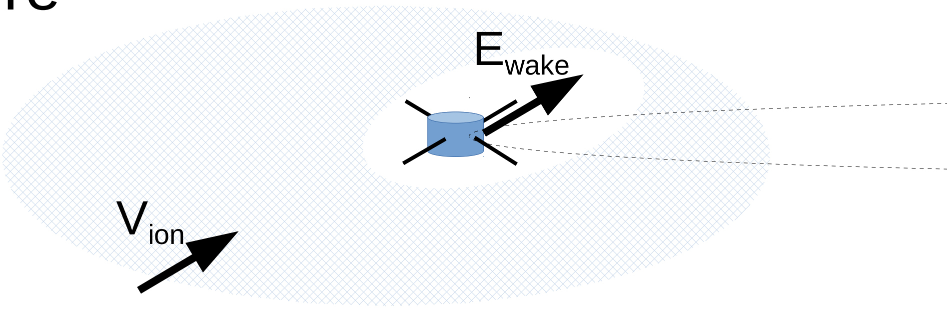


Wake field method

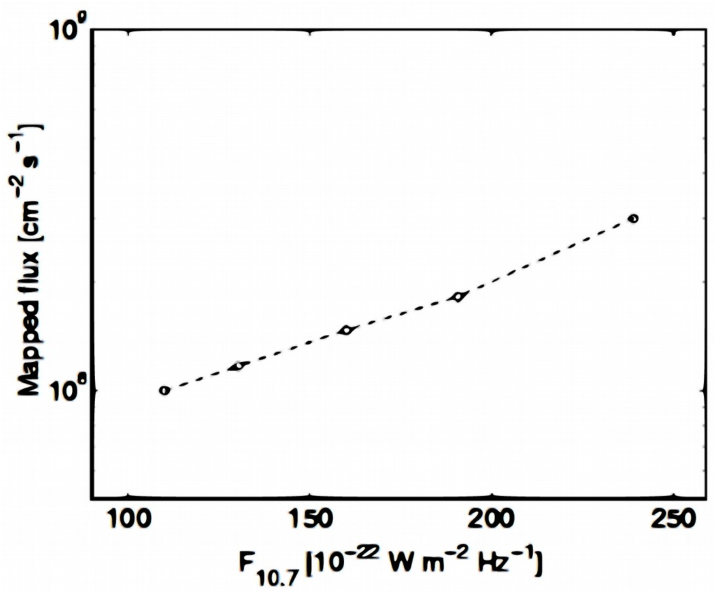
- Spacecraft charging
  - Polar wind difficult to measure
  - Creates wake
    $kT_i < mv_i^2/2 < eV_{sc}$



- Wake easier filled by e^- than ions [Eriksson et al., 2006]
  - Electric field
  - Can be measures with Cluster EDI and EFW
  - Dependent on velocity [Engwall et al., 2006, 2009]
- Get velocity from wake and density from spacecraft potential

Polar wind: F10.7

[Engwal et al. 2009]



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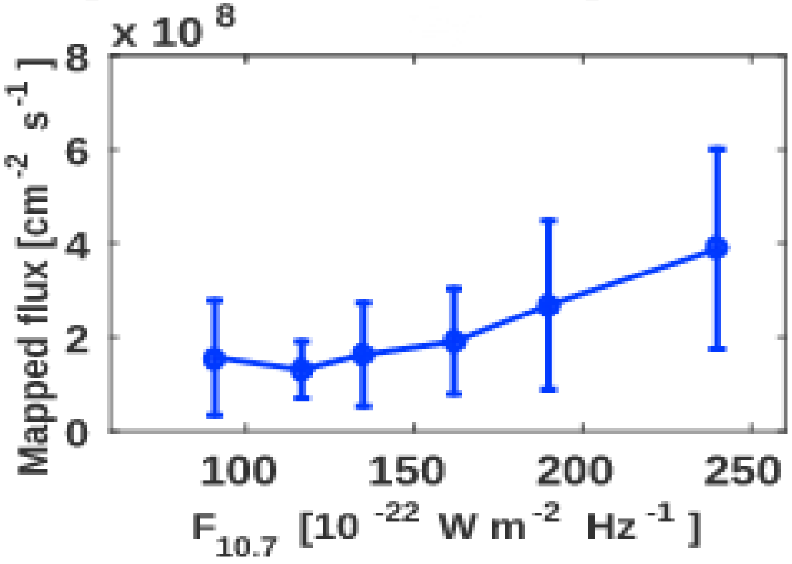

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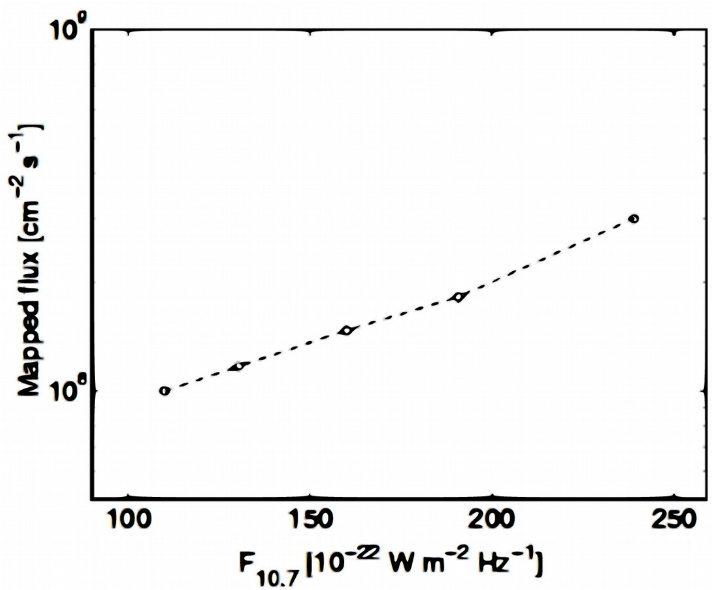

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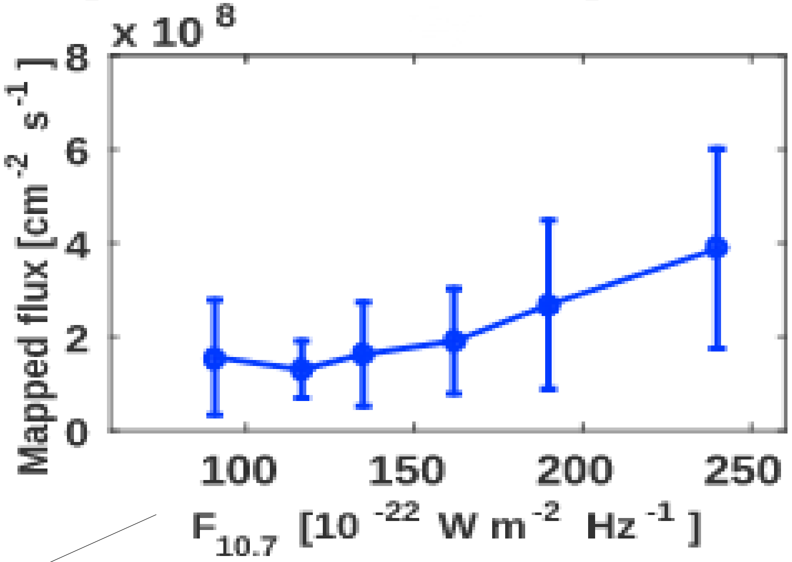
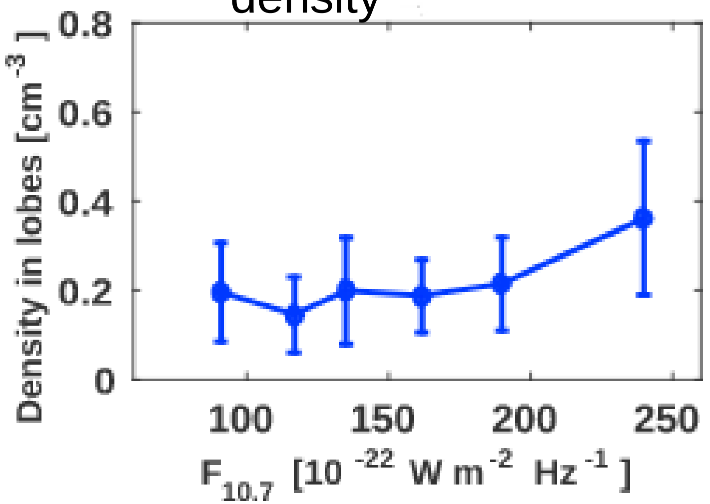


density



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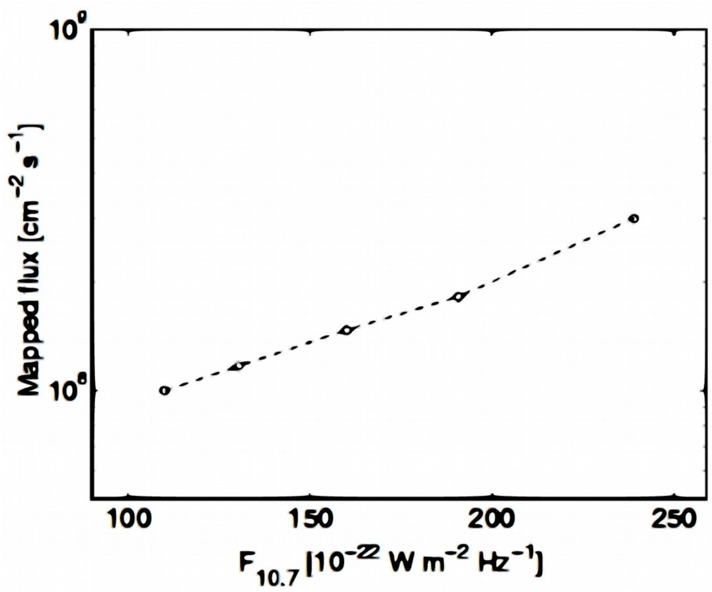

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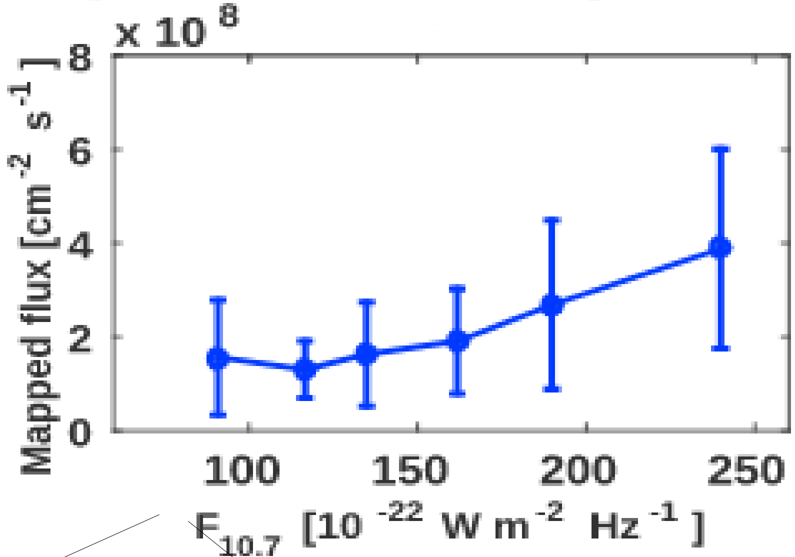

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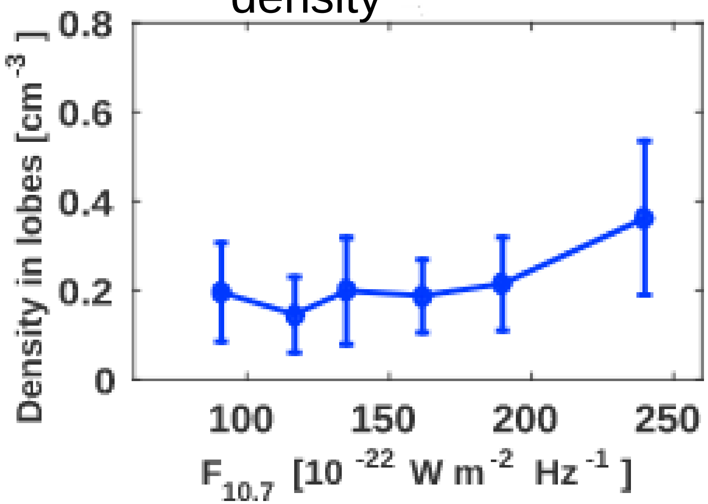
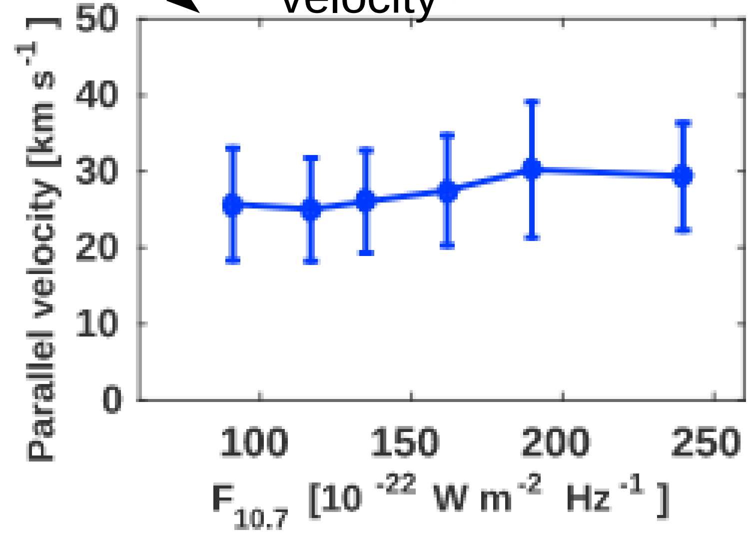


velocity



Polar wind: F10.7

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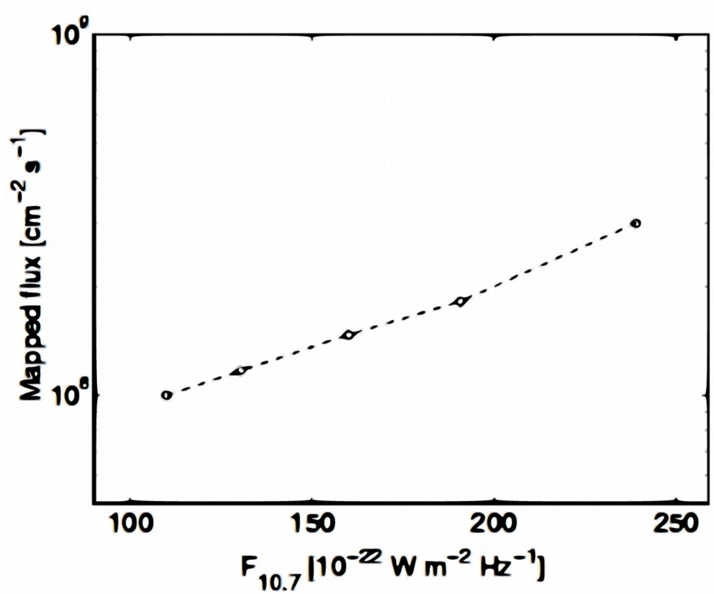

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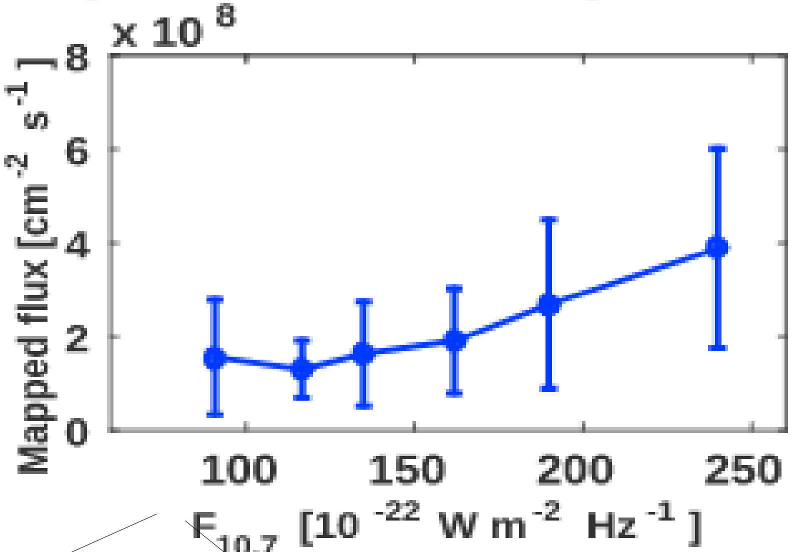

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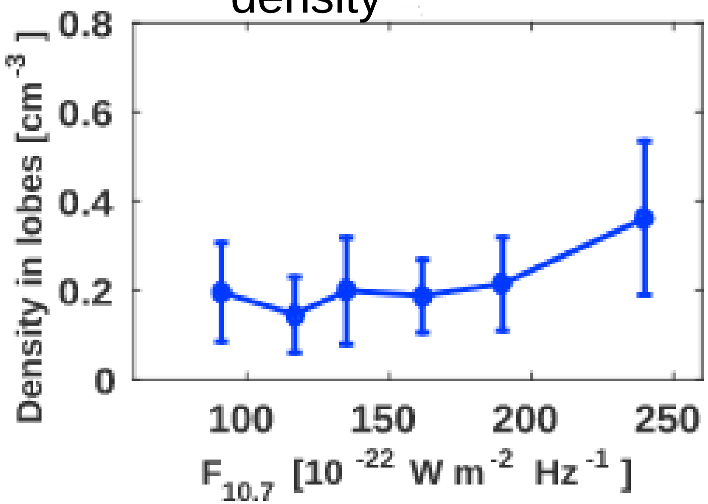

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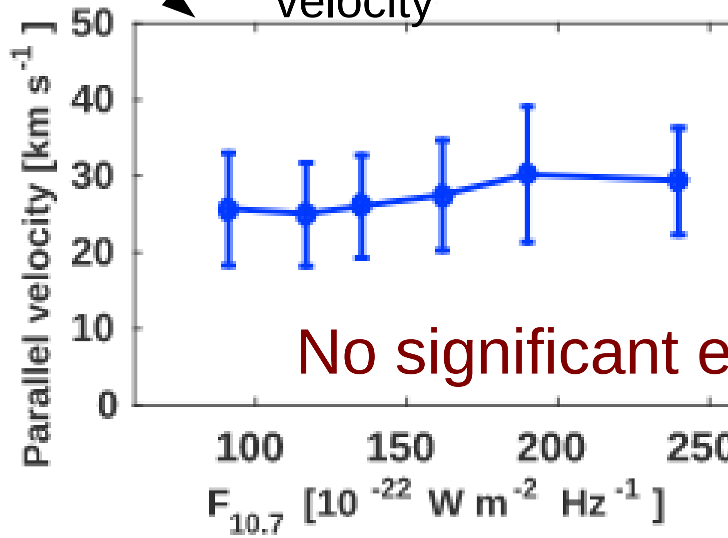
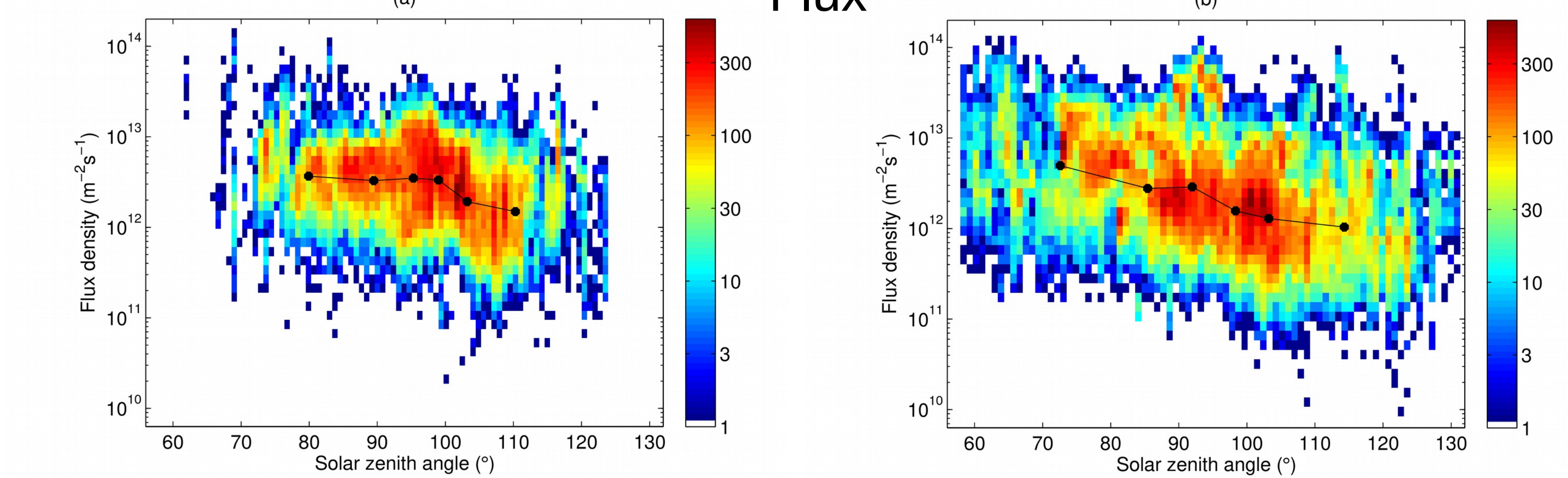


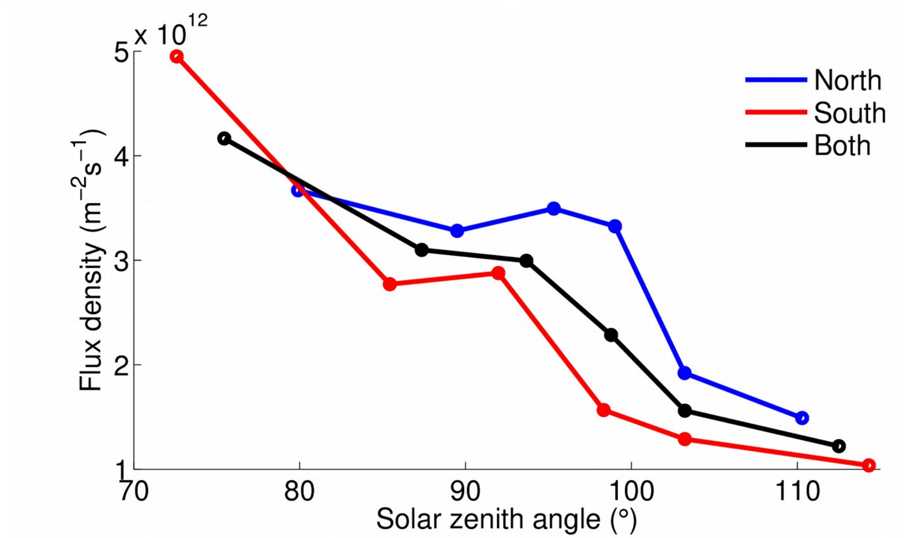
No significant effect

Polar wind: SZA

[Maes et al., 2017]

North Flux South





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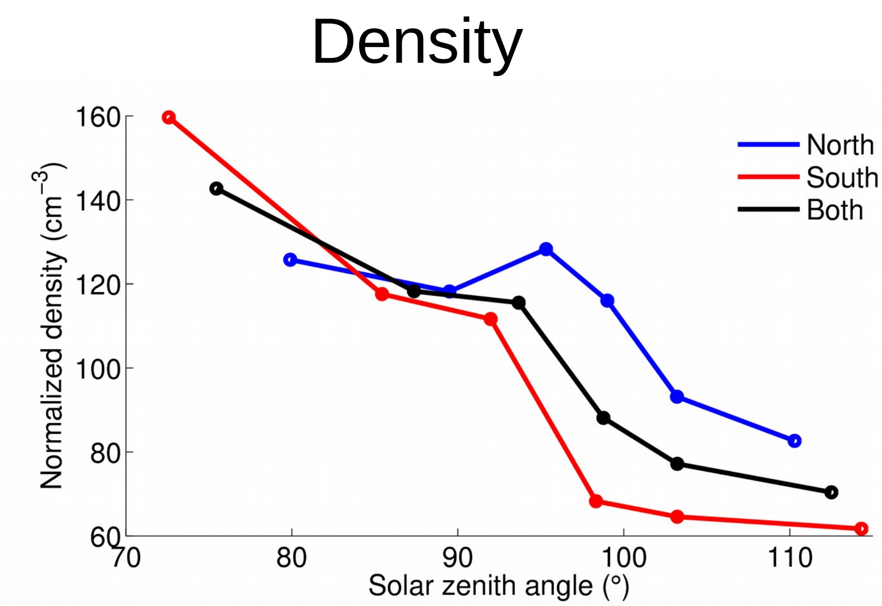

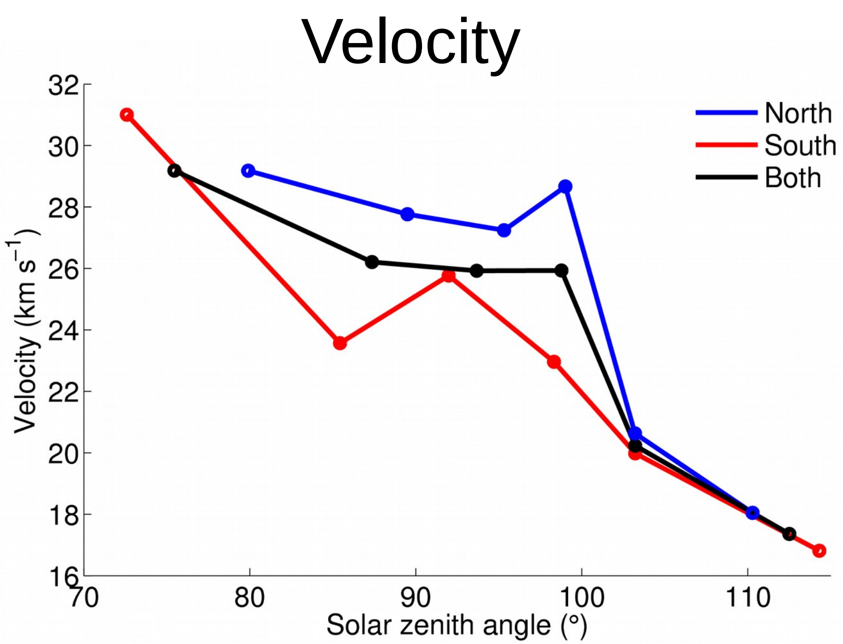

Polar wind: SZA

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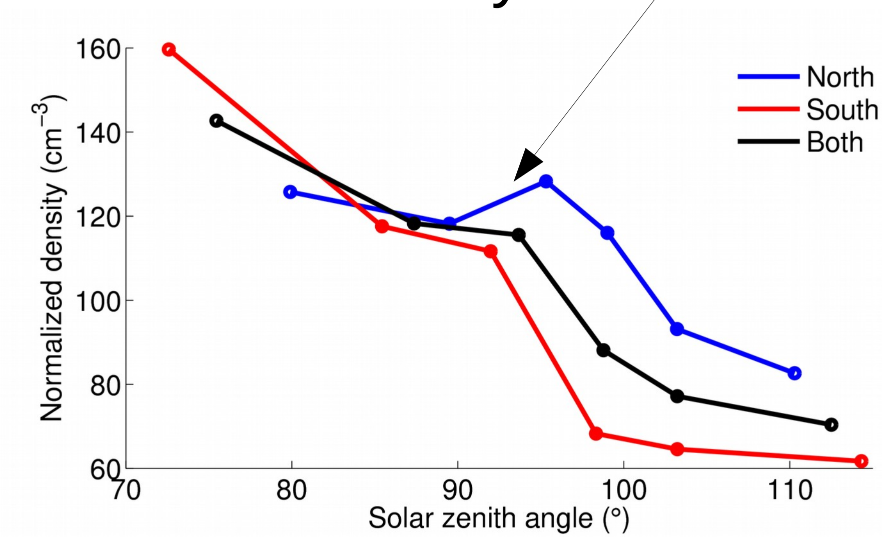
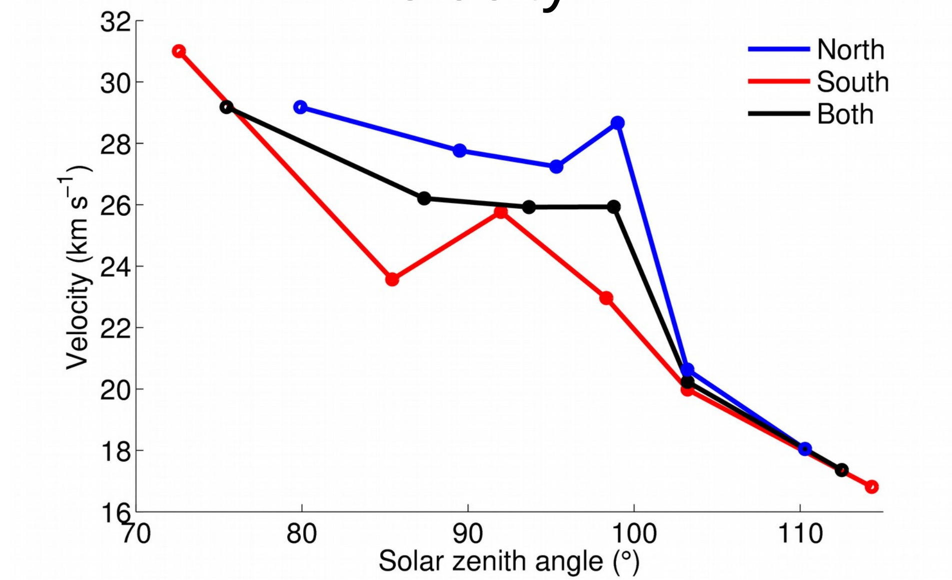
Effect in density

Density



Velocity



Polar wind: SZA

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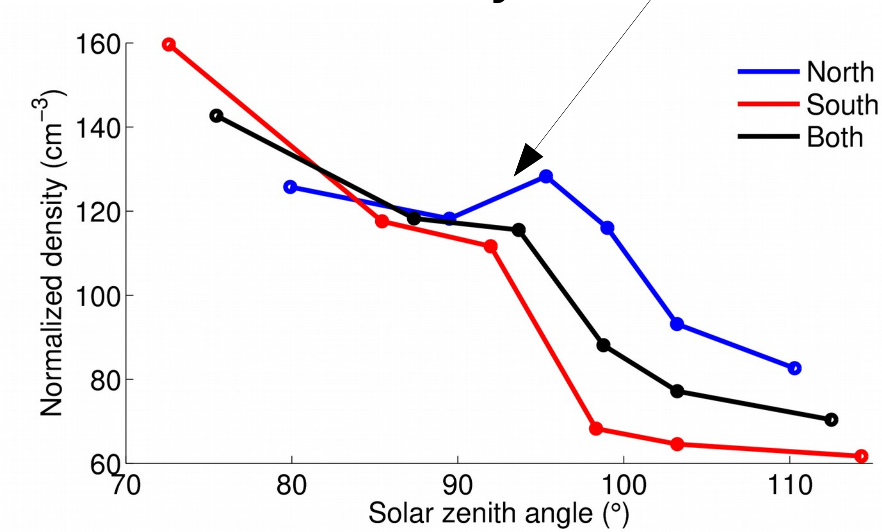
Effect in density

Effect also in velocity!

Density



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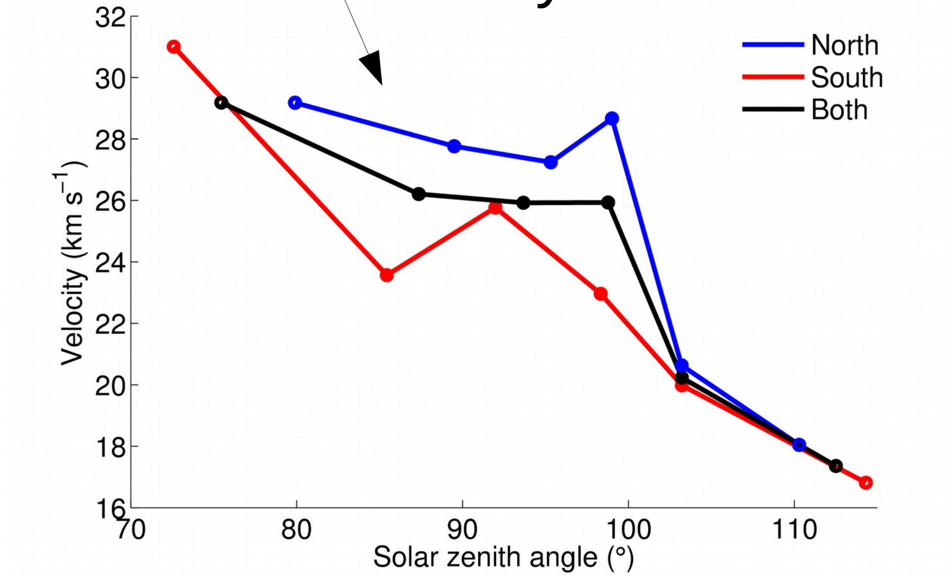
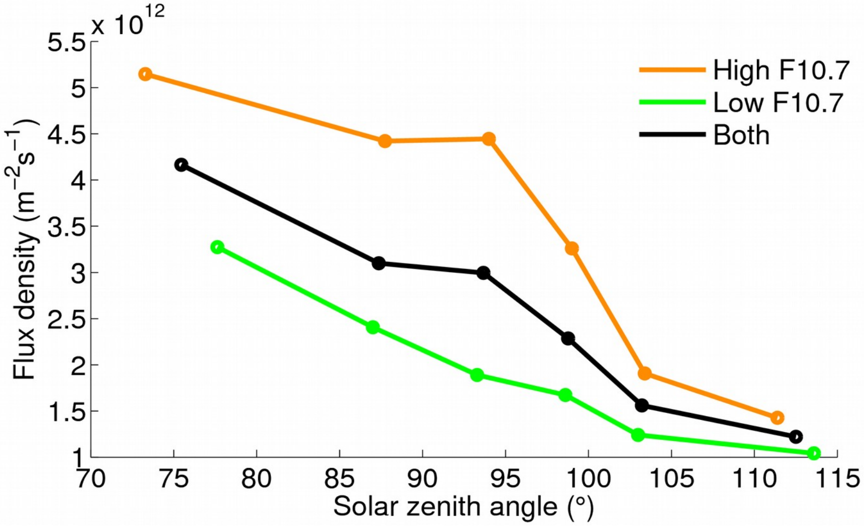
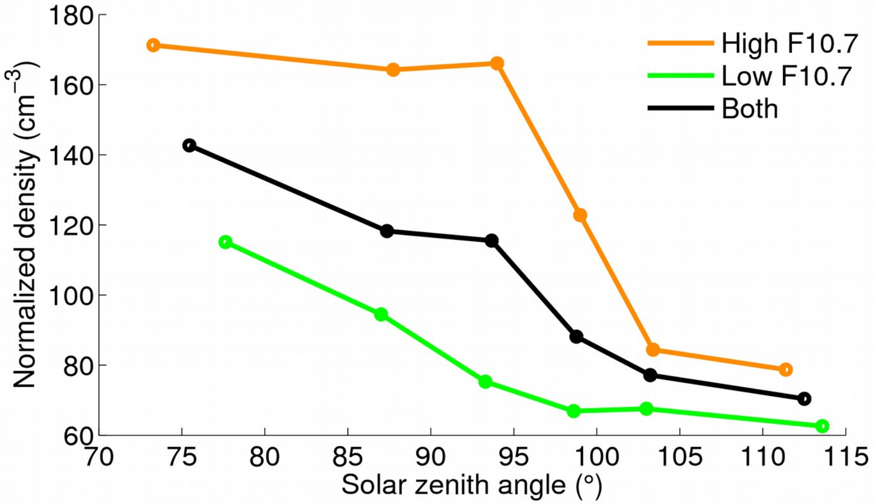


F10.7 and SZA

[Maes et al., 2017]





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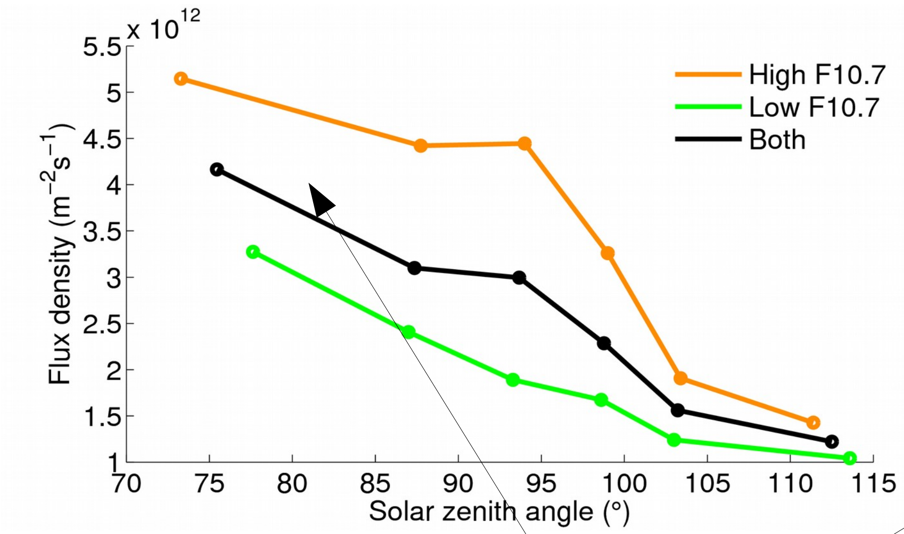
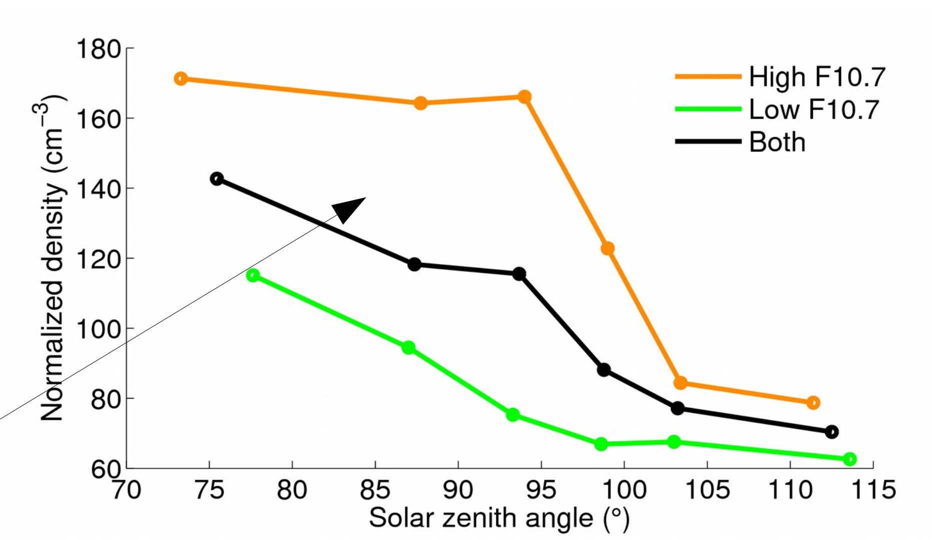
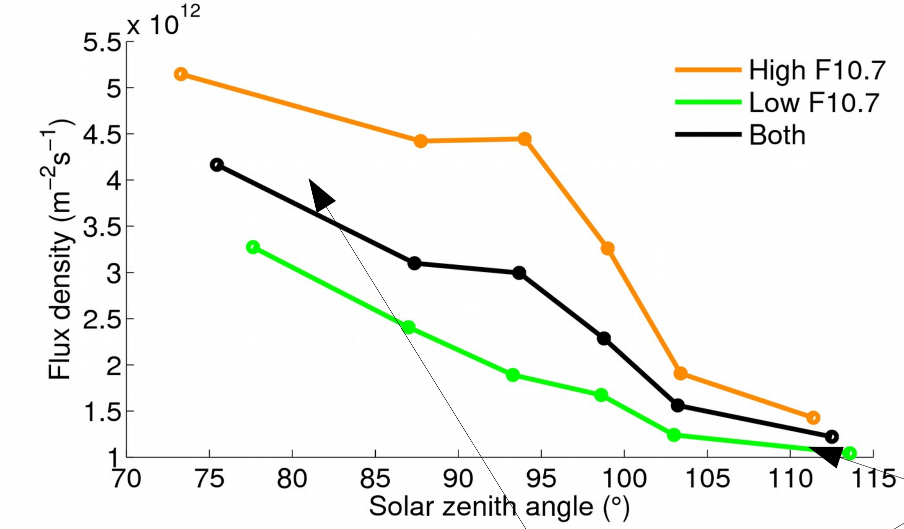


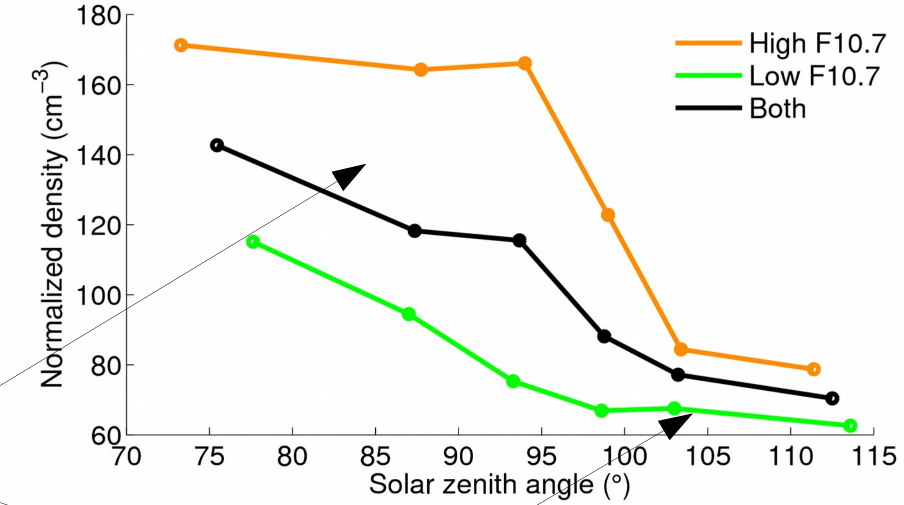


Large difference between low and high F10.7 at **small SZA**

F10.7 and SZA

[Maes et al., 2017]





Large difference between low and high F10.7 at **small SZA**

Small difference at **large SZA**

F10.7 and SZA

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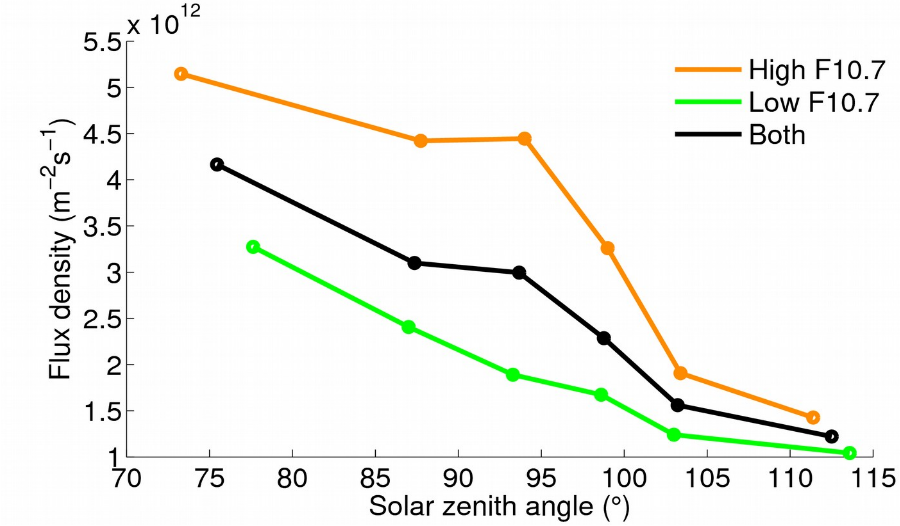
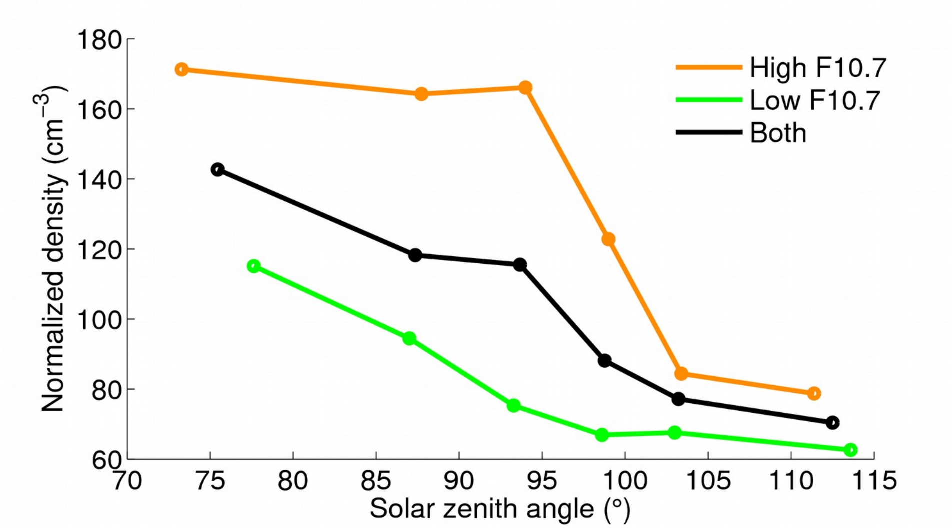
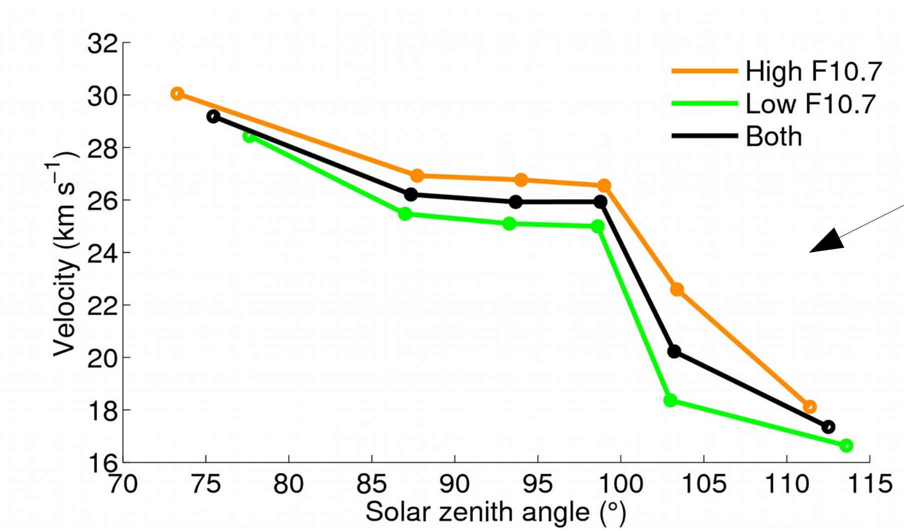




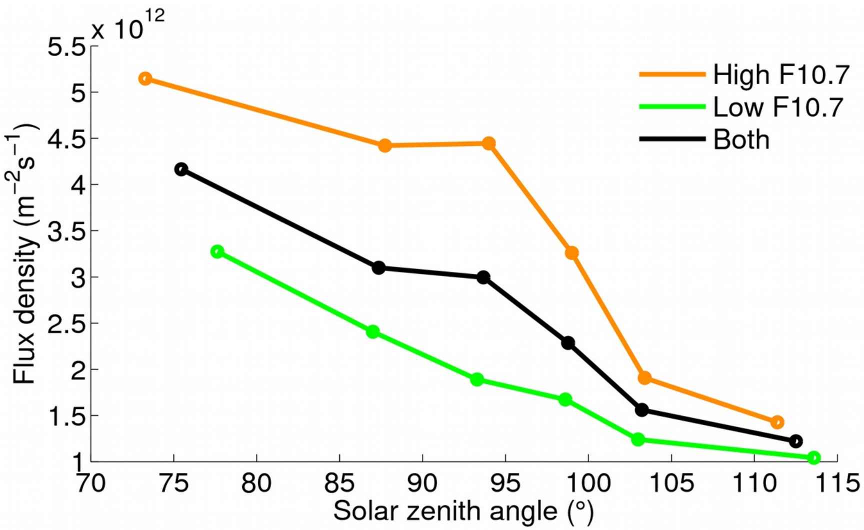


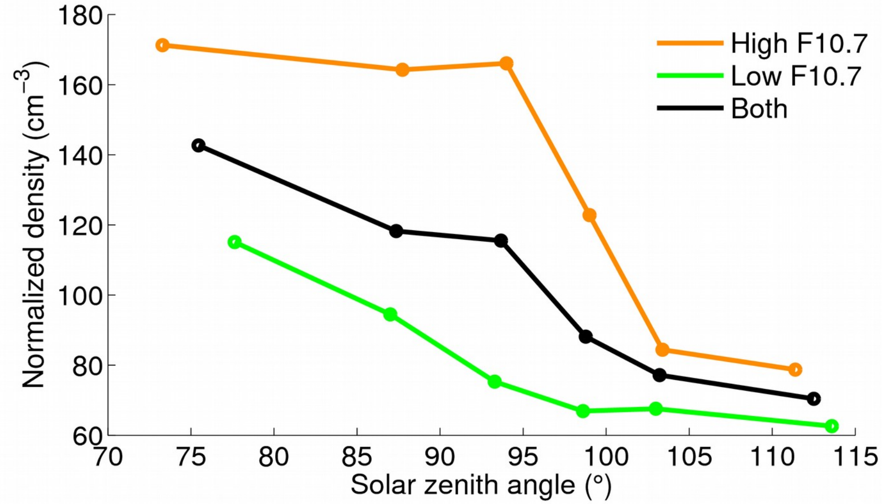
No (large) effect of F10.7 on velocity

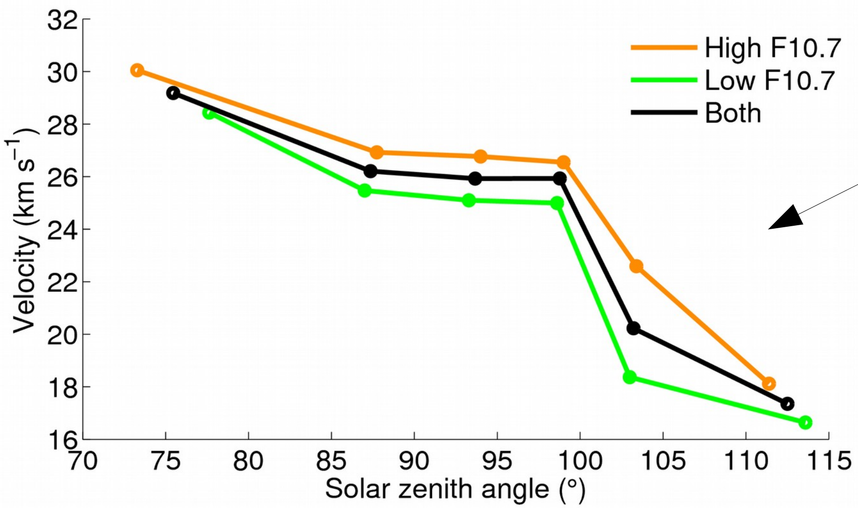
Large effect of SZA on velocity

F10.7 and SZA

[Maes et al., 2017]







No (large) effect of F10.7 on velocity

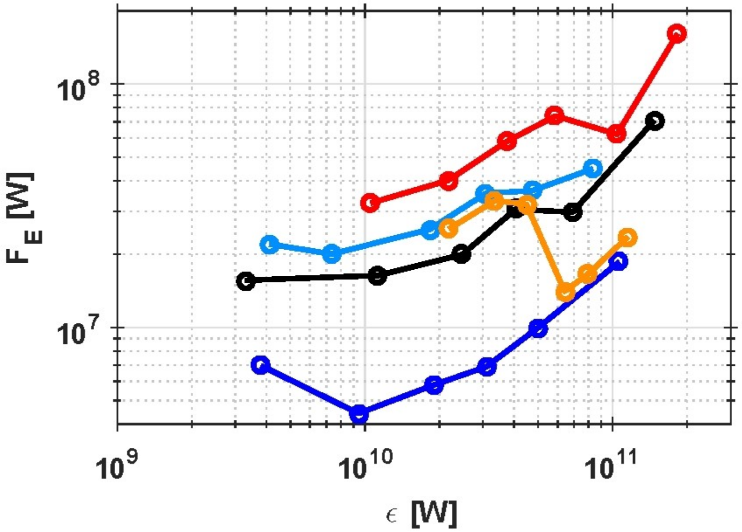
Large effect of SZA on velocity

EUV (F10.7) mostly important for ionization?

Lower energy also important for heating ⇒ ambipolar E-field?

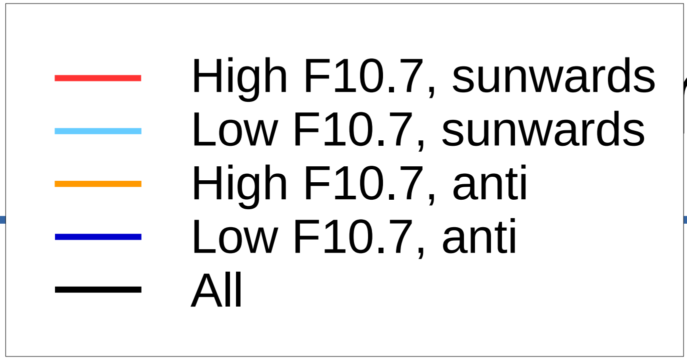
Solar wind and solar illumination

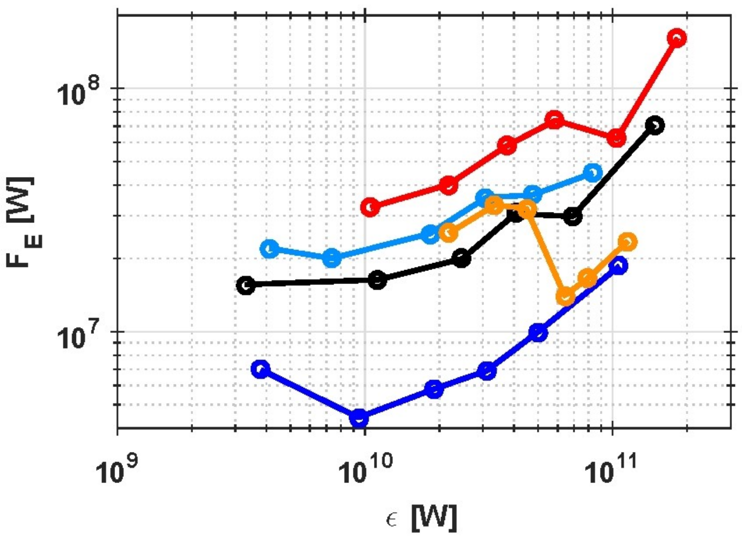
[Li et al., 2017]



Solar wind and sol... n

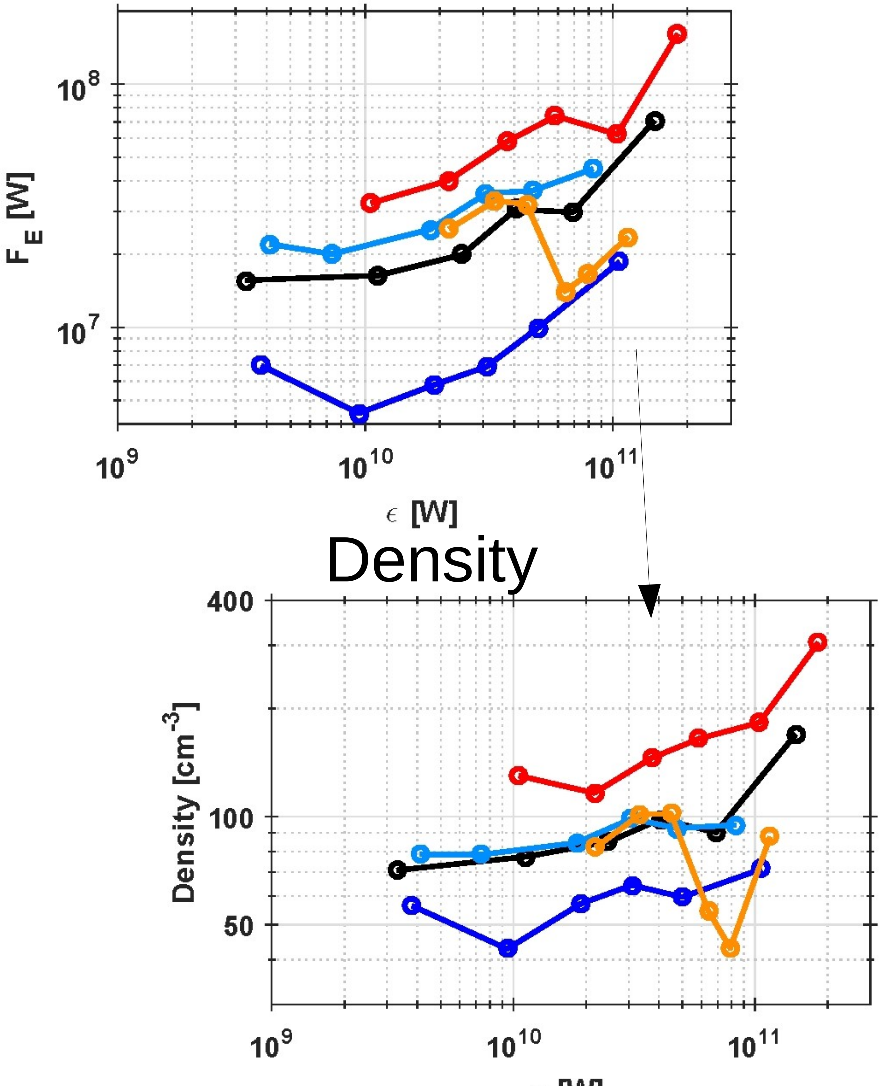
[Li et al., 2017]





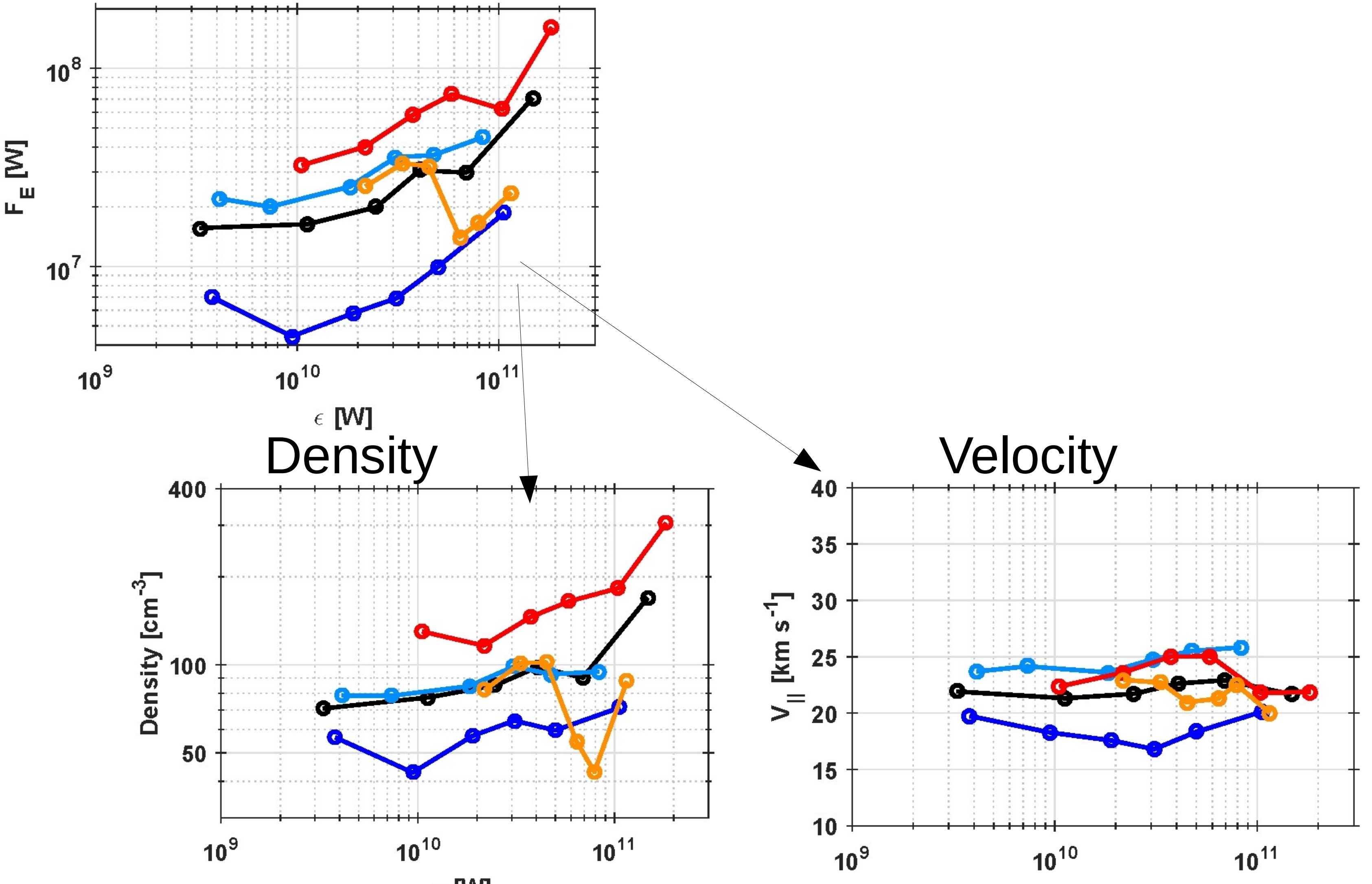
Solar wind and sol n

[Li et al., 2017]



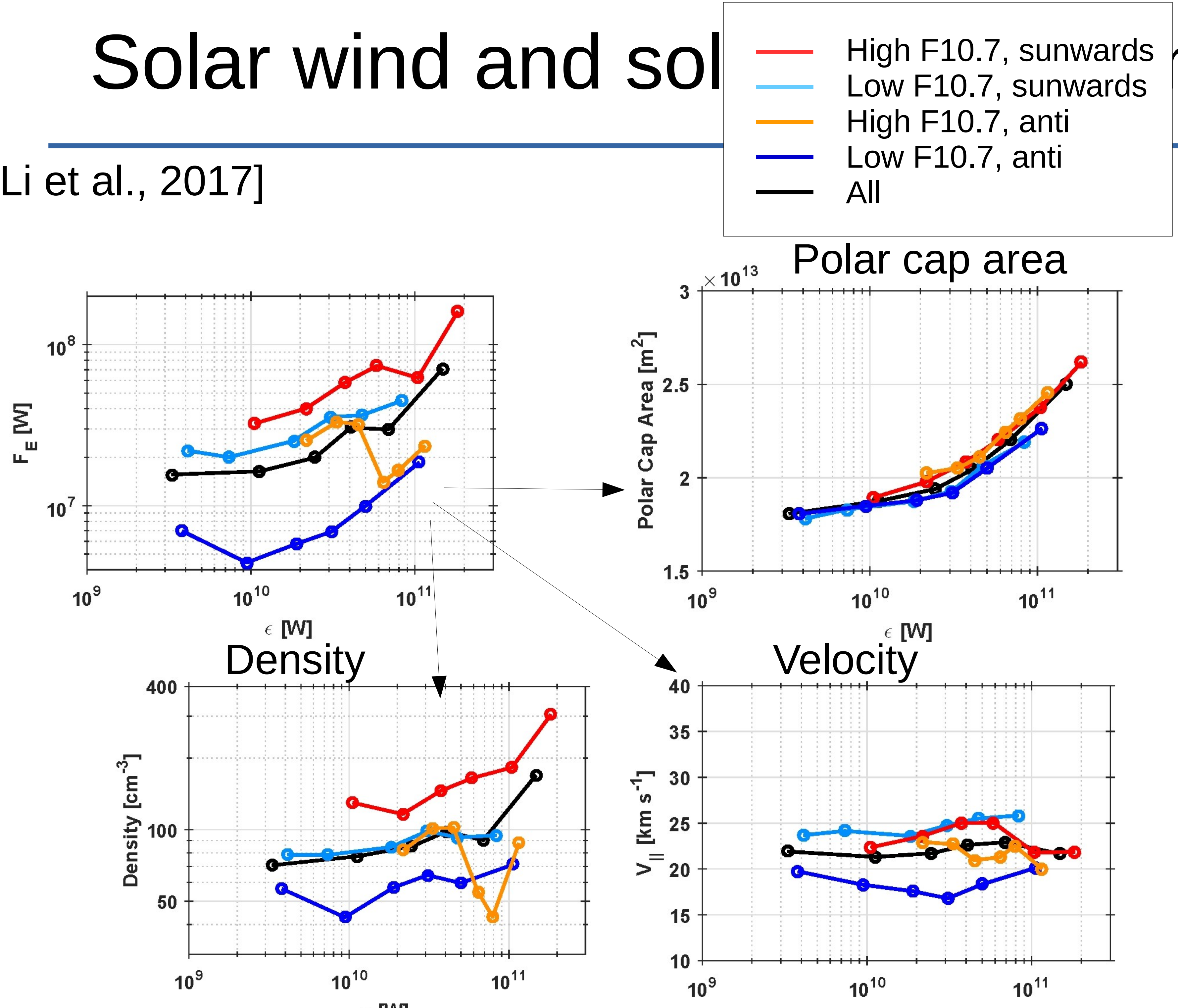
Solar wind and sol n

[Li et al., 2017]



Solar wind and sol n

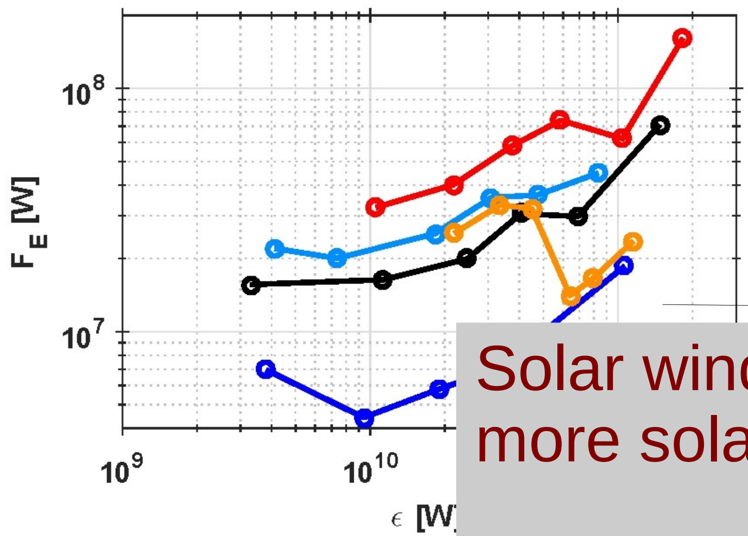
[Li et al., 2017]

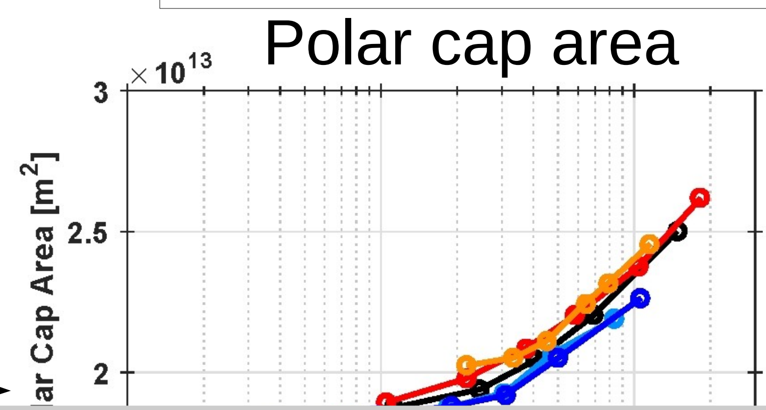


Solar wind and sol n

[Li et al., 2017]

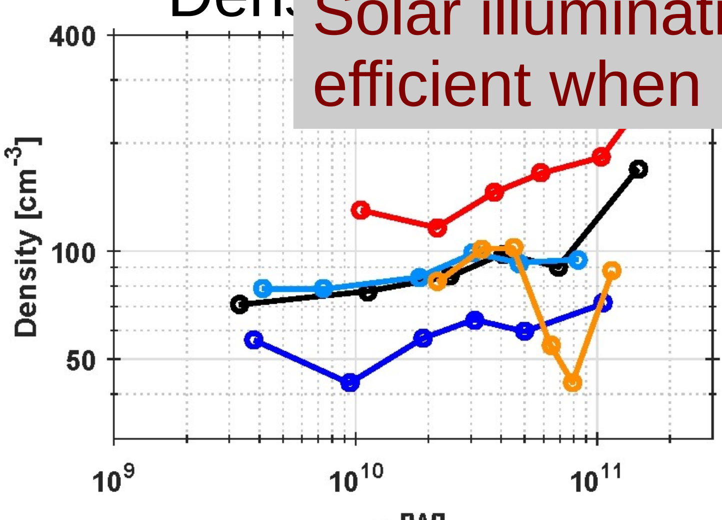
High F10.7, sunwards
Low F10.7, sunwards
High F10.7, anti
Low F10.7, anti
All

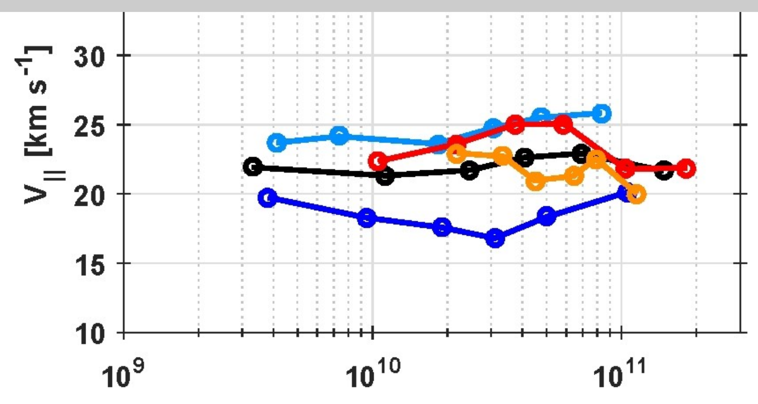




Solar wind energy input more efficient with more solar illumination

Solar illumination energy input also more efficient when more solar wind

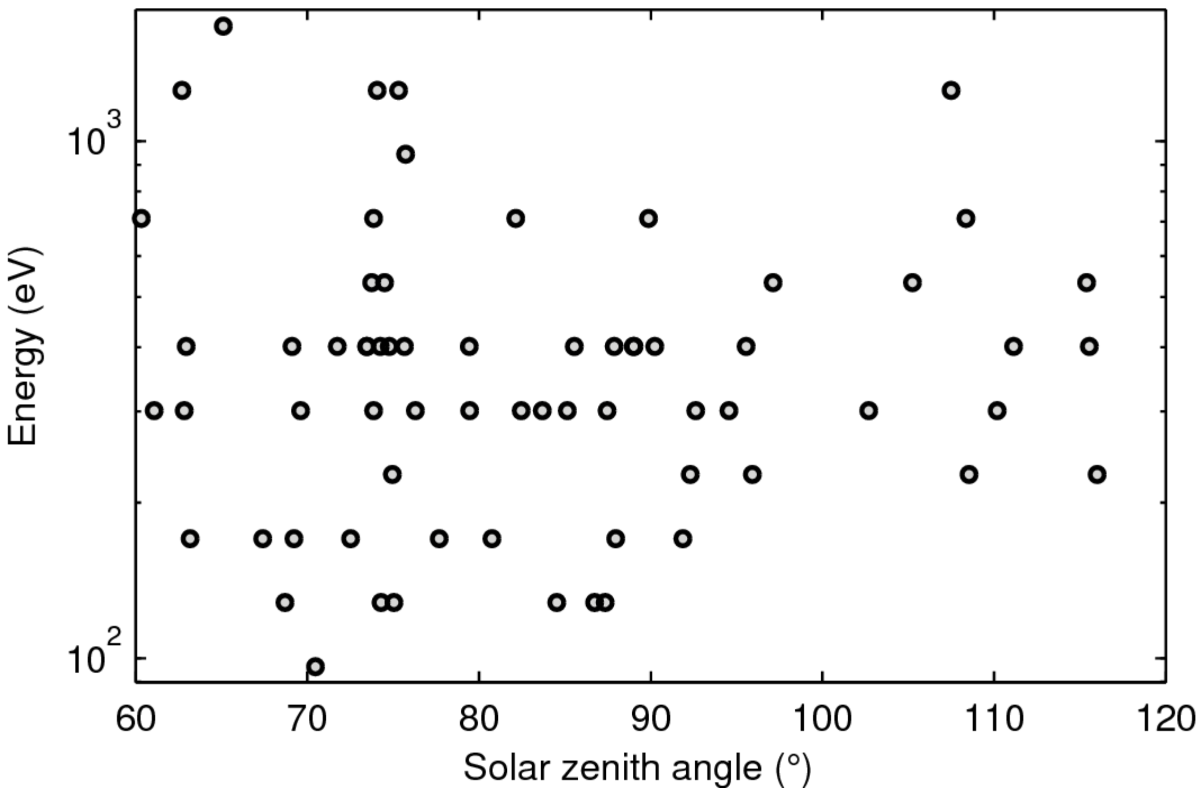




Solar illumination affecting magnetosphere

Outflowing ions above polar cap arcs [Maes et al., 2015]

Ion energy ≈ Field-aligned potential drop



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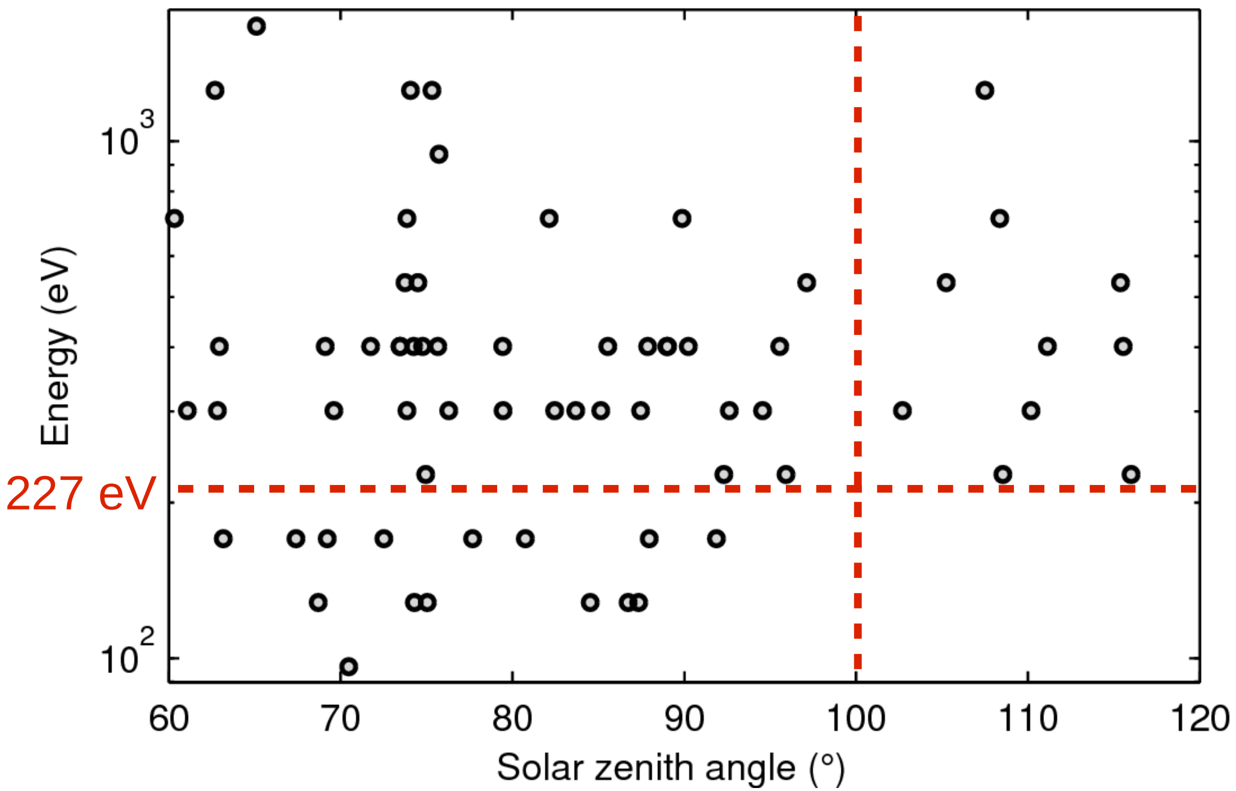

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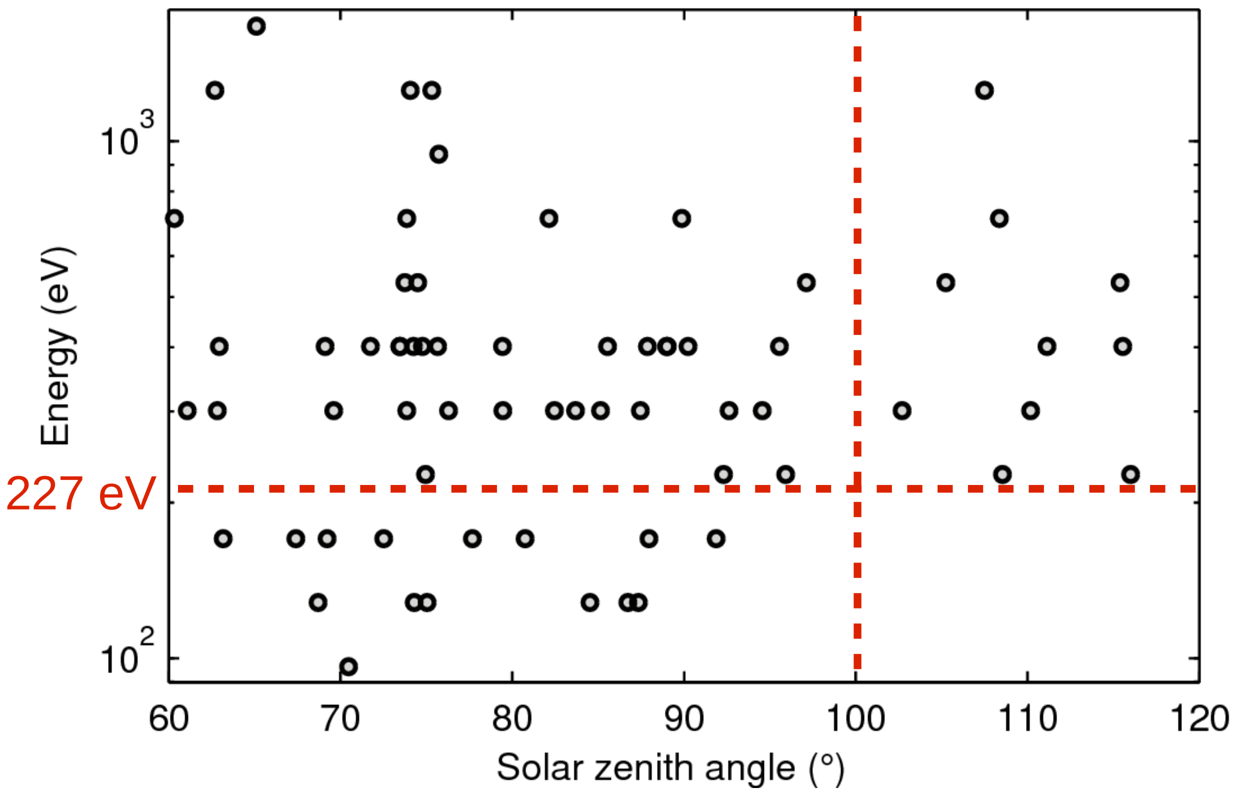

Solar illumination affects potential drop (similar for auroral arcs)

⇩

Ionospheric conductivity

⇩

Effect on current system

Seasonal variation effect on magnetosphere

- ~90% of ions in lobes end up in plasma sheet [Haaland et al., 2012]
- Cold/heavy ions may affect geomagnetic dynamics
- Daily and seasonal variation in
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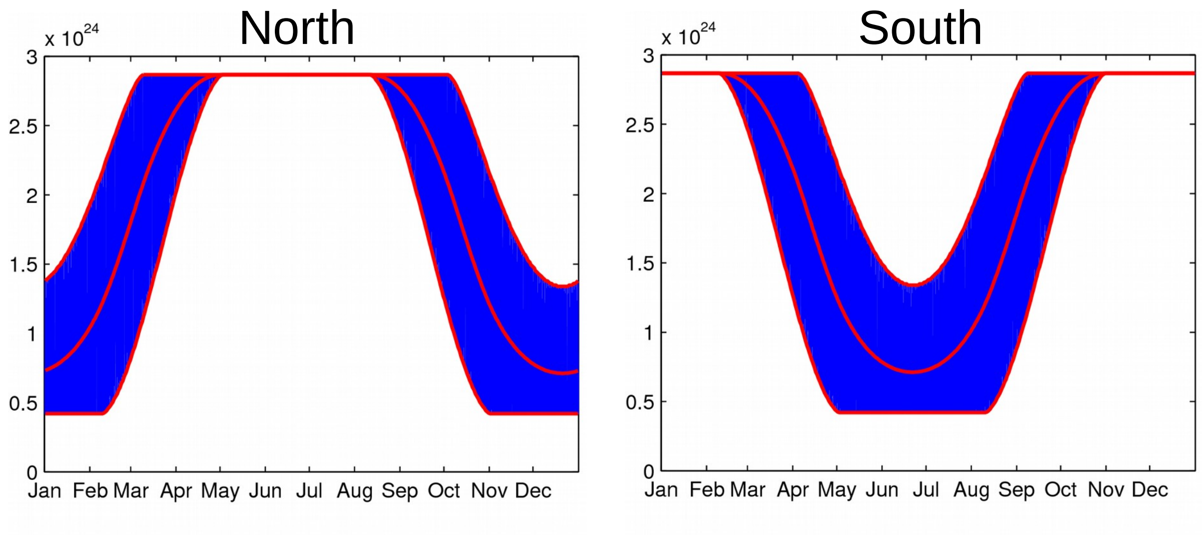

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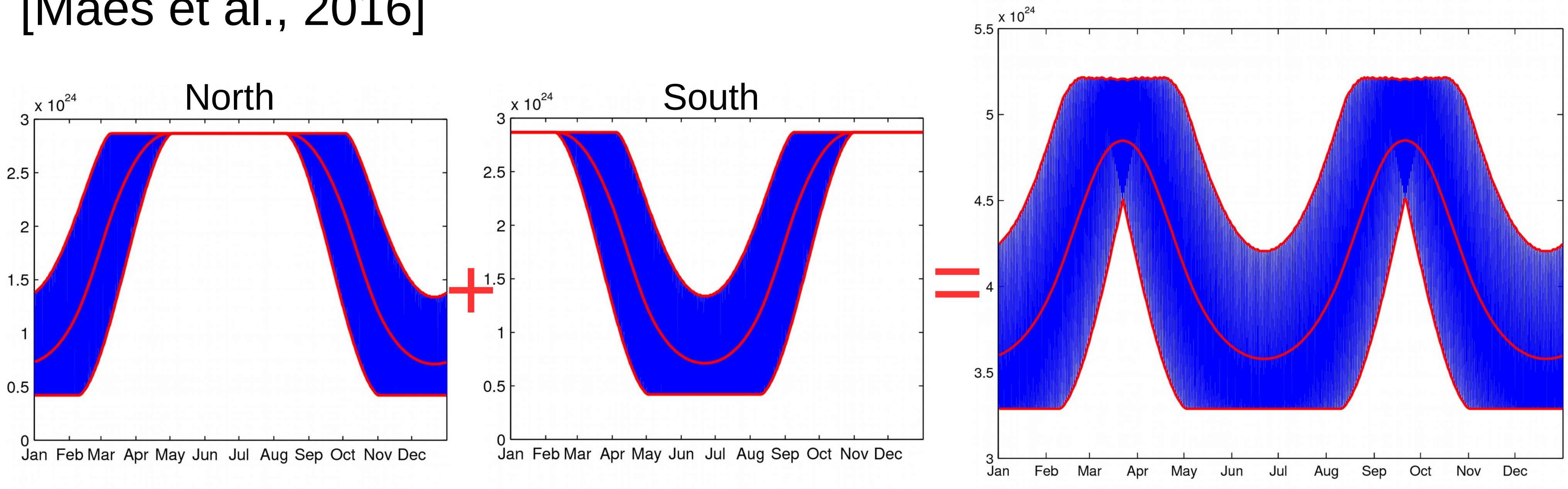

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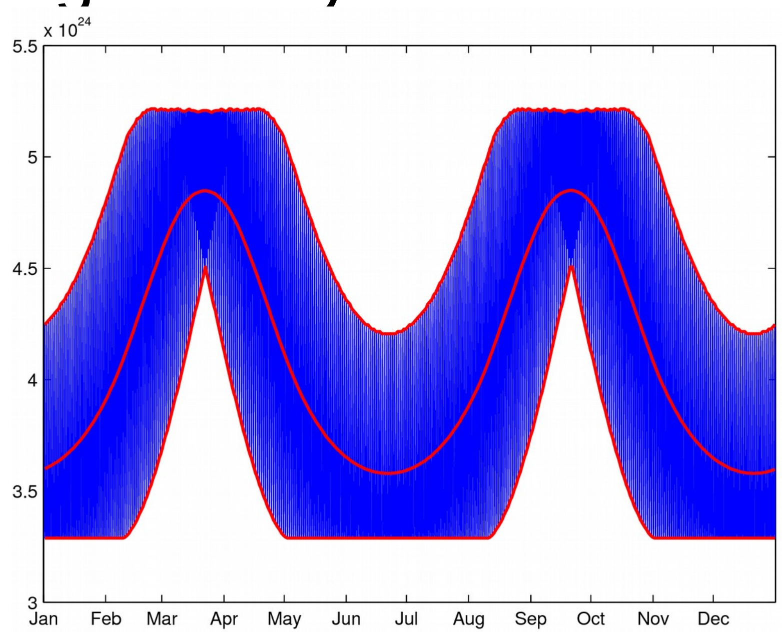

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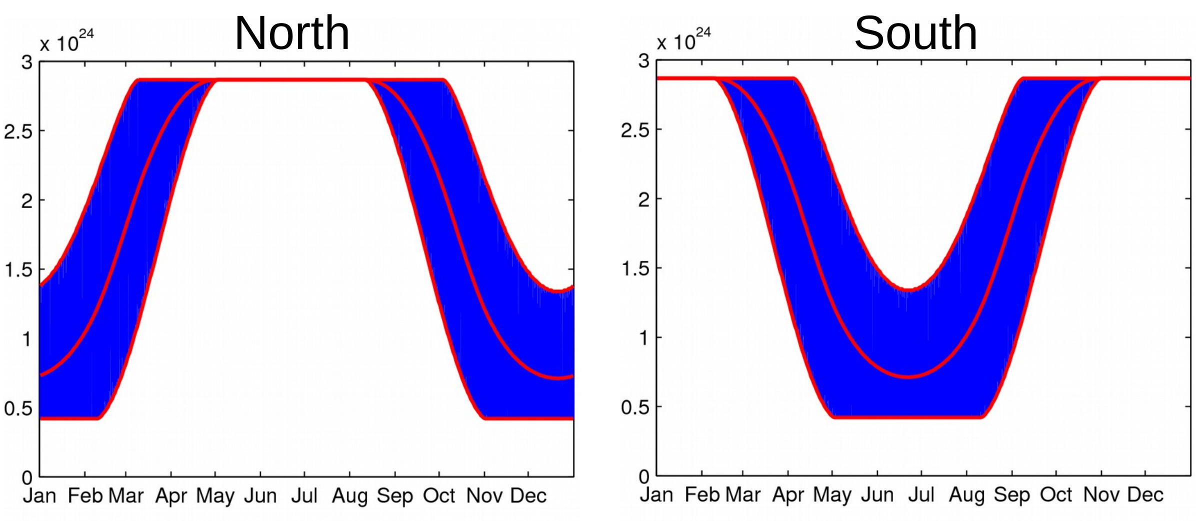
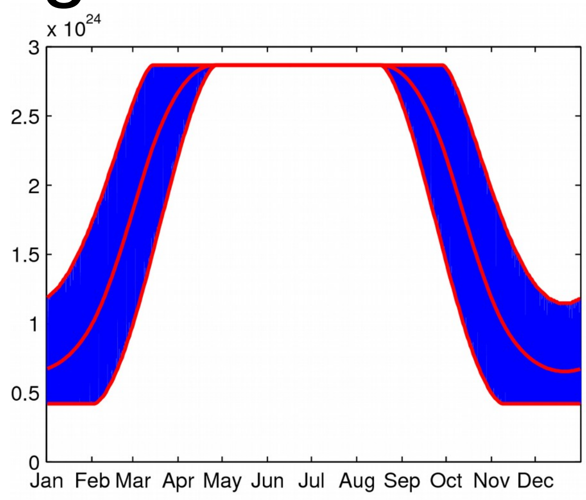


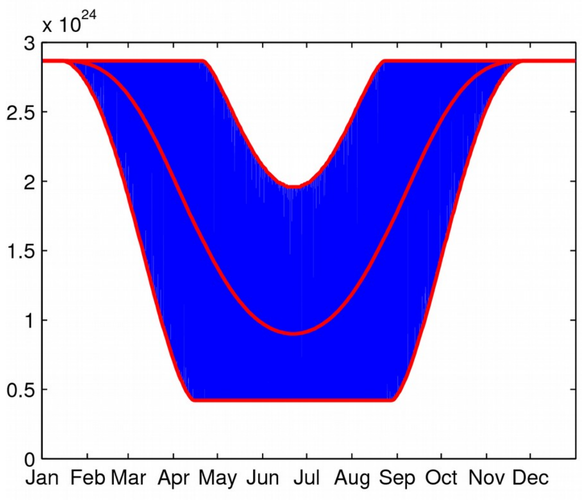
[Clua de Gonzalez et al., 2001]

N-S magnetic field asymmetry

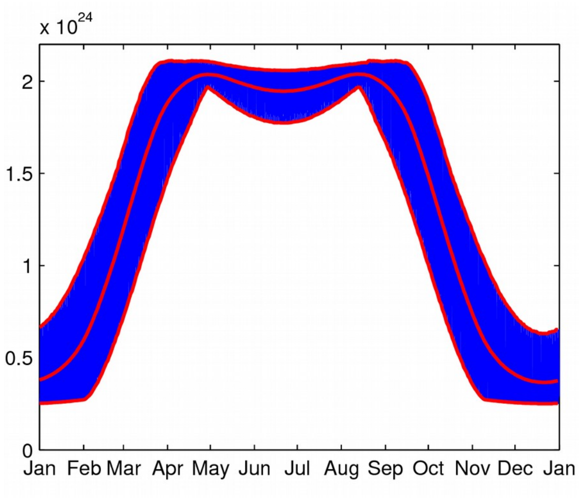
[Maes et al., 2016]

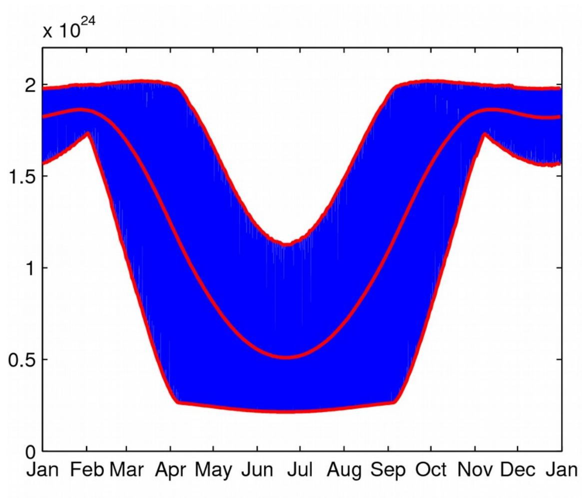
Larger offset in south:





Larger polar cap in north:

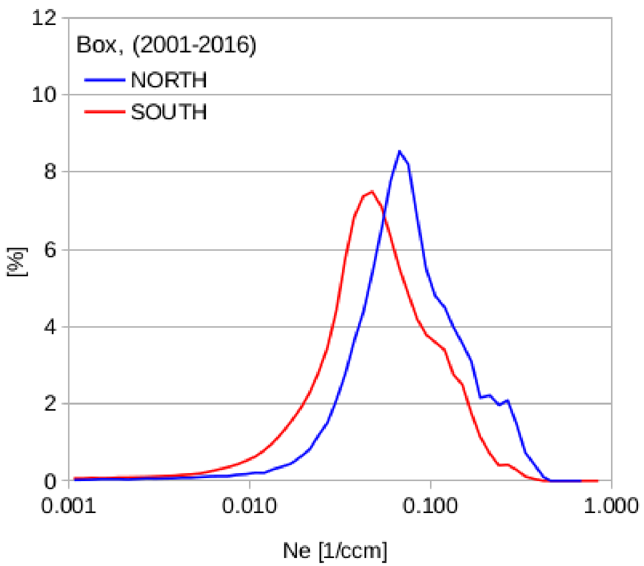




Time-lag

Persistent N-S asymmetry in lobes around equinox

[Haaland et al., 2017]



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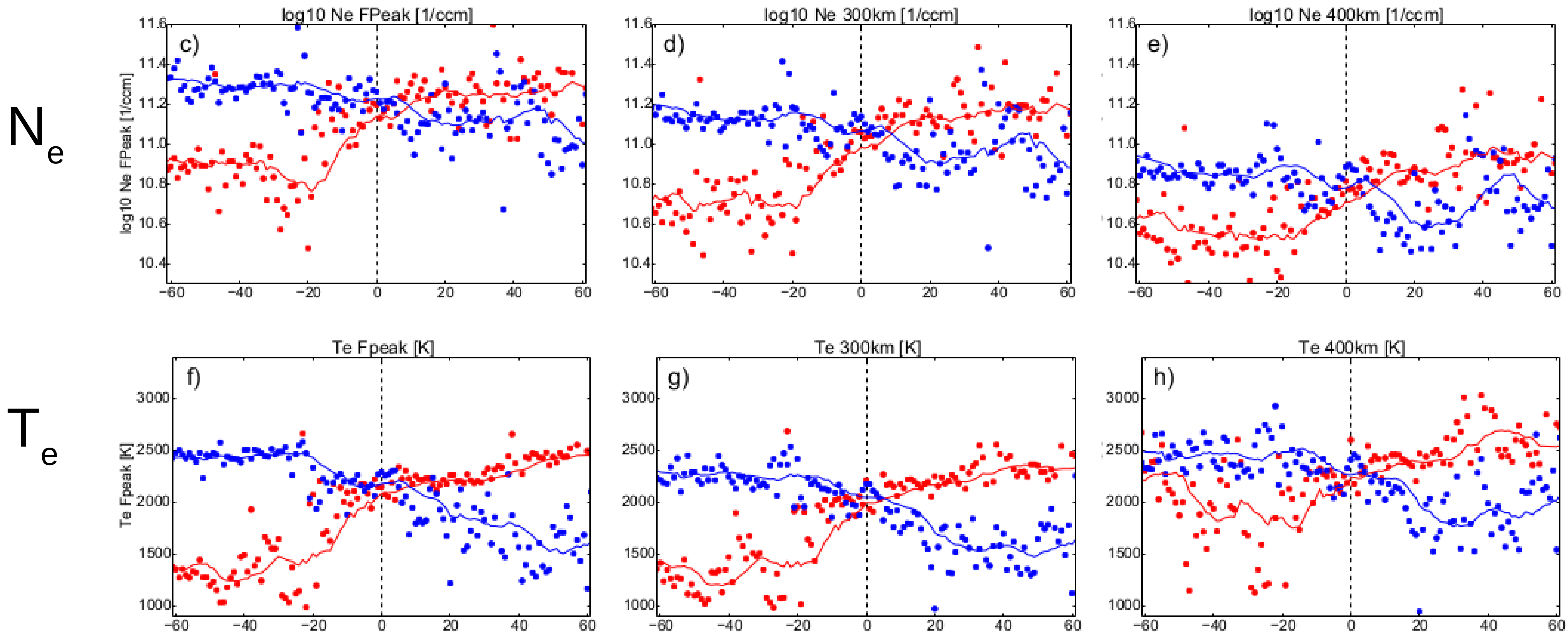
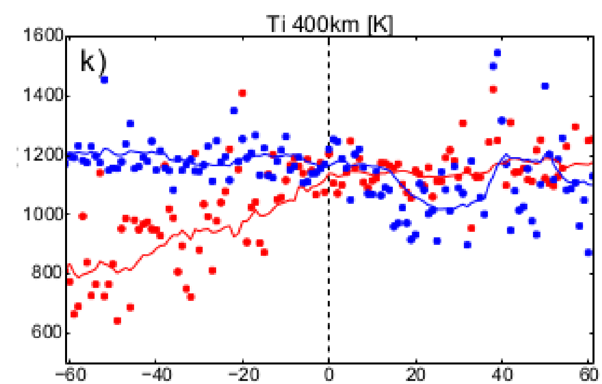
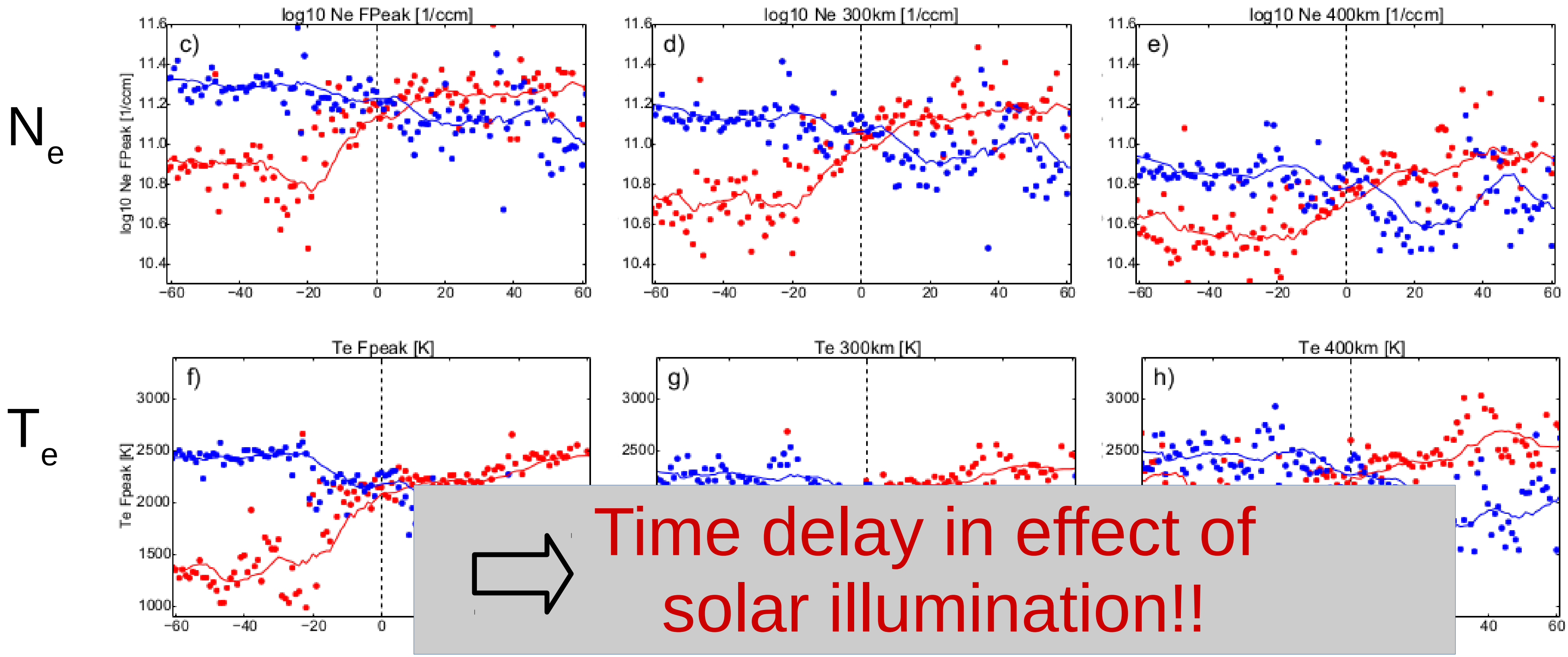


T_i

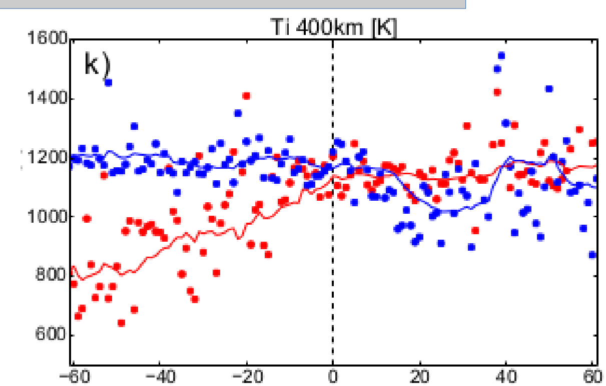


[Haaland et al., 2018 – in preparation]

Time-lag



T_i



[Haaland et al., 2018 – in preparation]

Conclusion

Solar illumination (not only EUV), by ionizing and heating:

- Increases ionospheric density
- Strengthens ambipolar electric field

⇨ Increases flux, density, and velocity
Changes composition

- Polar wind-like process base layer for other outflows
- Directly and indirectly affects magnetosphere

O^+ in polar wind?