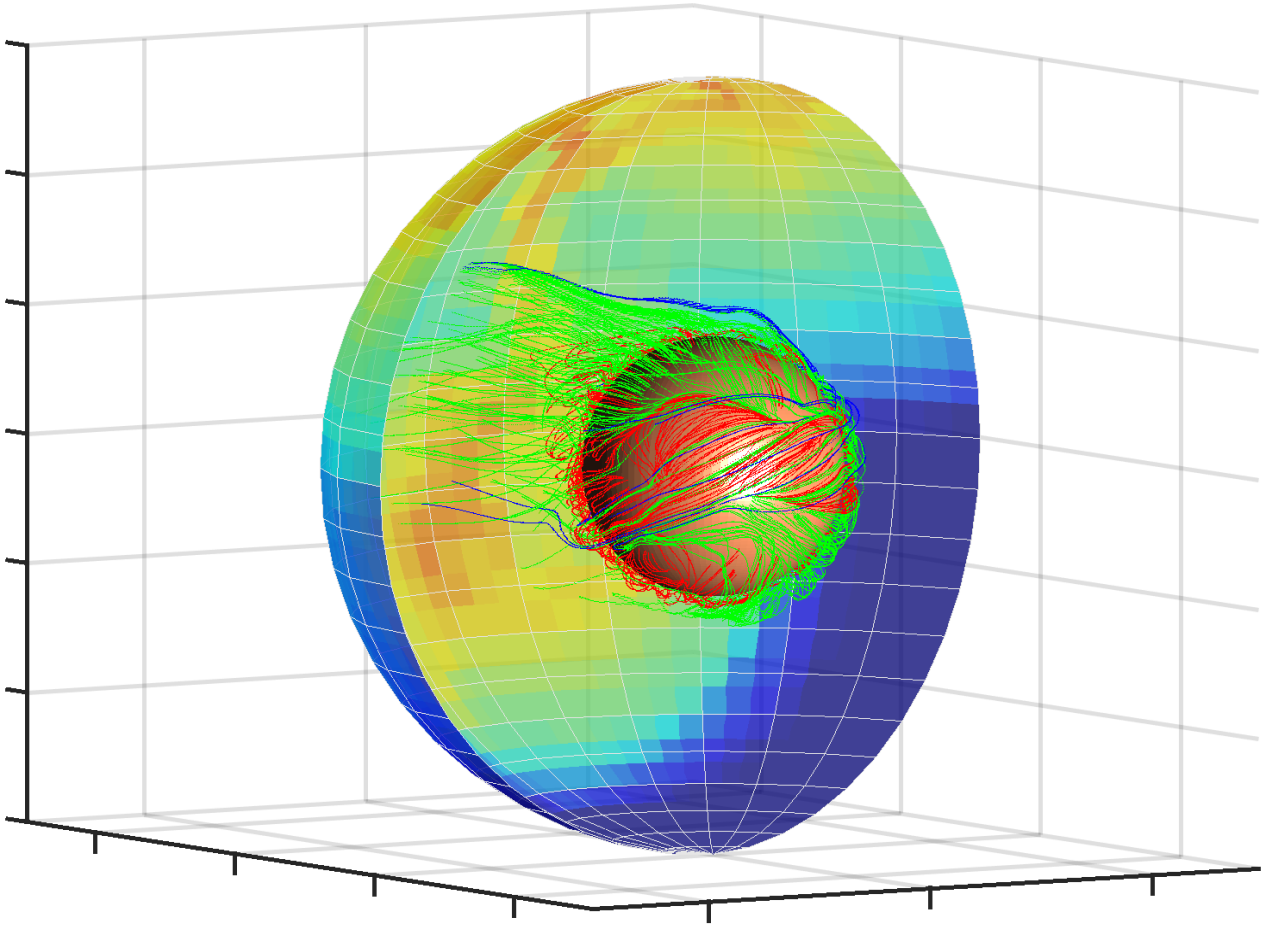
Magnetic topology during quiet and extreme conditions at Mars

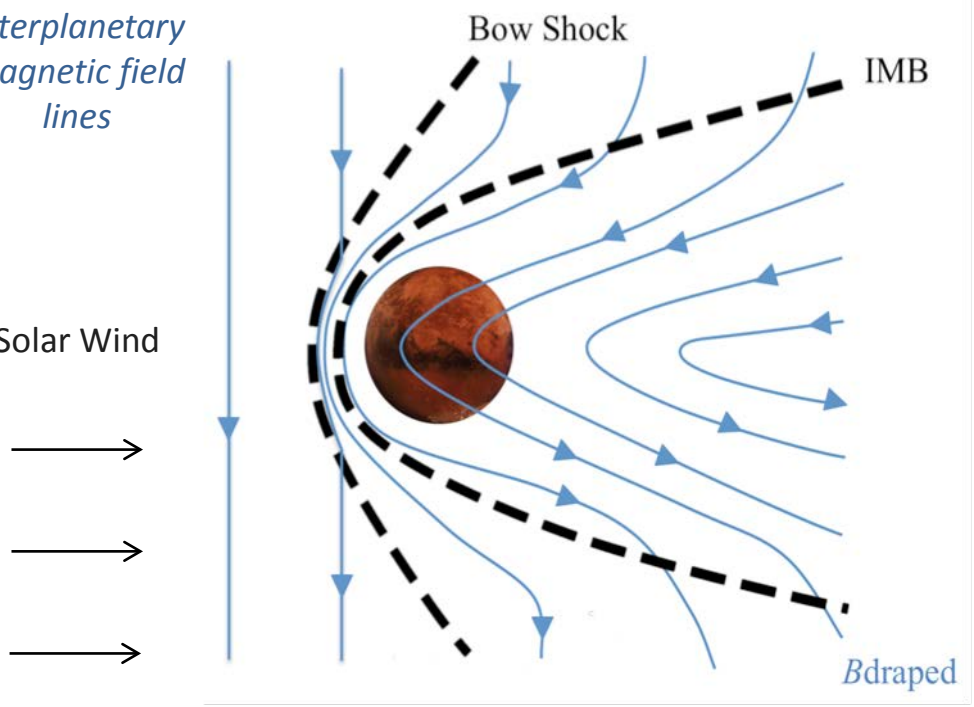


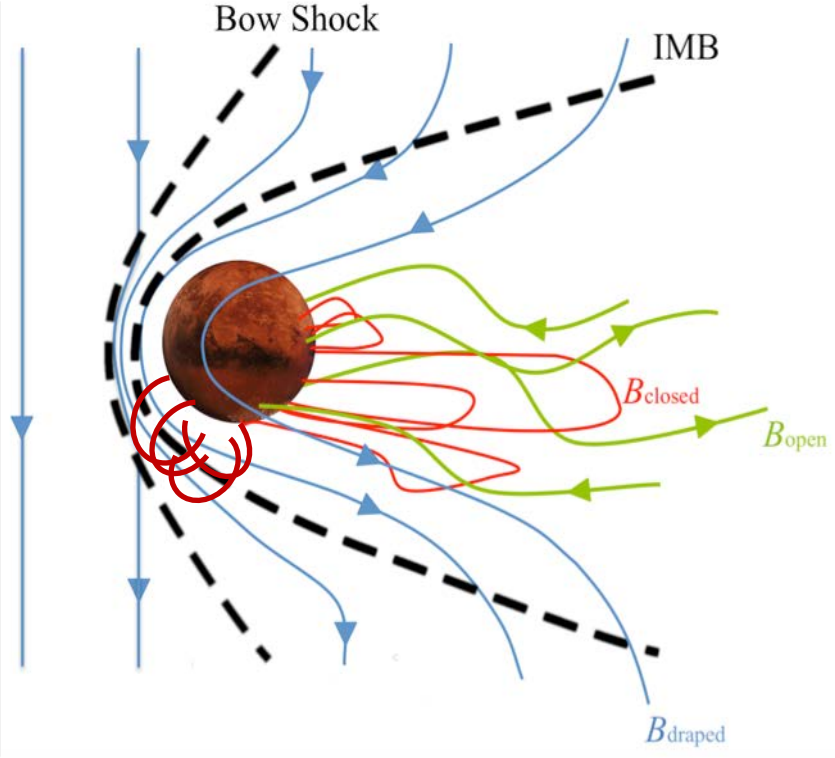
S.M. Curry, S. Xu, J. G. Luhmann, C. F. Dong, Y. J. Ma, D. Mitchell, G. Dibraccio, J. Gruesbeck, J. Espley, M. Elrod, D. Brain, J. McFadden

Mars magnetic topology

Interplanetary magnetic field lines

Solar Wind





Venus-like SW interaction

Mars-Hybrid SW interaction

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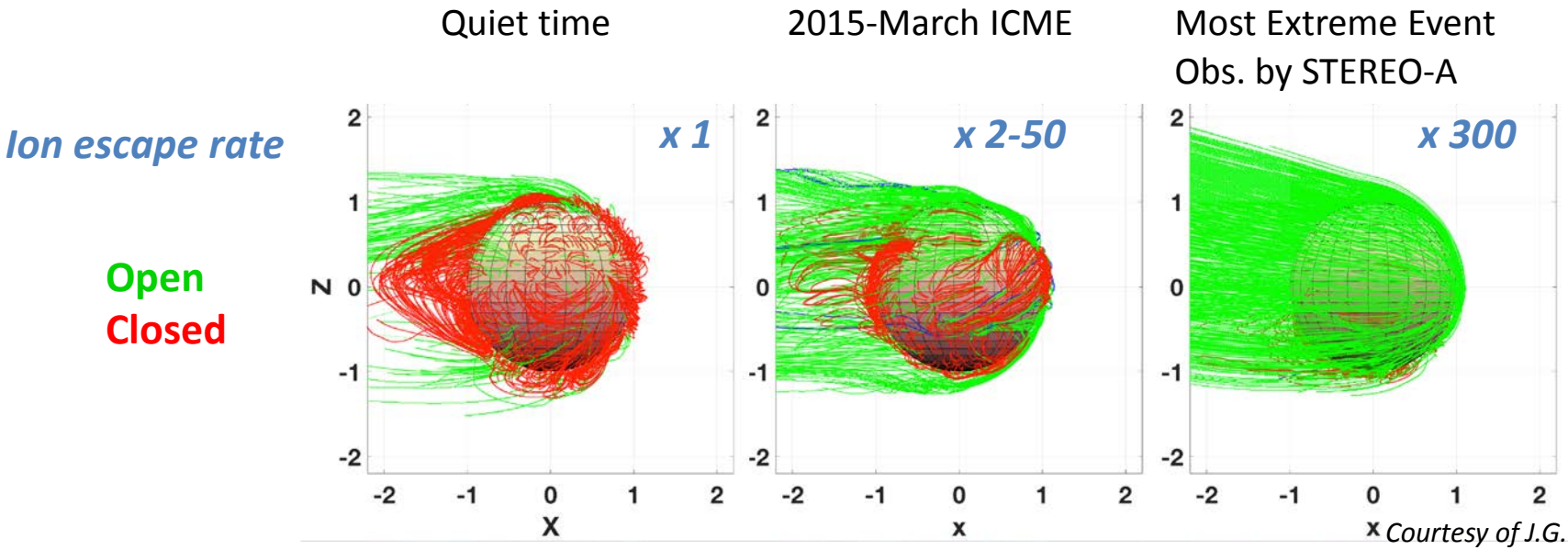
How does magnetic topology affect ion acceleration and escape?

- Mars' magnetic topology affected by crustal field position, IMF orientation and IMF strength
- MHD model results suggest magnetic topology may be responsible for ion escape enhancement

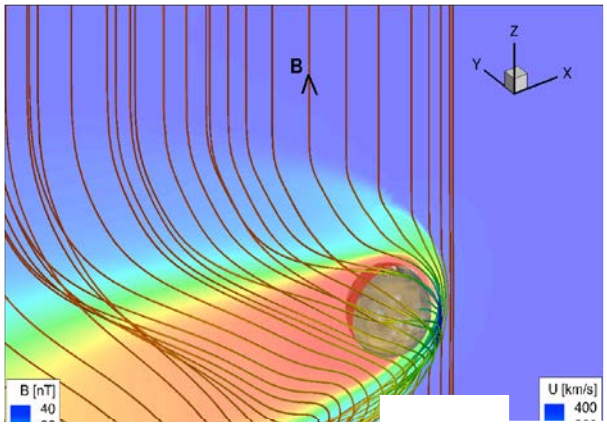


- Crucial to understand how the Martian plasma environment responds to extreme conditions
  - Early Sun was more active, transient events more frequent

Quiet conditions: crustal field strength and IMF orientation

+E

+E



+E

+E

We used the single-fluid, multi-species BATS-R-US MHD [*Dong et al. 2015*] to model 4 IMF cases:

- +By
- -By
- +Bz
- -Bz

Each IMF case was also run with 4 crustal field positions:

- Dayside, dawn, dusk and night

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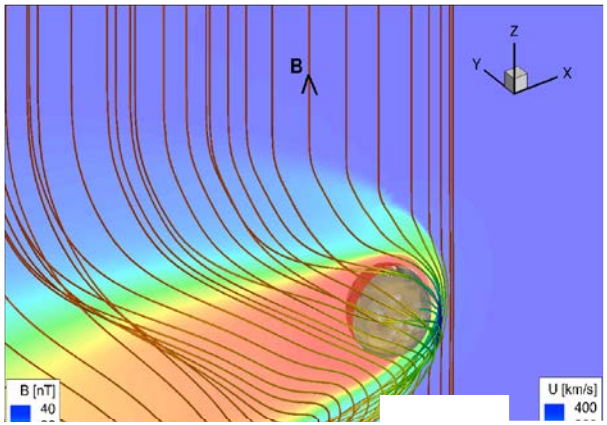
Quiet conditions: crustal field strength and IMF orientation

+E

+E

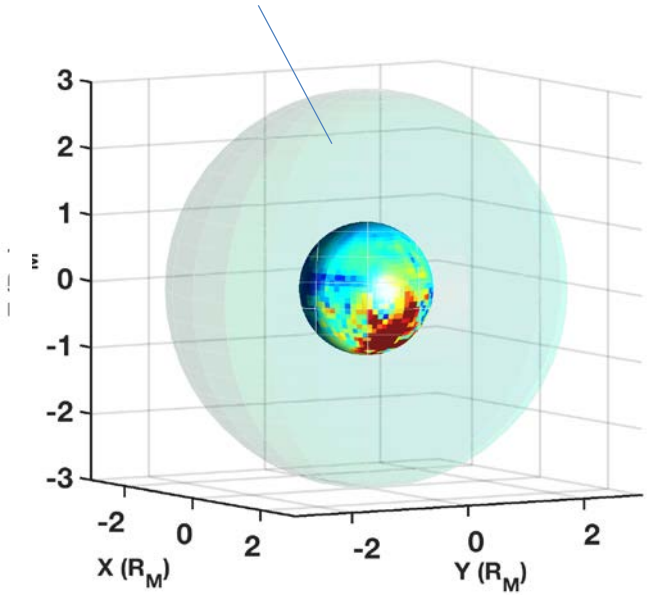


+E

+E

- Magnetic field lines are traced from 150 km
- Escape rate:

6 R_M shell



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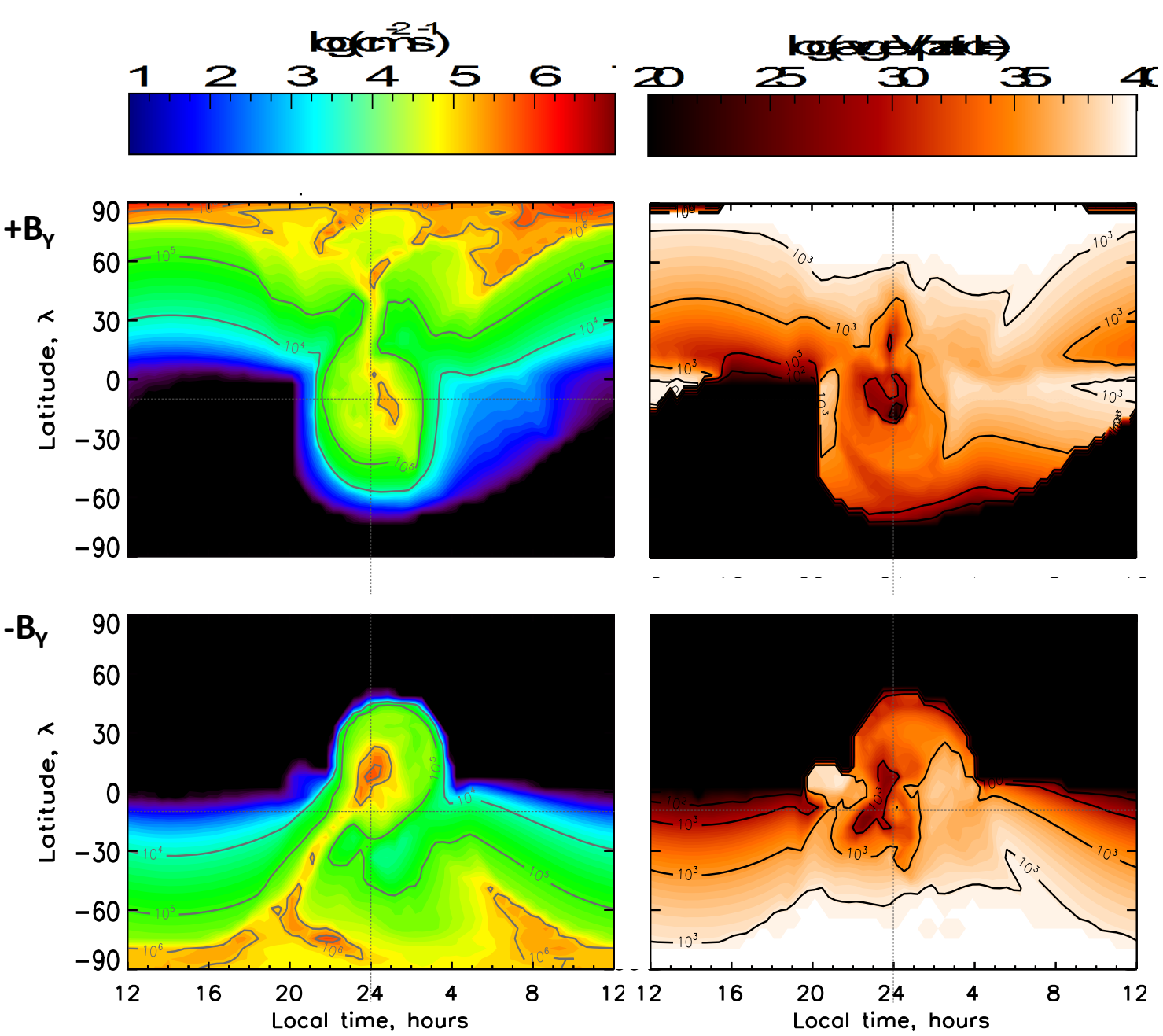

+E

+E

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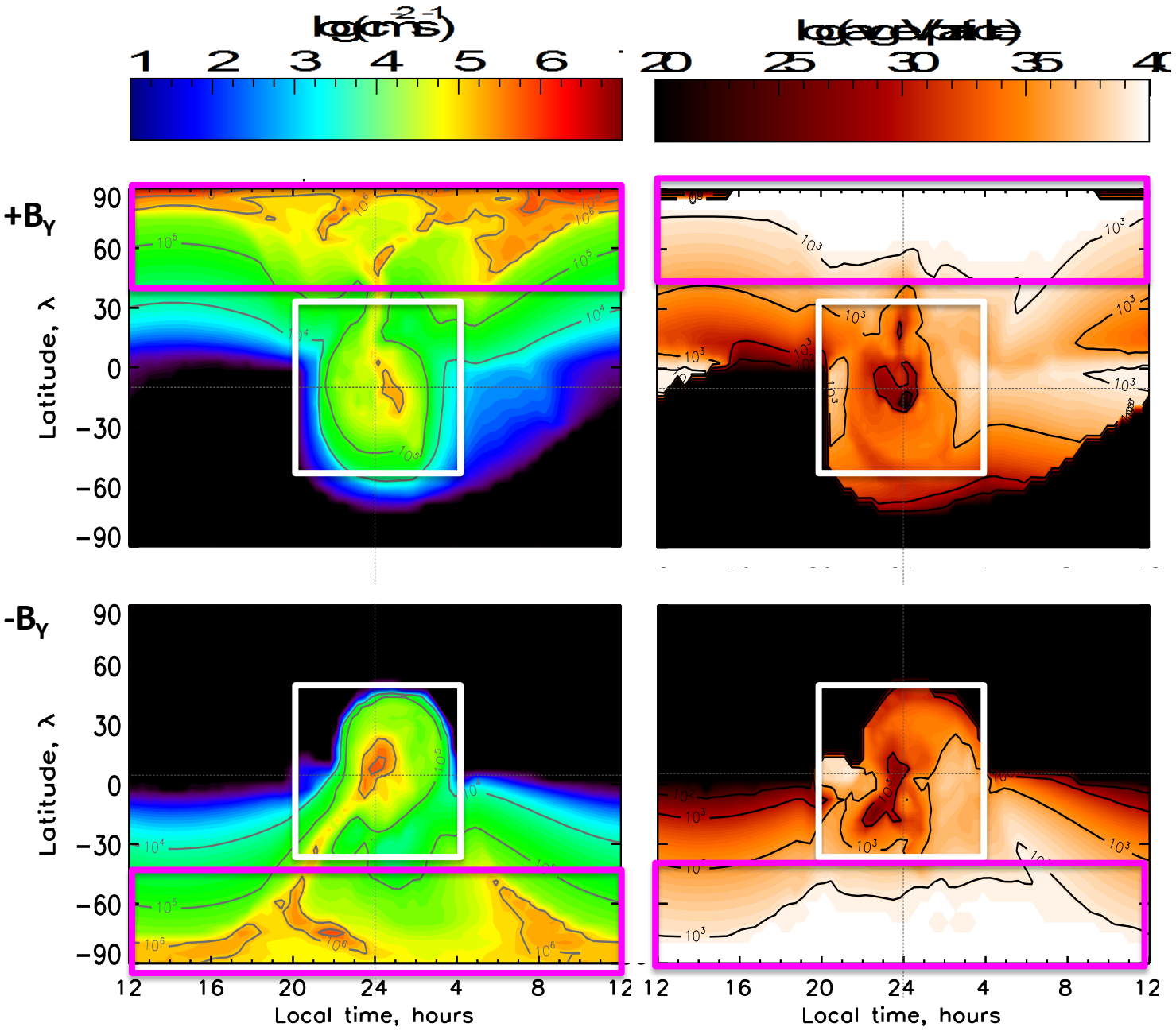

- Low energy cold ion outflow in the tail
- High energy 'plume' in poles (-U×B)

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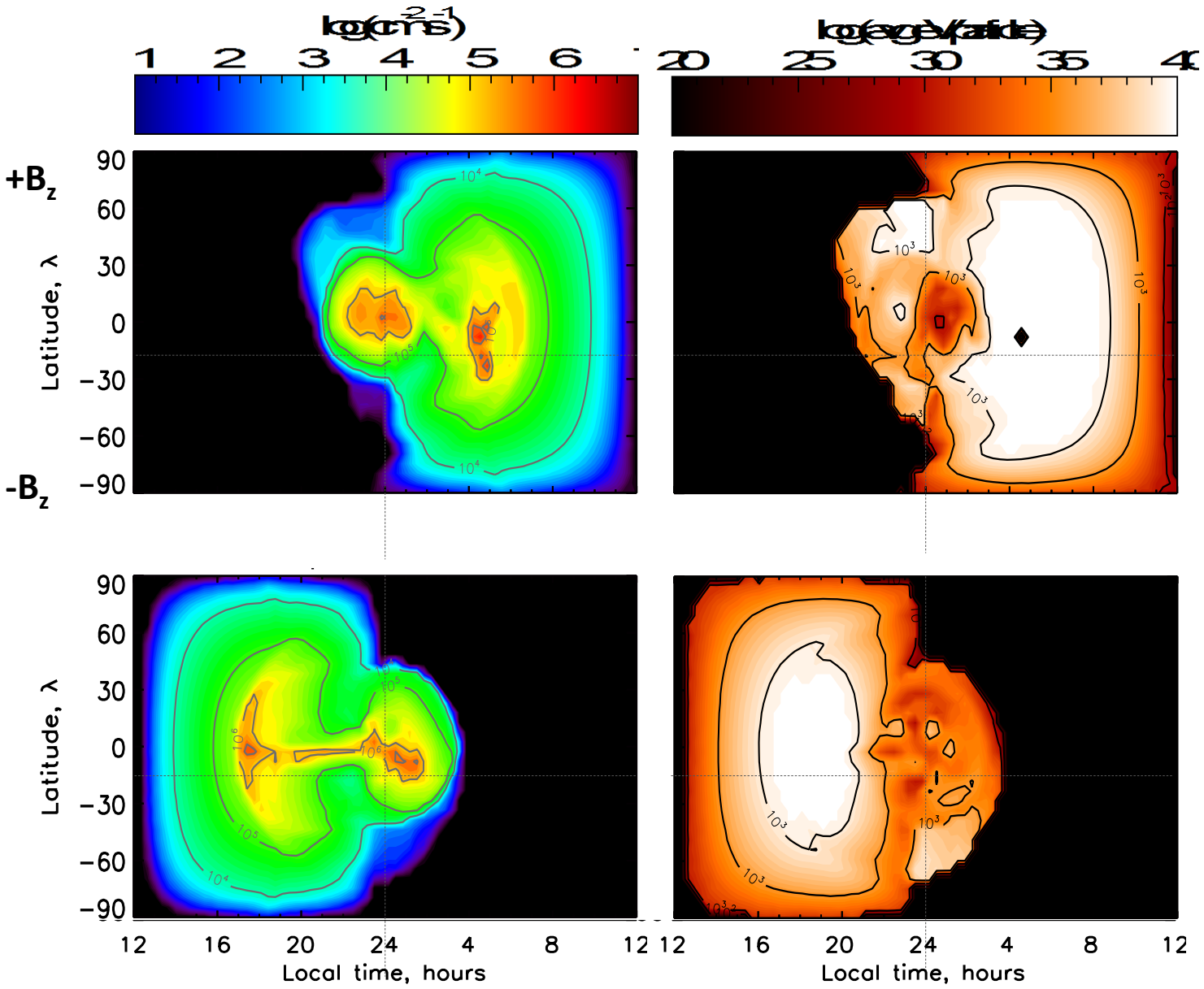

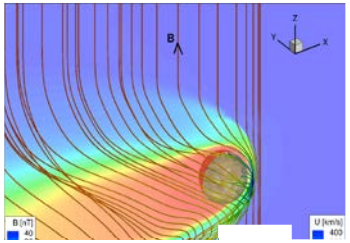

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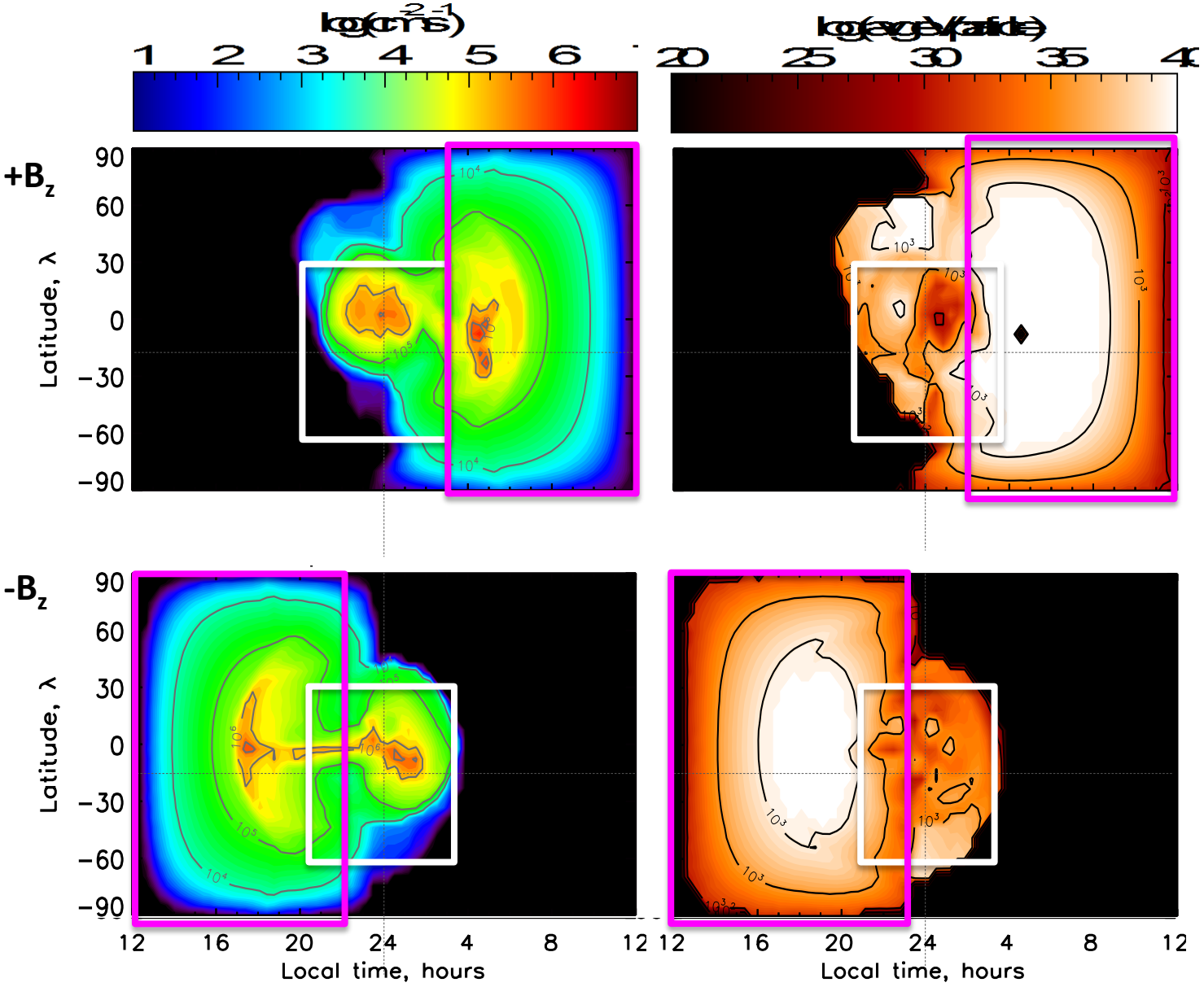

- Low energy cold ion outflow in the tail
- High energy 'plume' in equatorial plane (-U×B)

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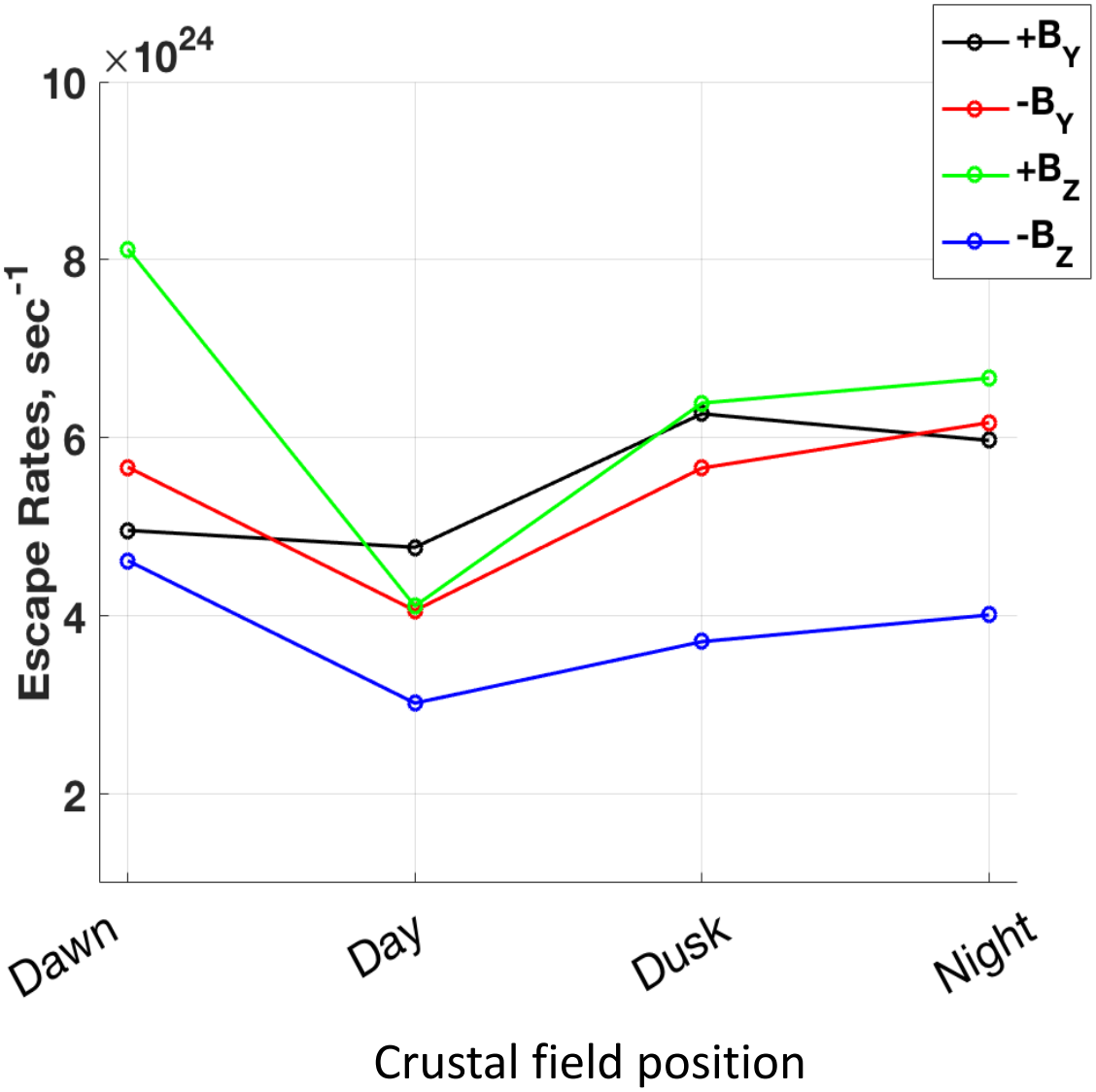
Quiet conditions: crustal field strength and IMF orientation



- Dawn crustal fields yield highest escape rates (as opposed to the nightside)
- Dayside crustal fields yield lowest escape rates
- Generally **+Bz** has highest rates but **–Bz** has lowest rates
- *The –Bz case is analogous to a southward IMF at Earth!

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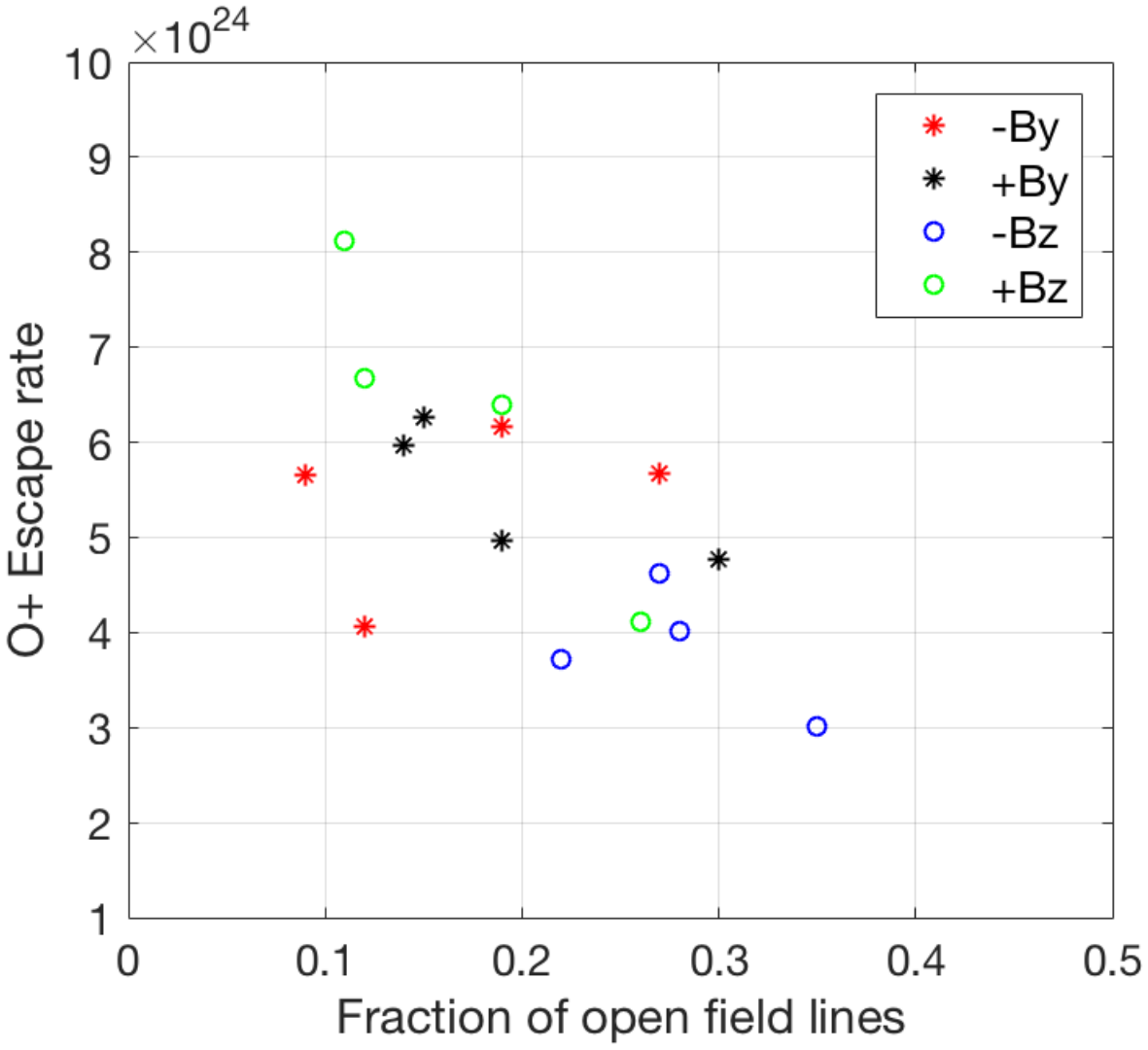
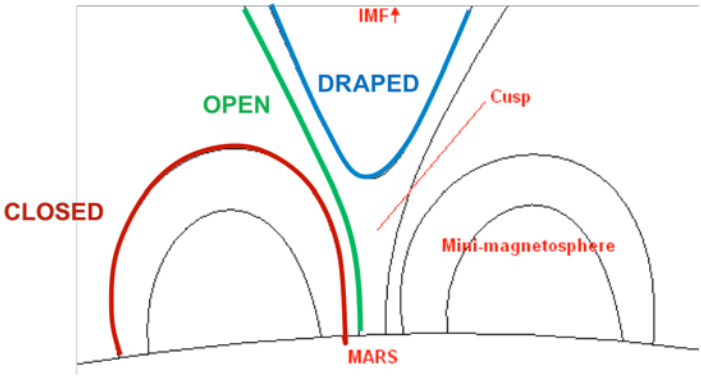
Quiet conditions: crustal field strength and IMF orientation





- During quiet conditions, more open field lines result in a *lower* planetary ion escape rate
- This suggests that draped fields are responsible for ion acceleration (particularly the cold ion outflow)

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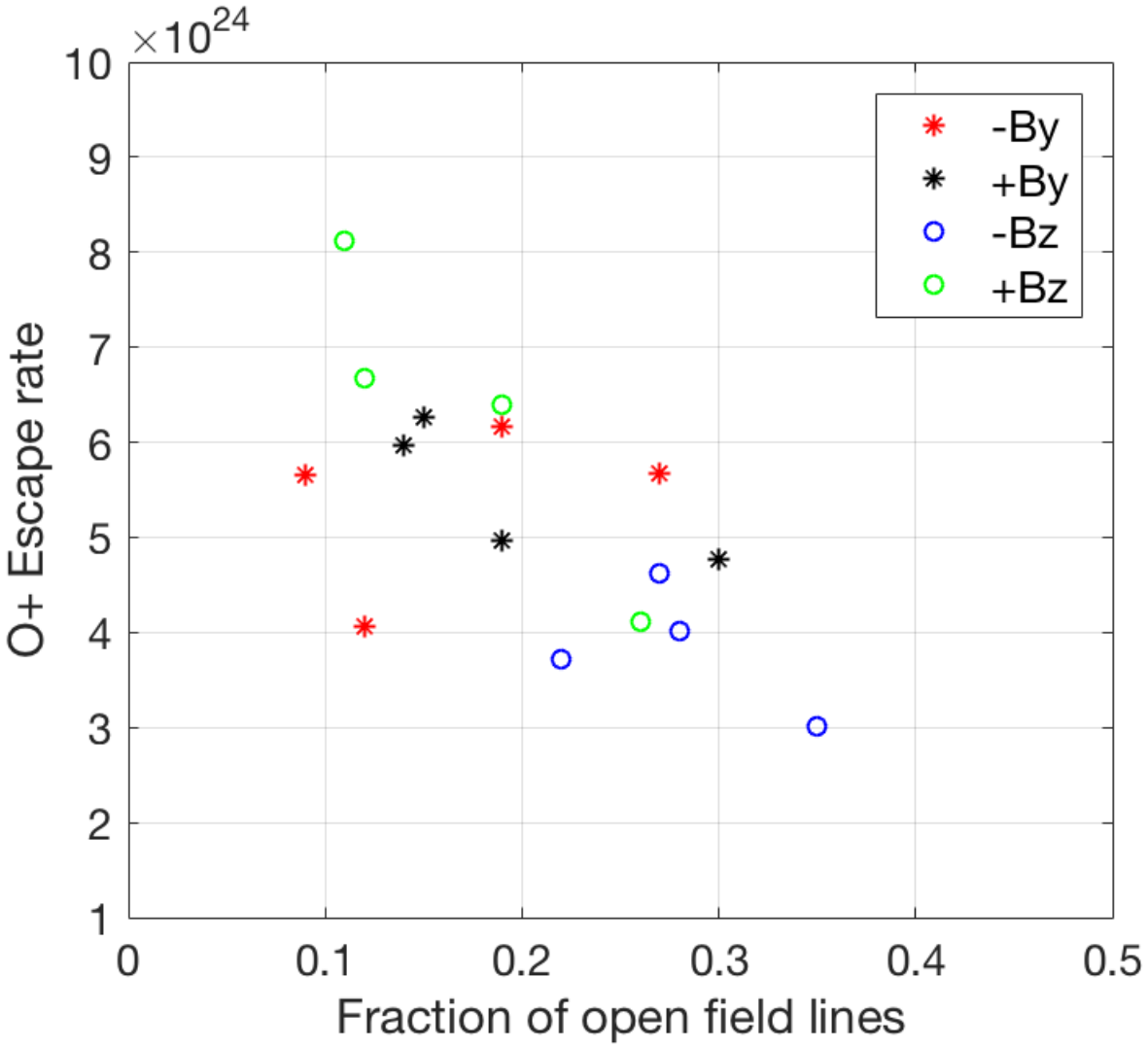
Quiet conditions: crustal field strength and IMF orientation



- This is consistent with MAVEN observations of cold ion outflow (see Dave Mitchell's talk tomorrow)
- STATIC integrated oxygen flux for magnetic field topology:
  - 7.3e24 (open)
  - 9.5e24 (draped)

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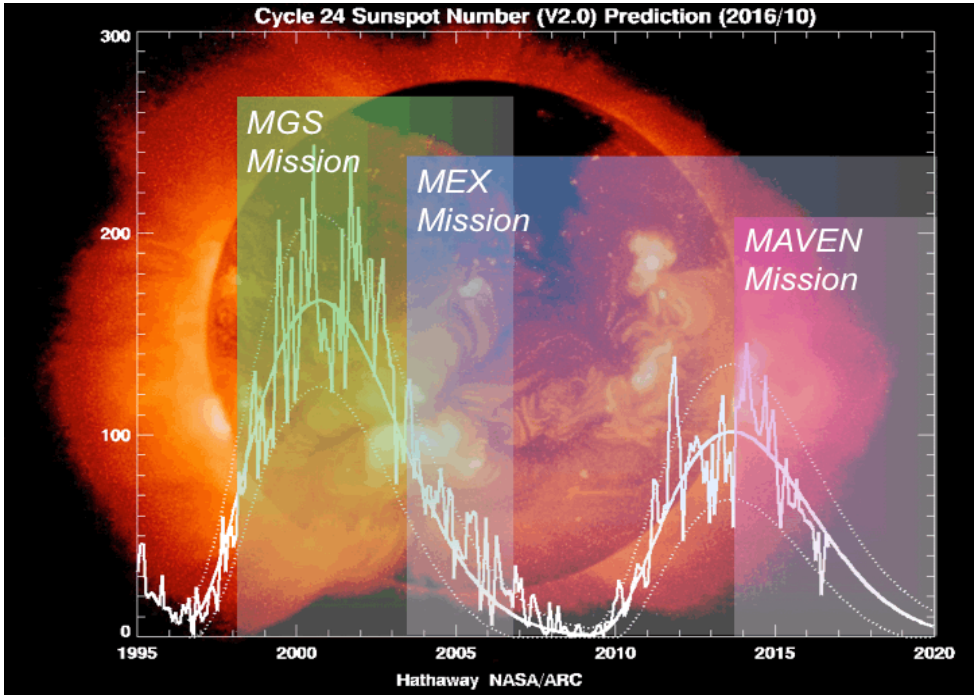
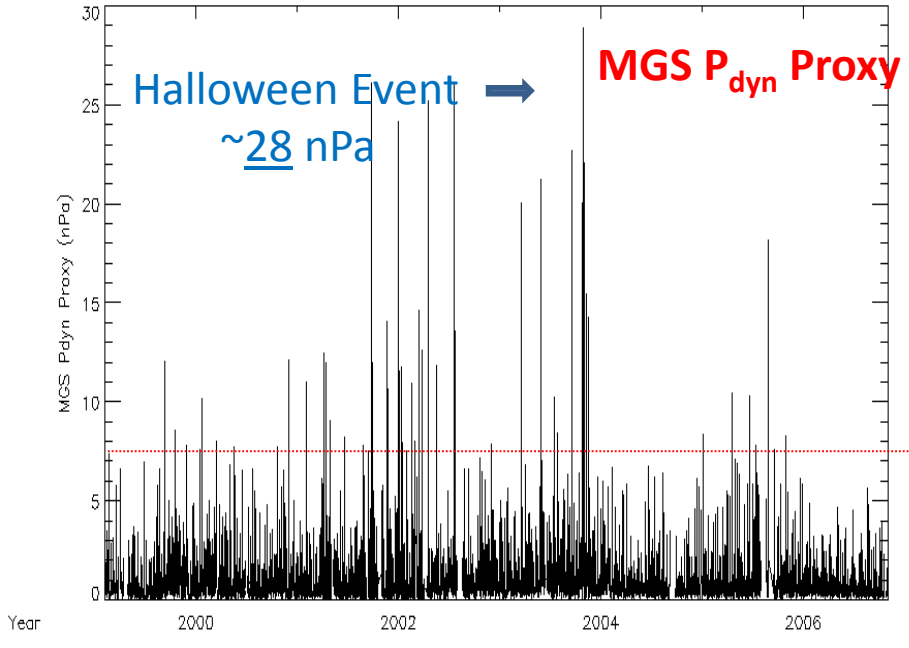
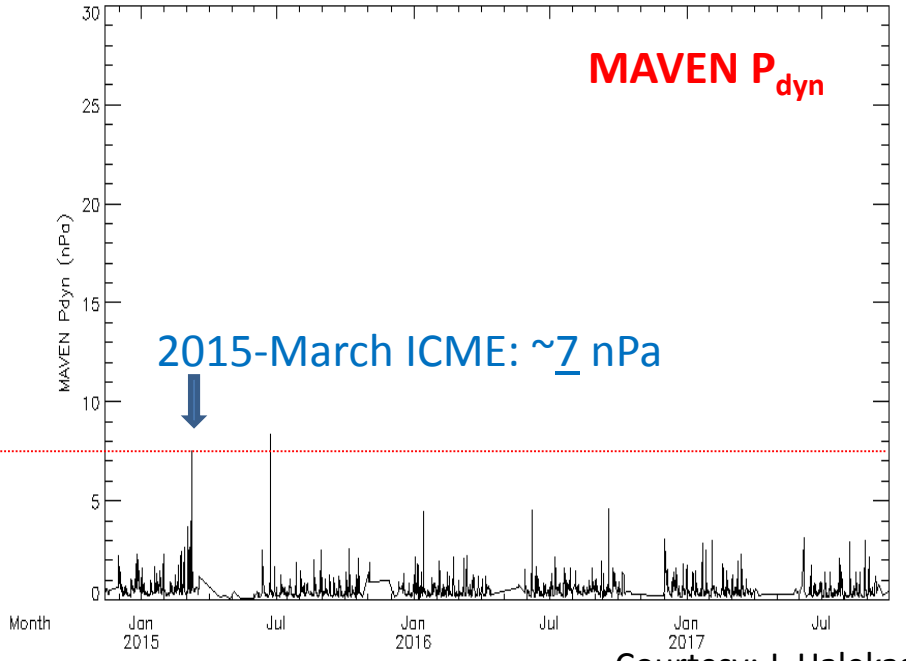
Extreme conditions

- Why MGS data?
  - Encountered more active solar maximum
  - Circular orbit at a fixed 400-km altitude



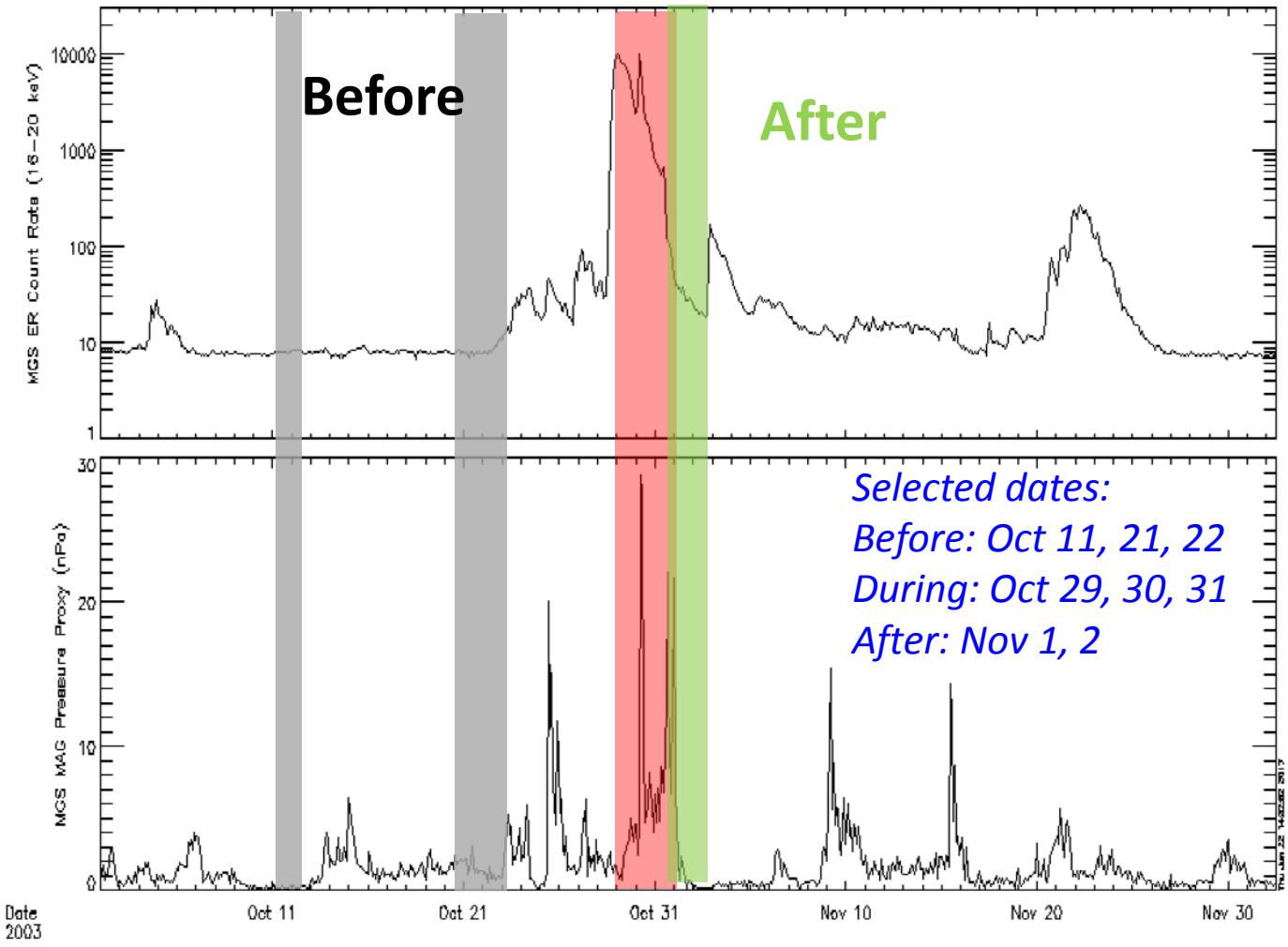




Courtesy: J. Halekas

Halloween Event Upstream Proxies at Mars

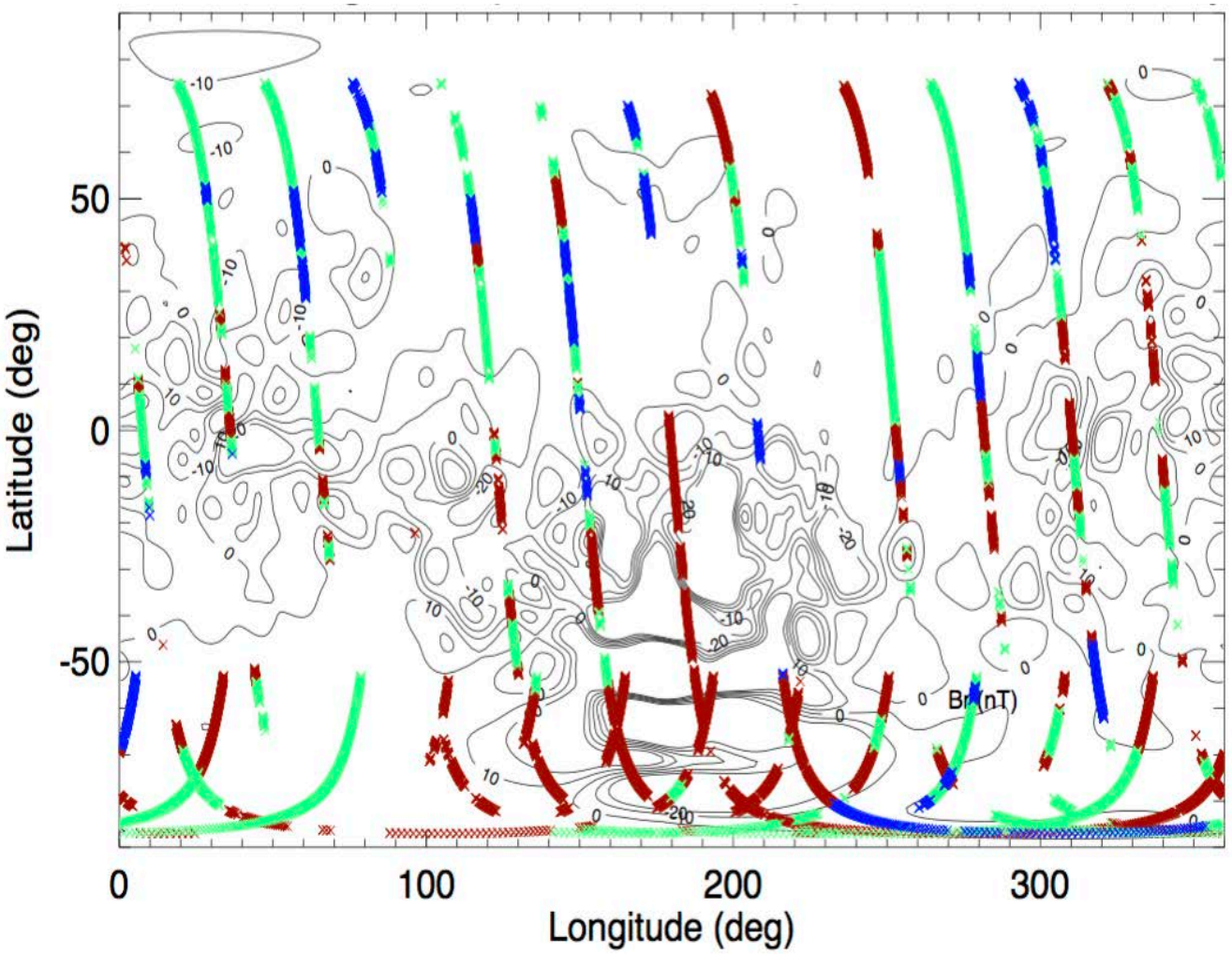
During



ER Background Count Rate: Penetrating Particles

Dynamic Pressure Proxy: From MAG data by assuming pressure balance

Magnetic Topology Response

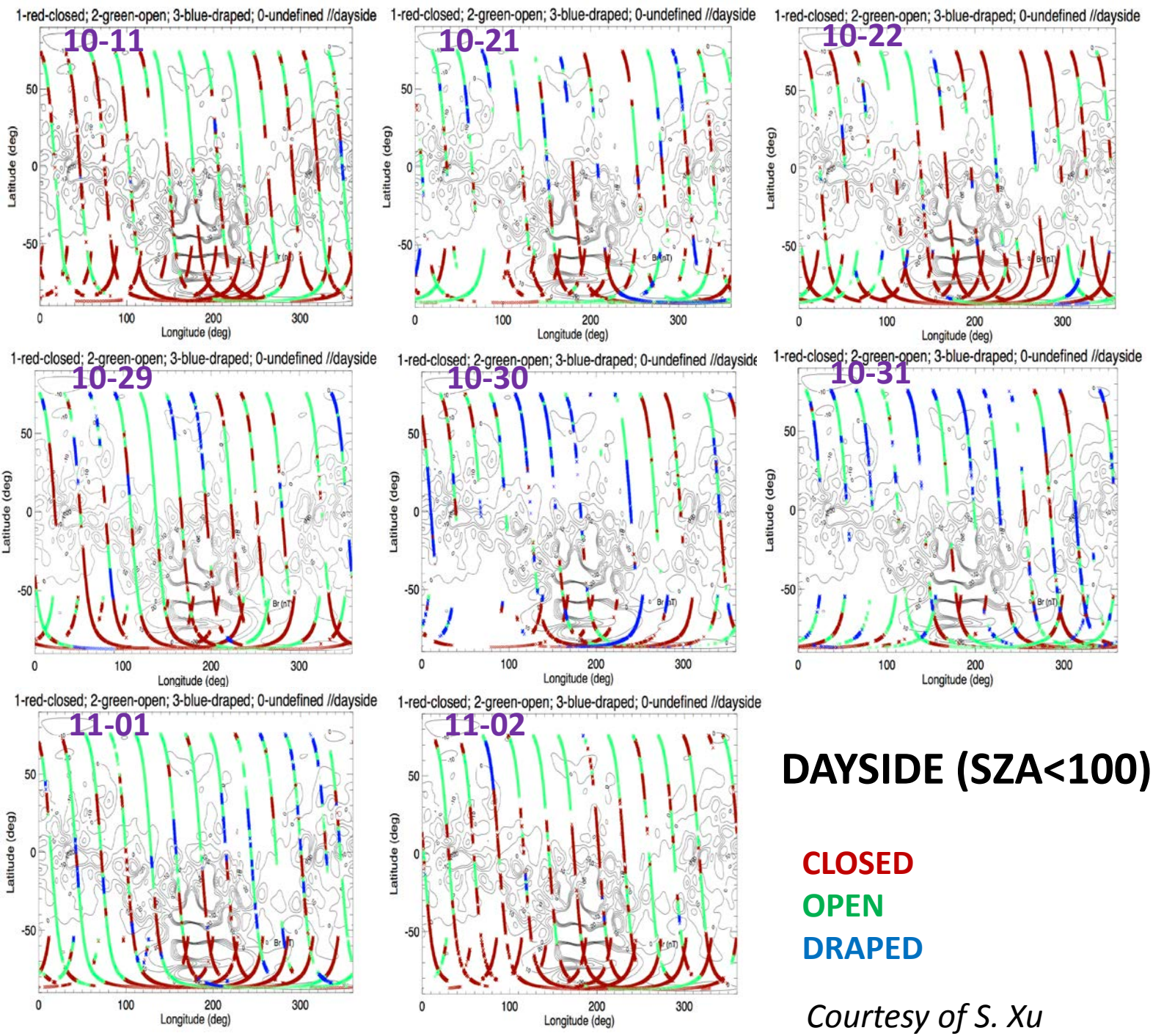


CLOSED

OPEN

DRAPED

Courtesy of S. Xu



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Before ICME

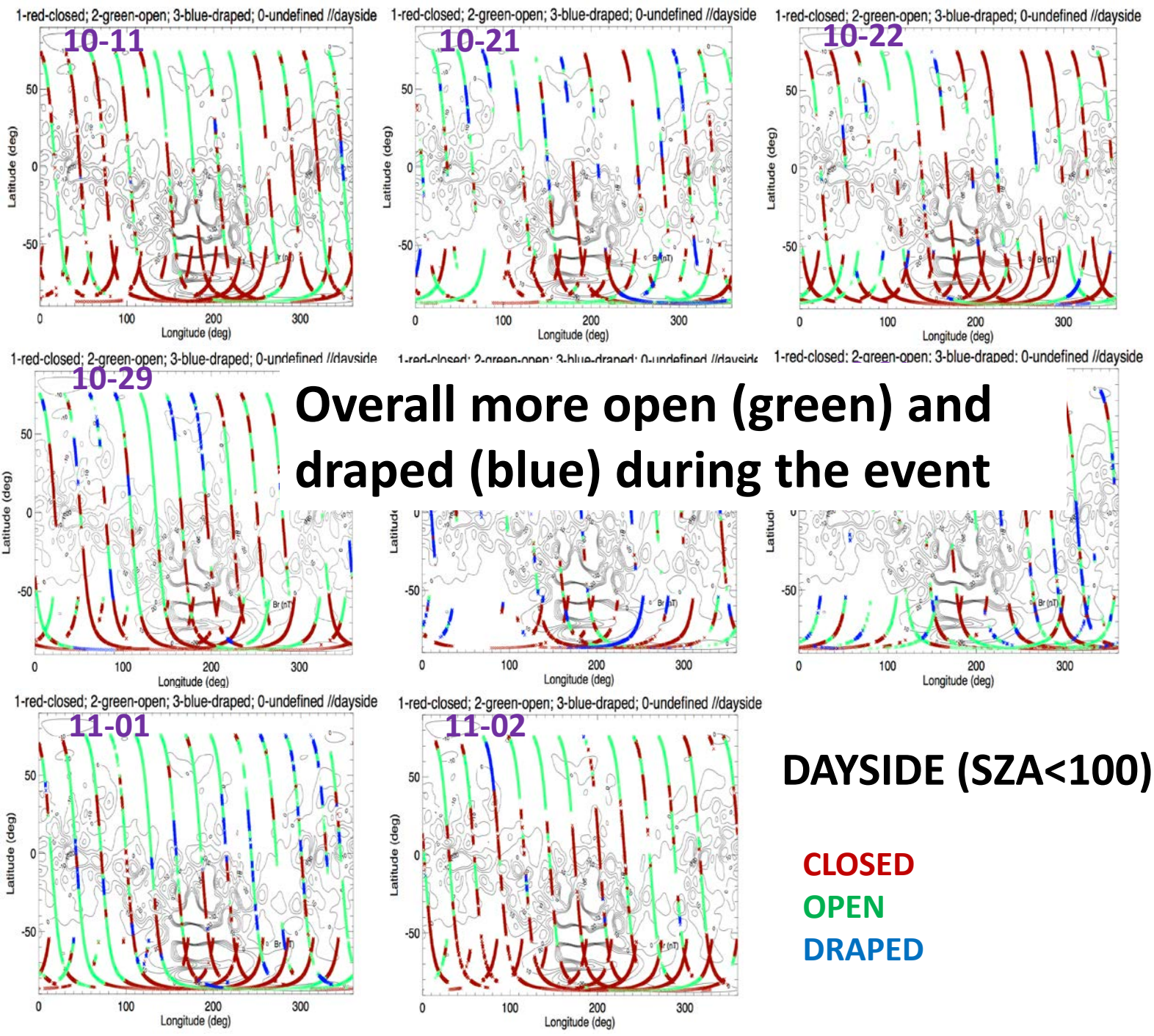
During ICME

After ICME

DAYSIDE (SZA<100)

CLOSED
OPEN
DRAPED

Courtesy of S. Xu



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Before ICME

Overall more open (green) and draped (blue) during the event

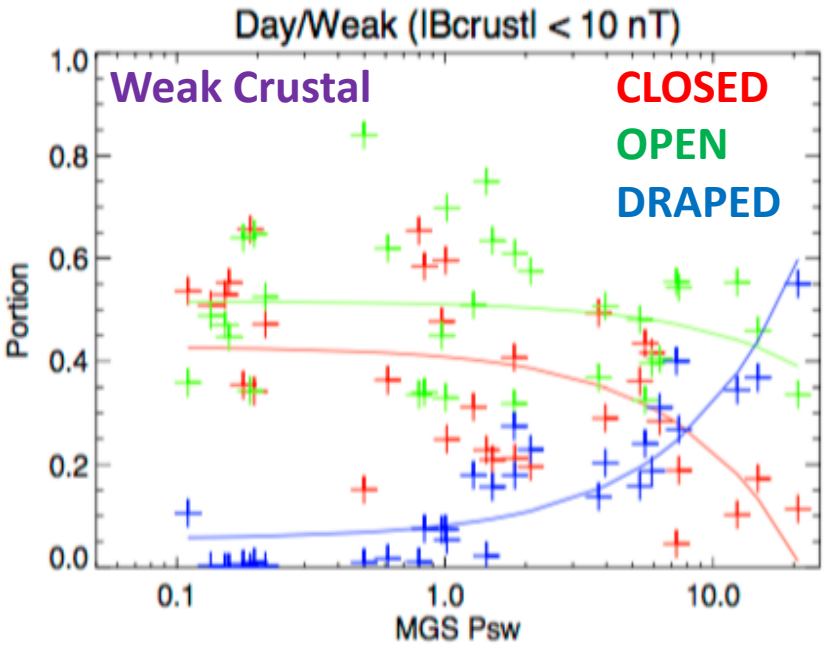
During ICME

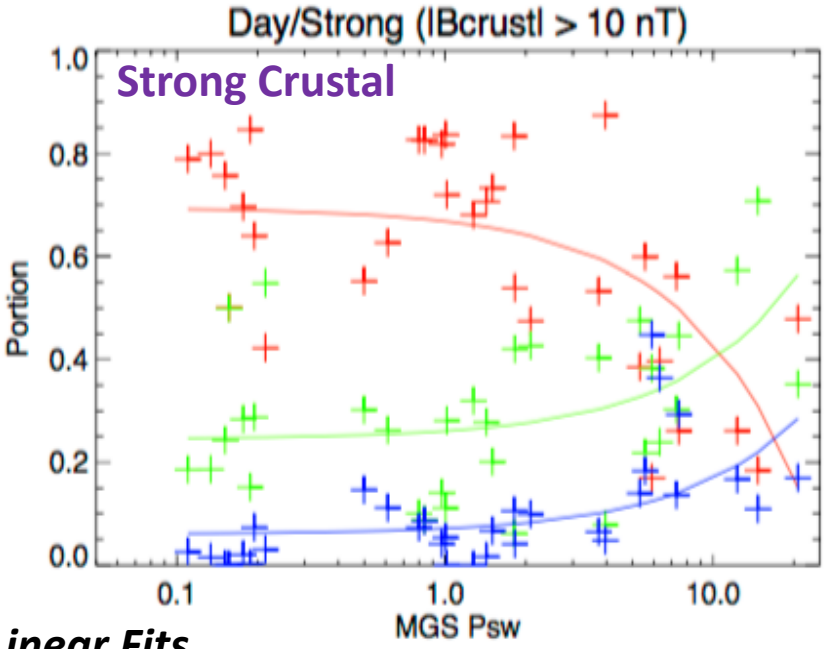
DAYSIDE (SZA<100)

CLOSED
OPEN
DRAPED

After ICME

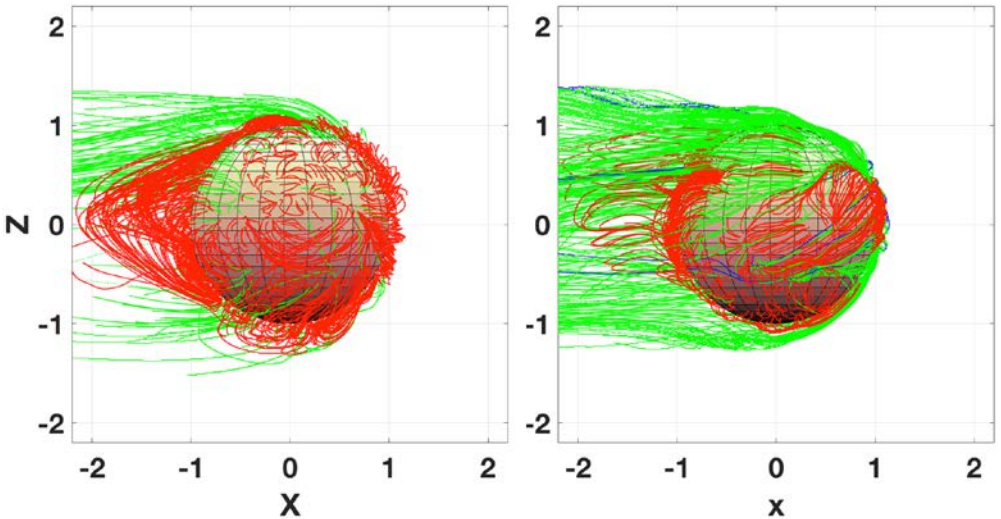
Dayside





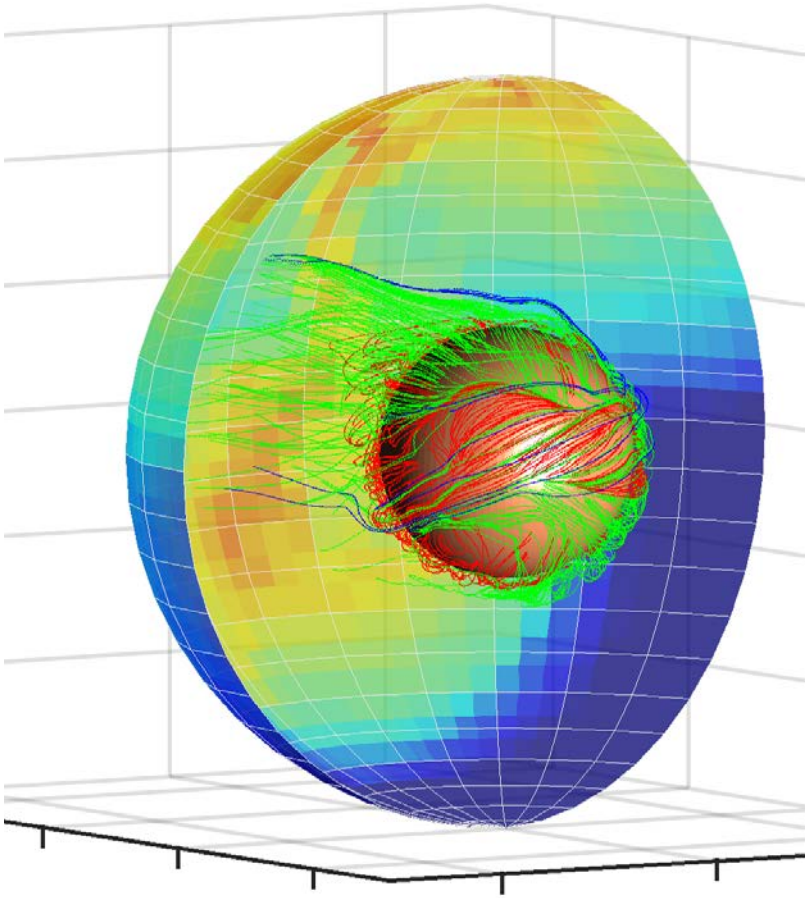
Linear Fits

- **<u>Weak</u>** crustal regions, increasing Pdyn:
  - Less open/closed, more draped
  - Indicating a compression
- **<u>Strong</u>** crustal regions, increasing Pdyn:
  - Less closed, more open/draped
  - Implying more reconnection



Conclusions

- Draped fields are associated with slightly higher escape rates during quiet conditions
- Both the **IMF configuration** and the **crustal field location** determine the magnetic topology
- During extreme conditions, the magnetic topology at Mars becomes more open in the vicinity of the crustal fields but also has over an order of magnitude higher escape



- Future work will include MHD models of the Halloween storm, along with an analysis of more recent events (i.e. September 2017)

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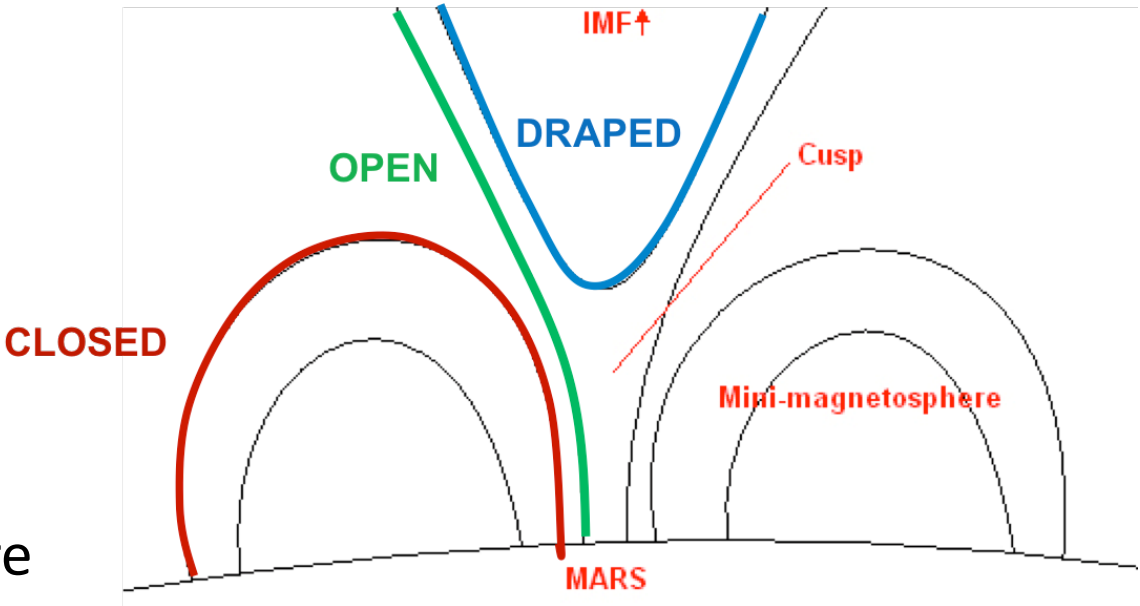
Data



- Electron pitch angle distribution (PAD):
  - One-sided loss cone: intersecting atmosphere on one end, open
  - Double-sided loss cone: intersection on both ends, closed

- Electron energy spectra for field-aligned directions:
  - Photoelectrons seeing in one direction, solar wind electrons in another, open
  - Photoelectrons in both directions, closed
  - Low energy flux: electron voids: closed
  - Solar wind electrons in both directions with no loss cone, draped

Backup

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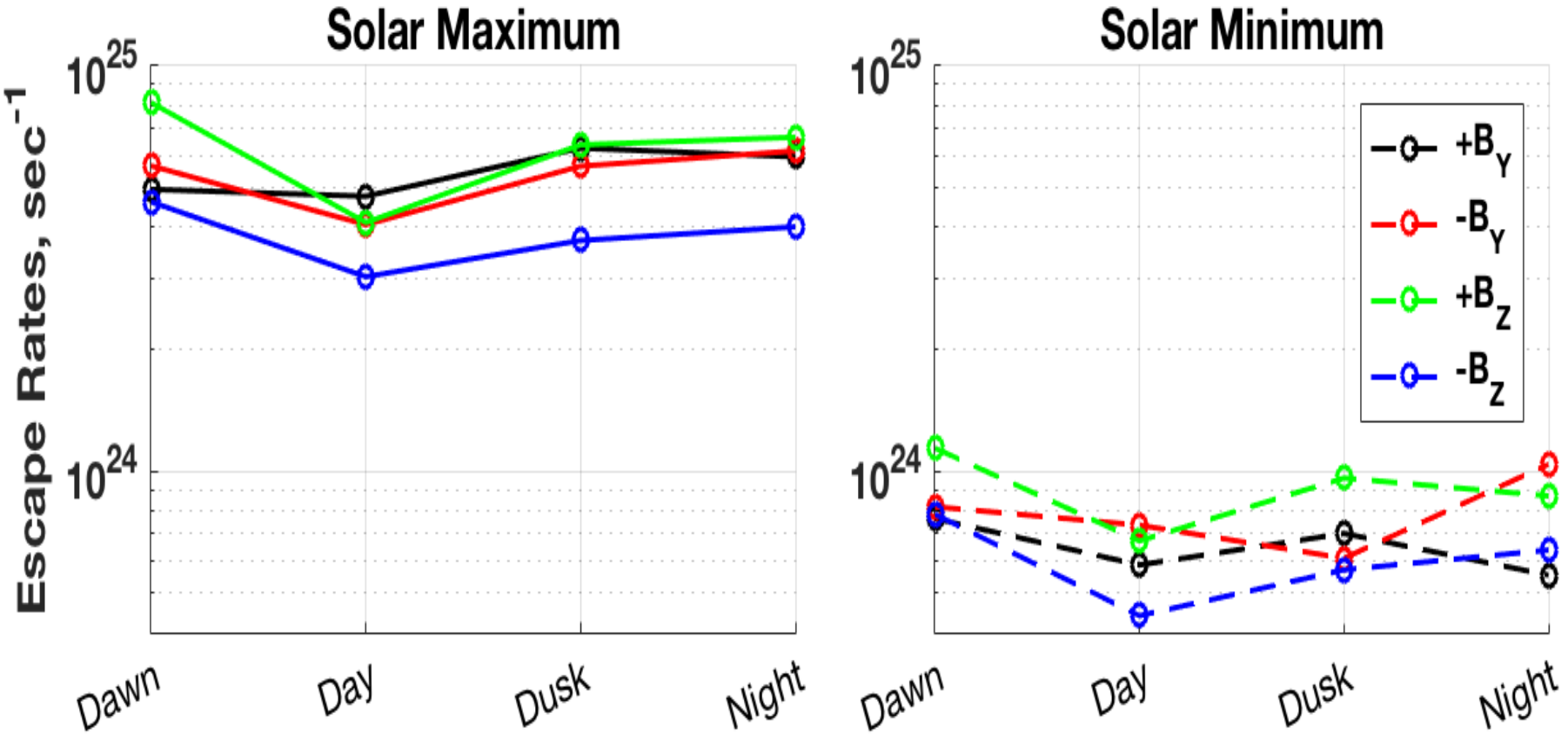

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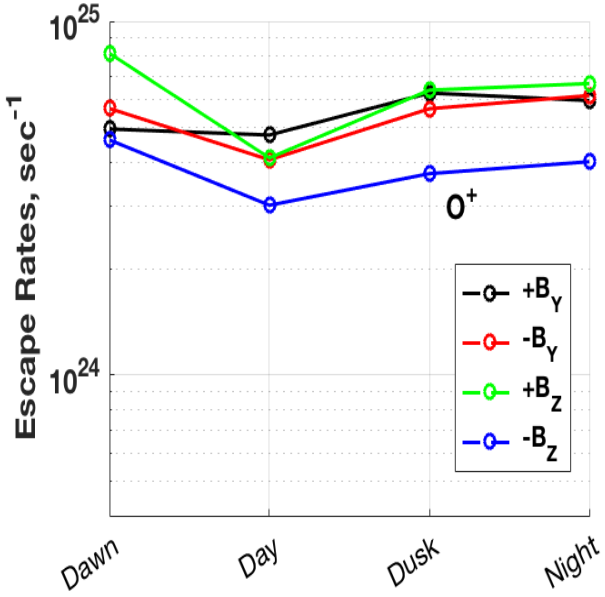

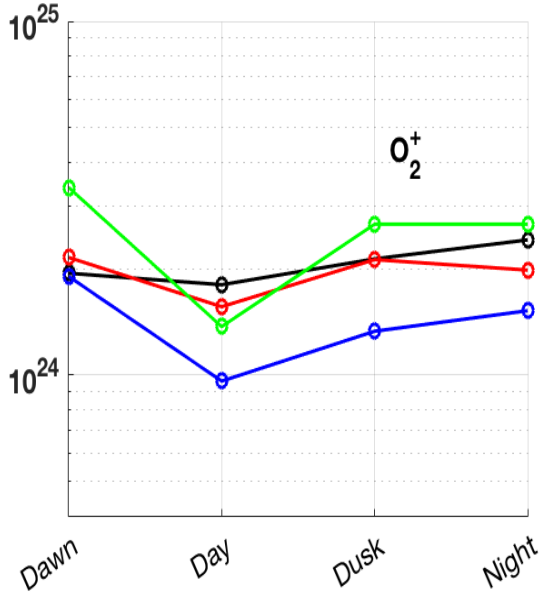

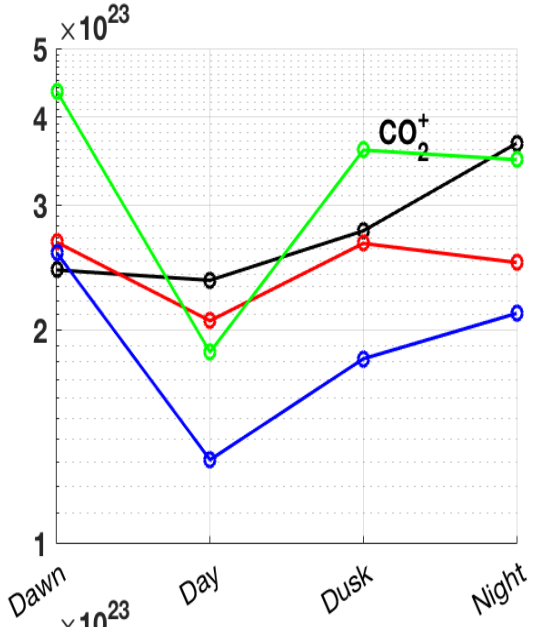

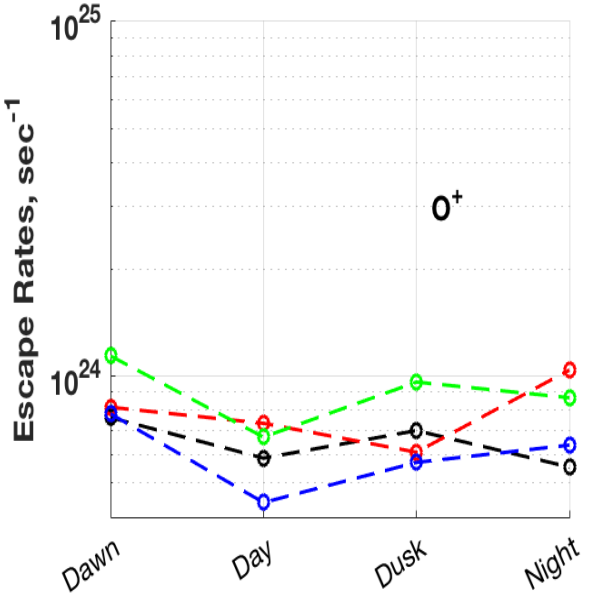

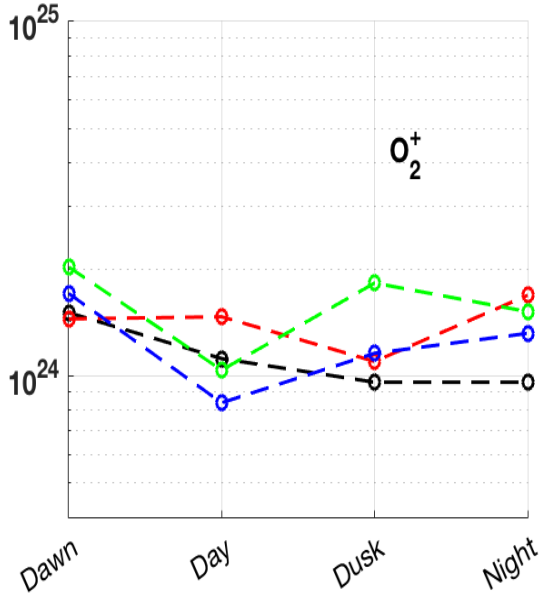

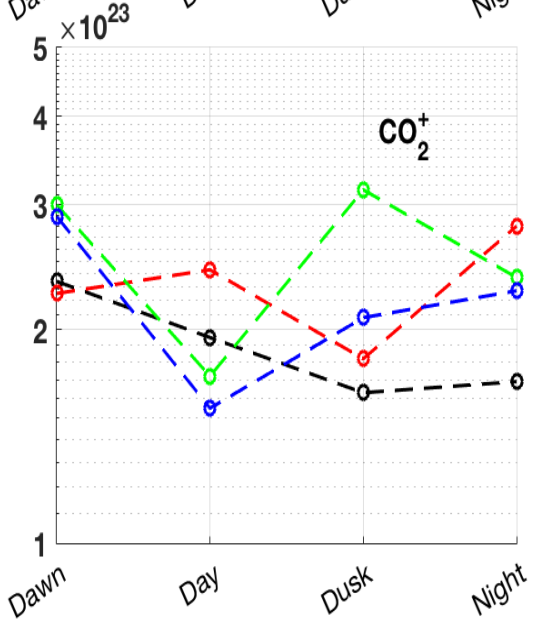

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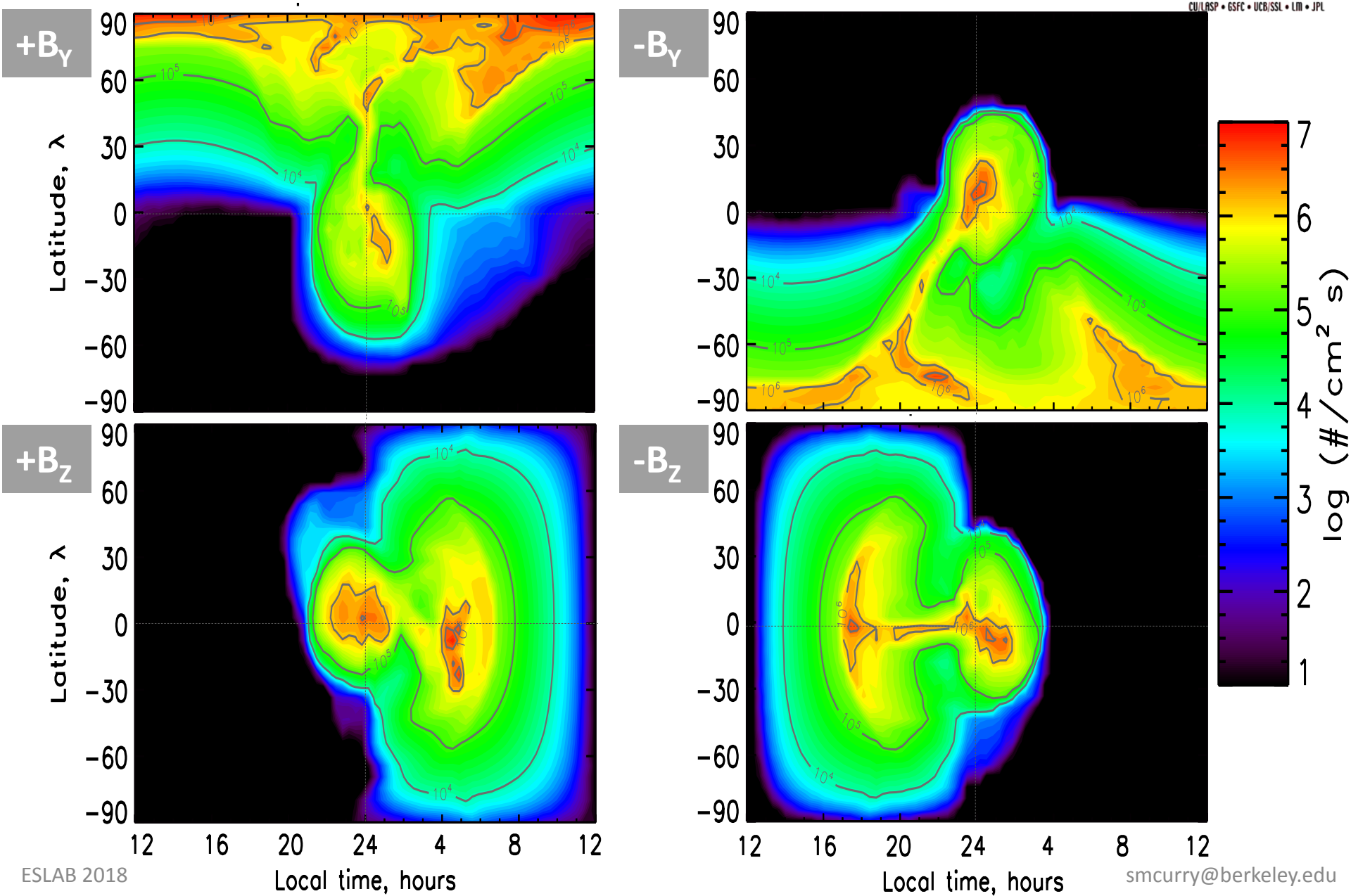
Maps of O^+ escape at 4 R_M ($B_{crustal}$)



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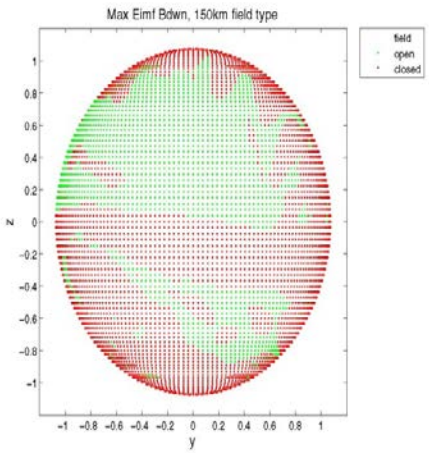
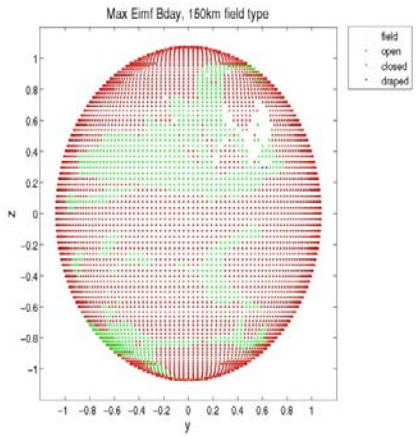
Open / closed field lines at 150 km

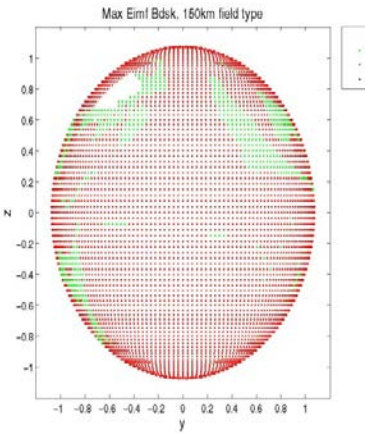
+By (day)



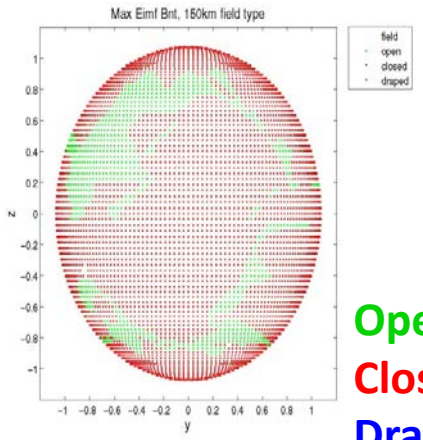
+By (dawn)



+By (dusk)

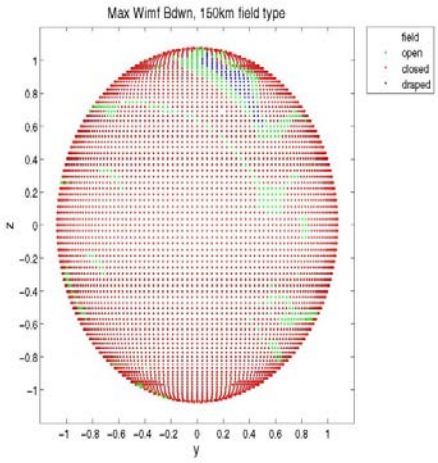


+By (night)

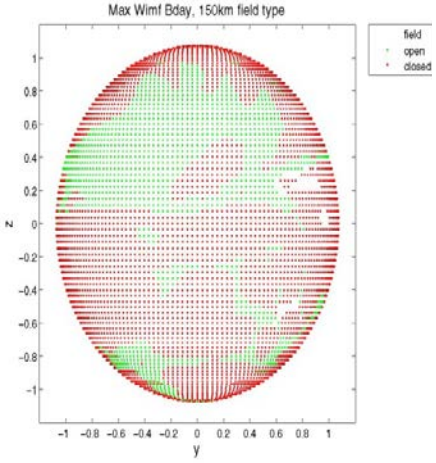


Open
Closed
Draped

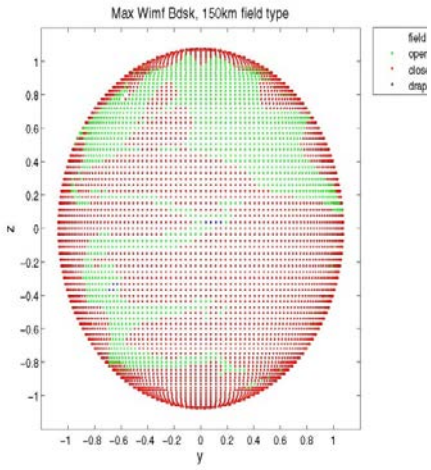
-By (day)



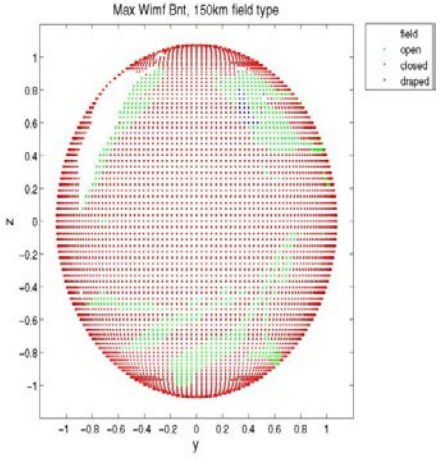
-By (dawn)



-By (dusk)



-By (night)



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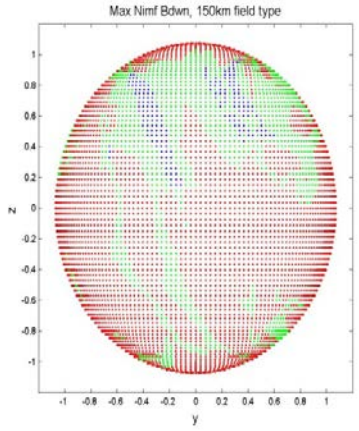
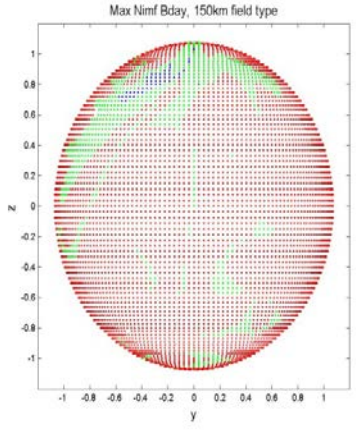
Open / closed field lines at 150 km

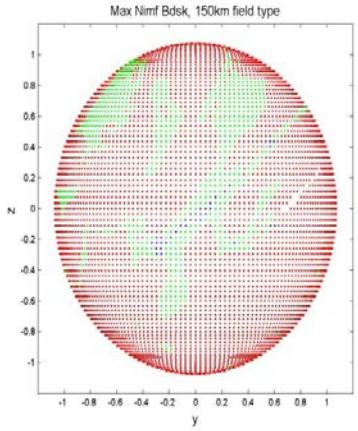
+Bz (day)



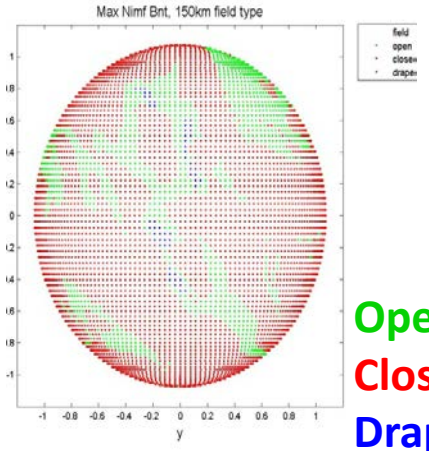
+Bz (dawn)



+Bz (dusk)

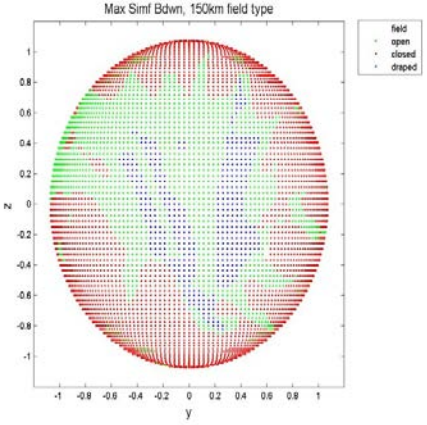


+Bz (night)

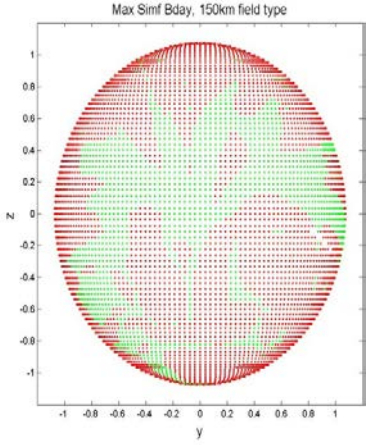


Open
Closed
Draped

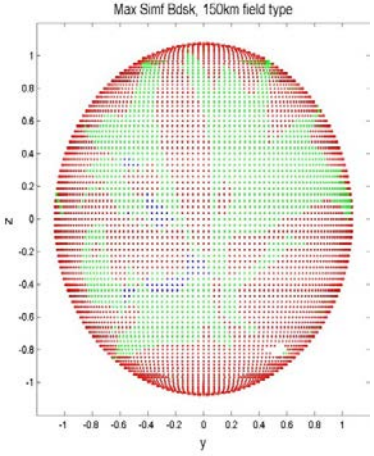
-Bz (day)



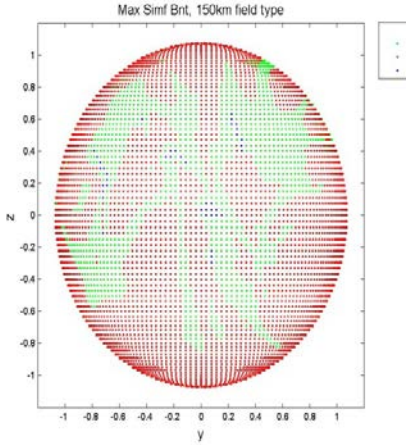
-Bz (dawn)



-Bz (dusk)



-Bz (night)



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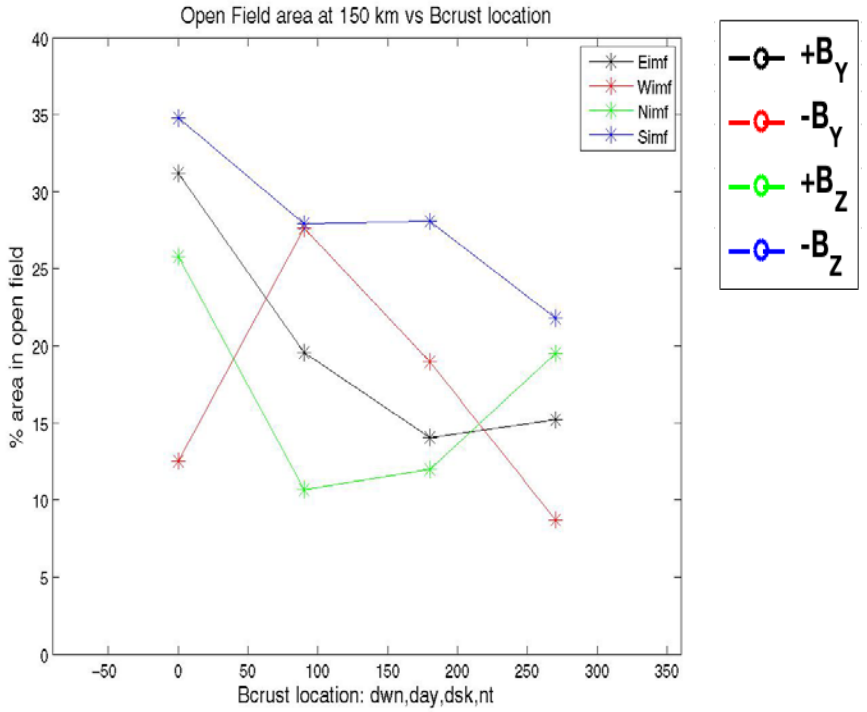
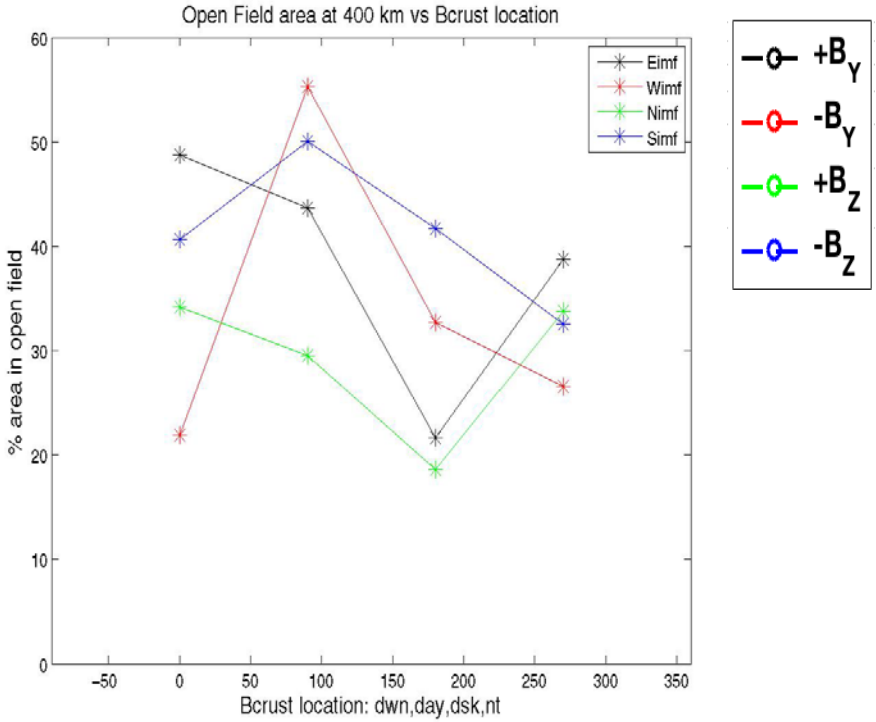
Open field lines at 150 km and 400 km





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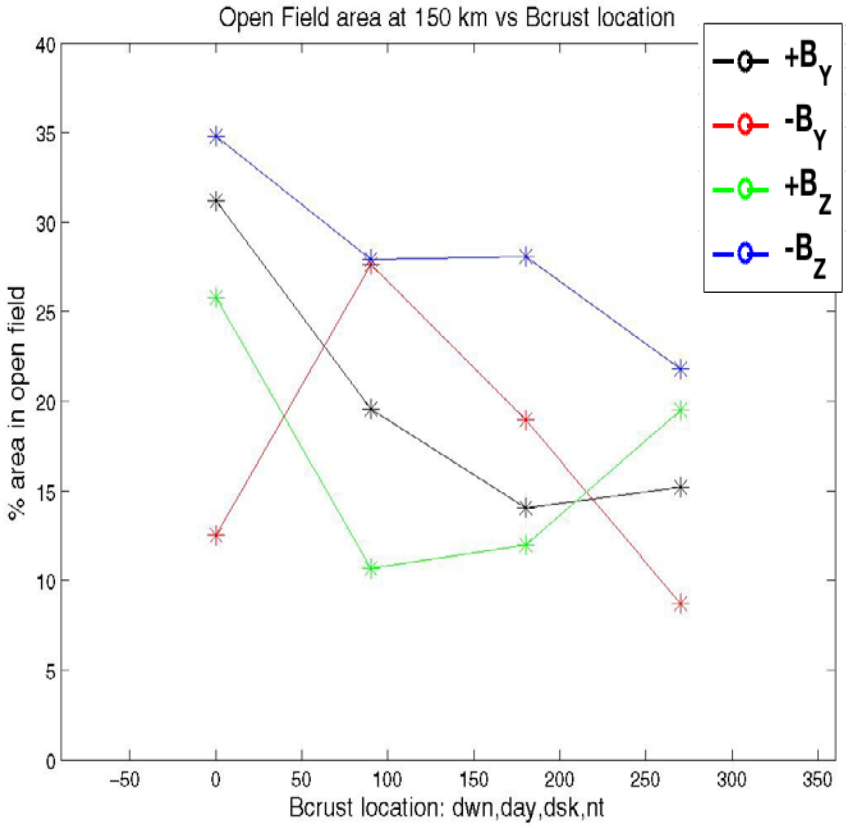
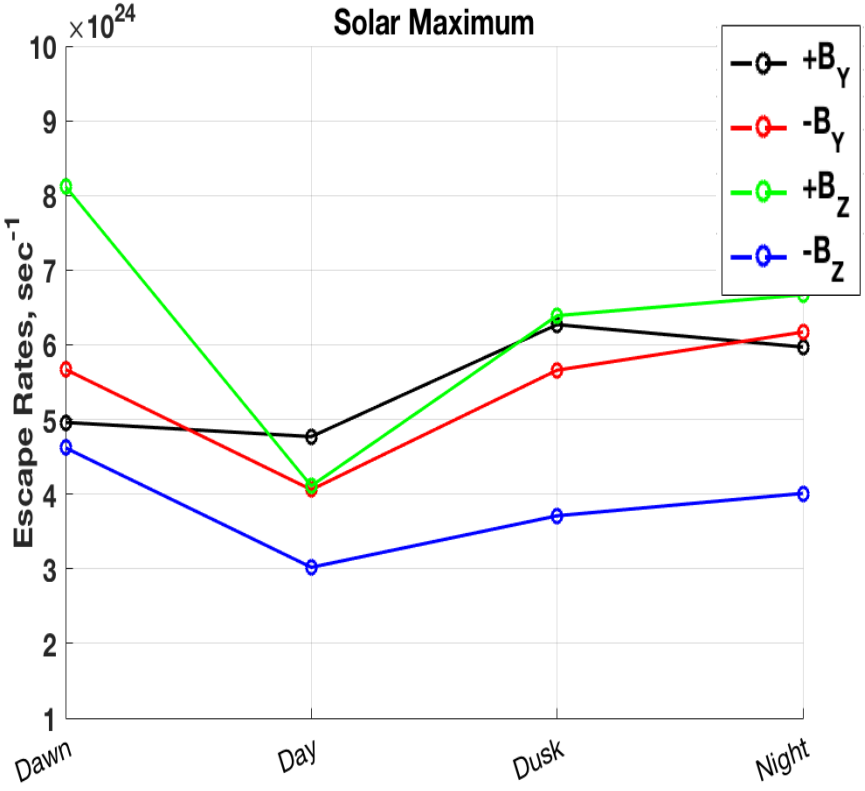
Open field lines and O+ escape





- The percentage of open field lines is inversely proportional to the escape rate
- The draped fields are able to

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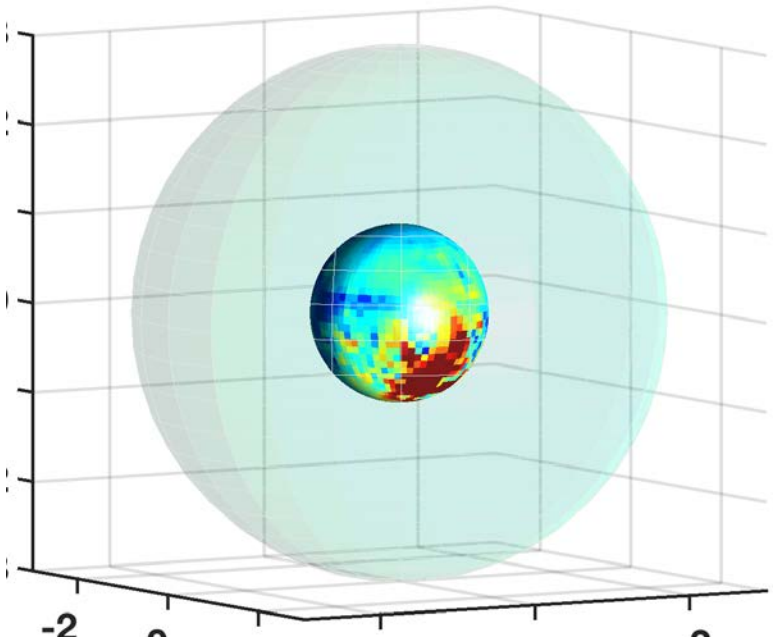

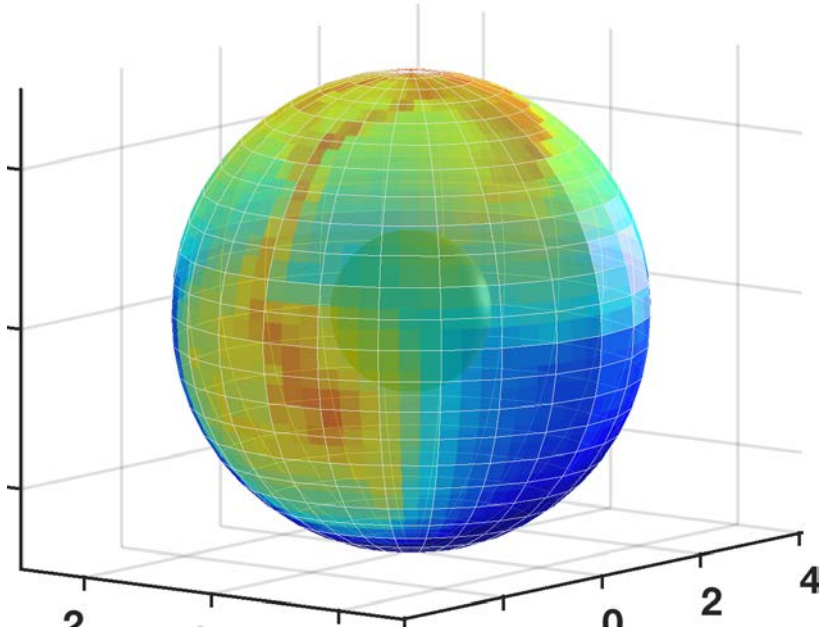

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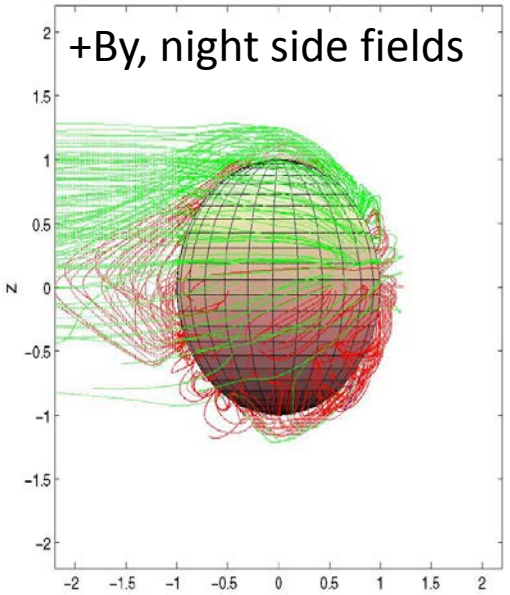
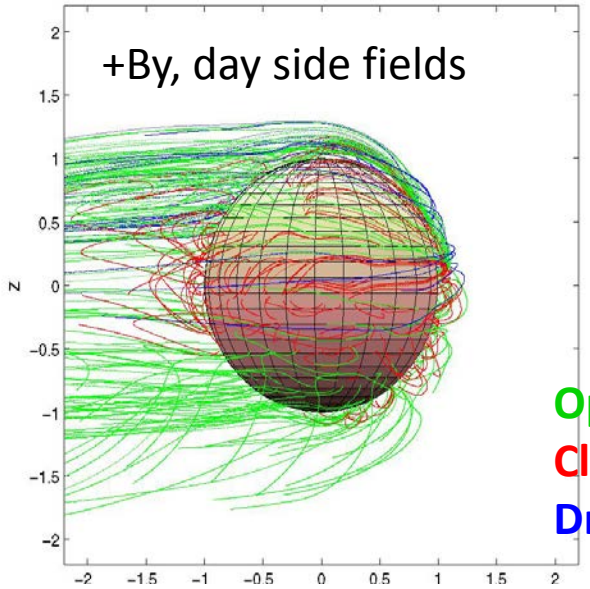
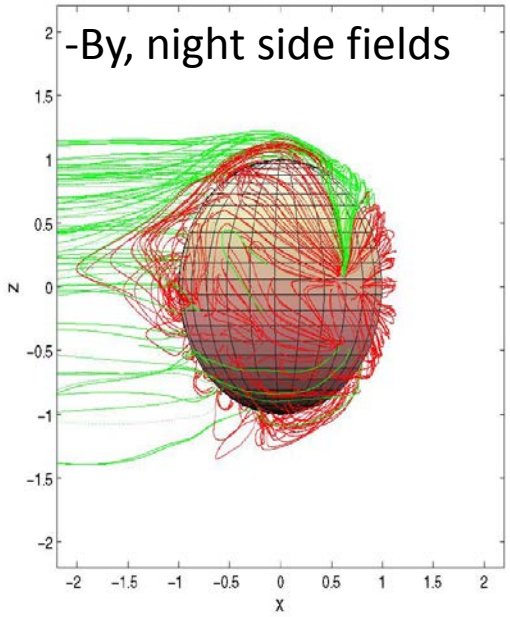
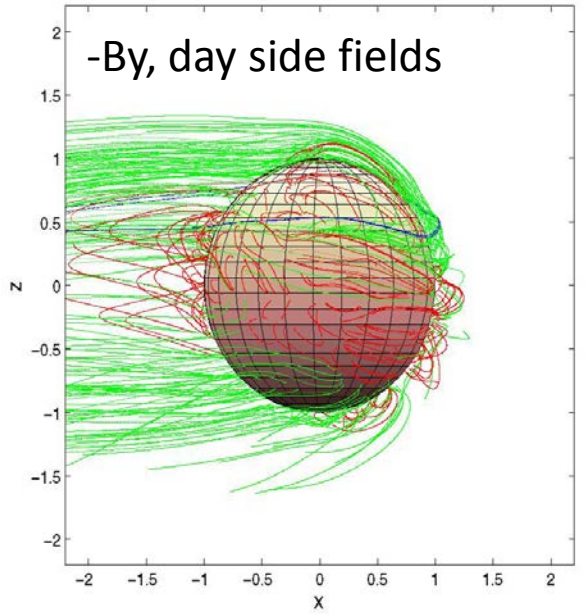
Why the change in escape?





Open
Closed
Draped





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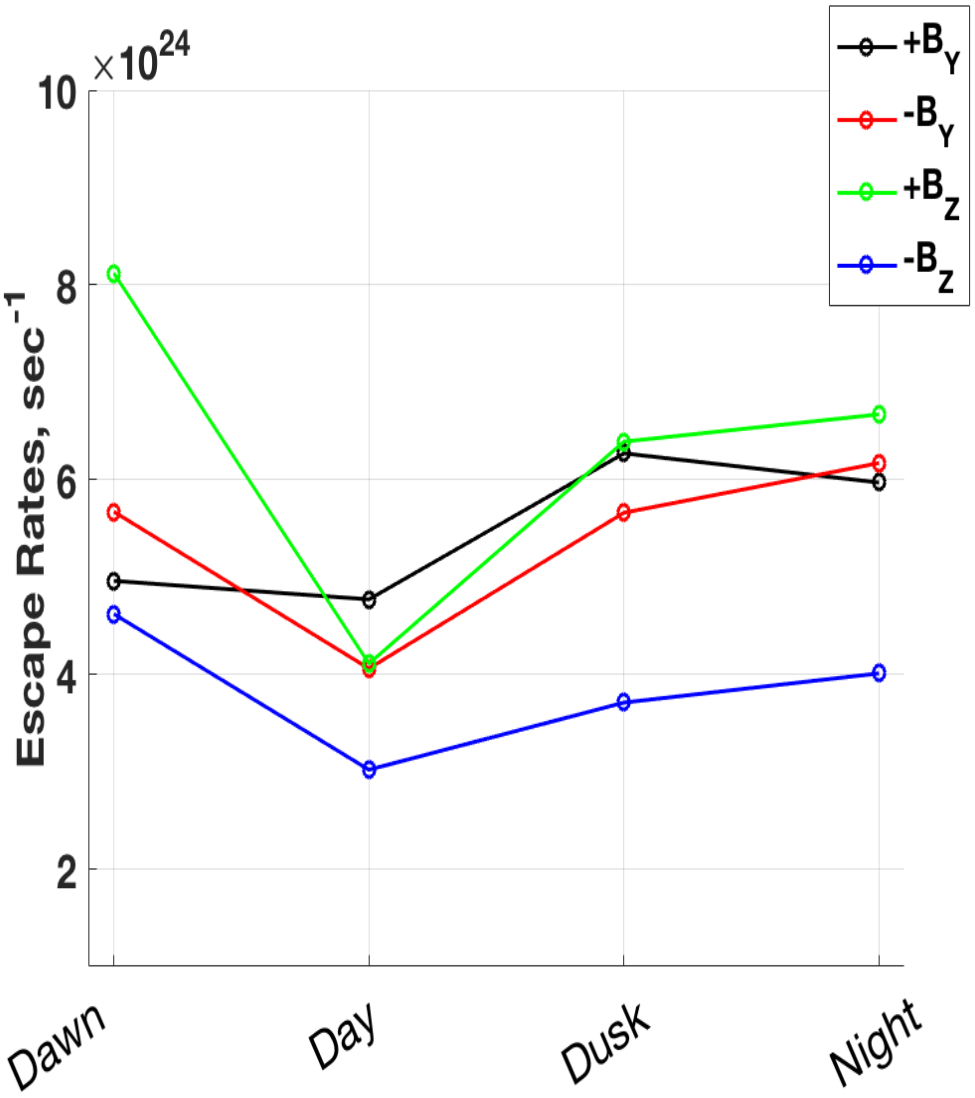
O^+ escape



- Dawn crustal fields yield highest escape rates (as opposed to the nightside)
- Dayside crustal fields yield lowest escape rates
- Generally **+Bz** has highest rates but **–Bz** has lowest rates

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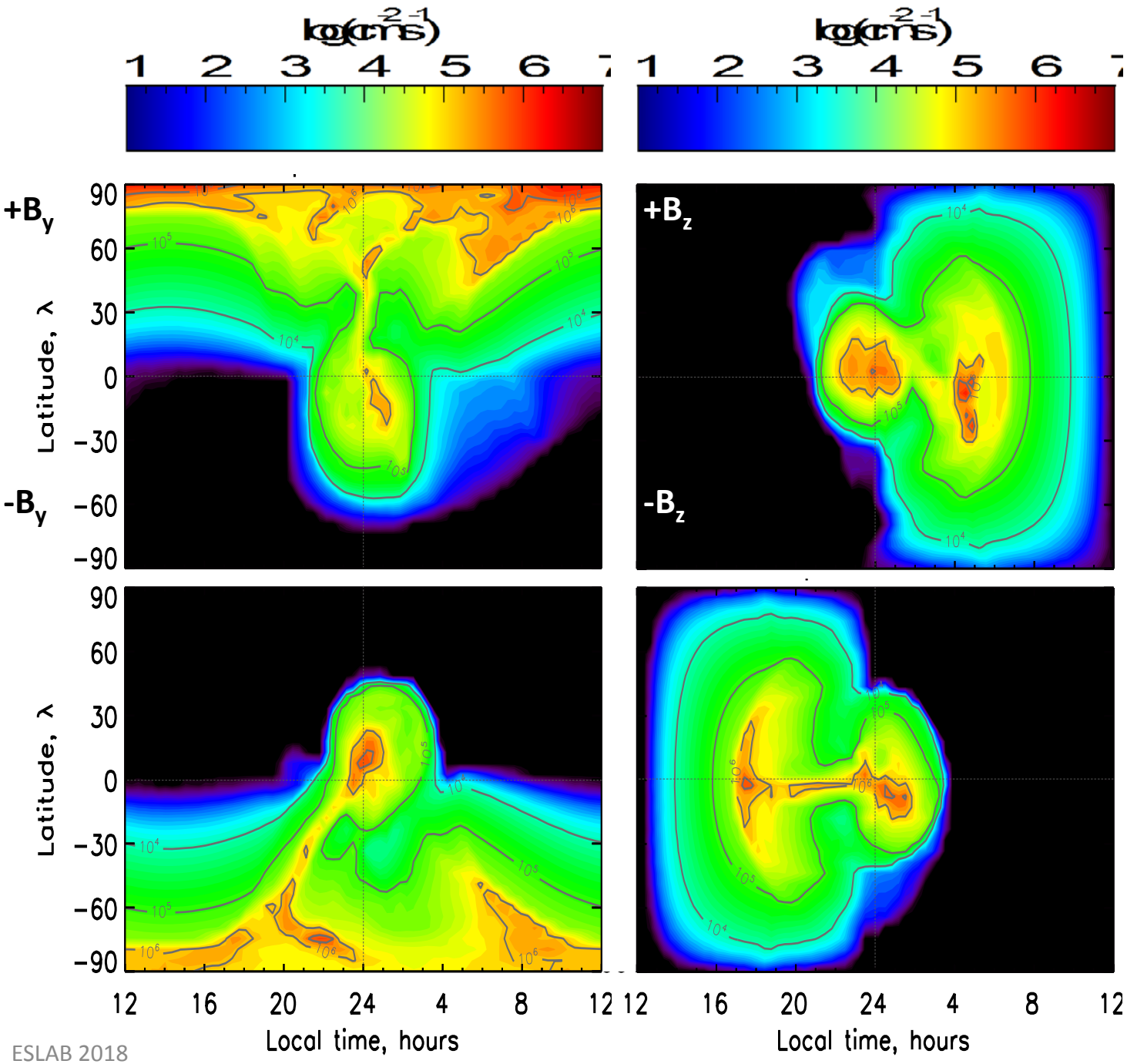

Escape rates

+By= 4.8×10^{24}

-By= 4.1×10^{24}

+Bz= 4.1×10^{24}

-Bz= 3.0×10^{24}

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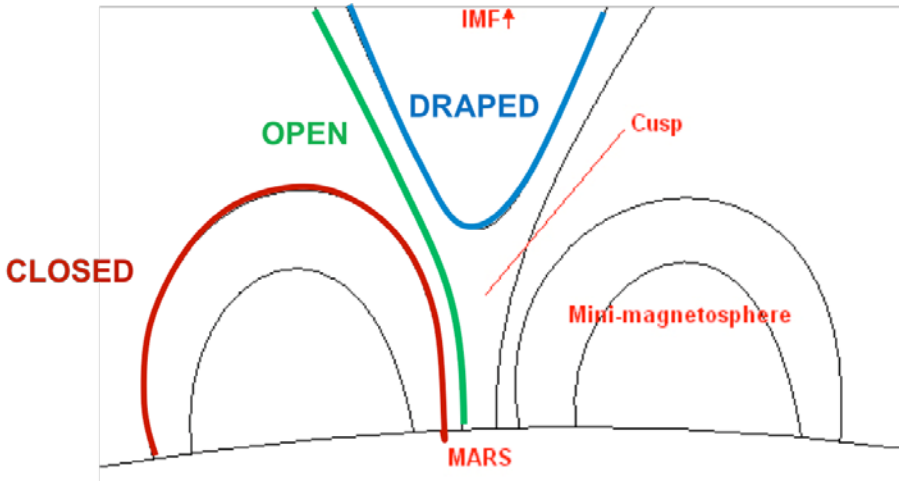
Data



Electron pitch angle distribution (PAD):

- One-sided loss cone: intersecting atmosphere on one end, open
- Double-sided loss cone: intersection on both ends, closed

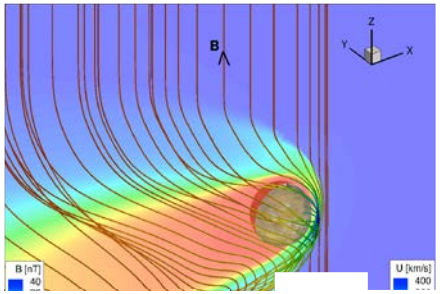
Electron energy spectra for field-aligned directions:

- Photoelectrons seeing in one direction, solar wind electrons in another, open
- Photoelectrons in both directions, closed
- Low energy flux: electron voids: closed
- Solar wind electrons in both directions with no loss cone, draped

Models

+E

+E



+E

+E

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