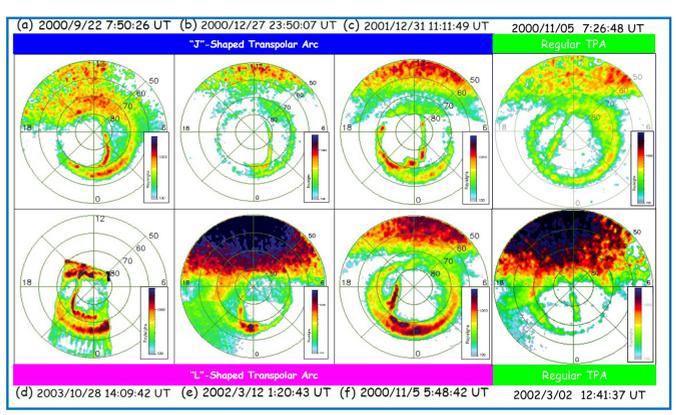


A Significant Finding of New Morphological Type of Transpolar Arc: Nightside Distorted Transpolar Arc

Motoharu Nowada(野和田 基晴)¹, Jun Yang¹, Qiu-Gang Zong², Quan-Qi Shi¹, Yong-Fu Wang², Hua-Yu Zhao², and Xu-Zhi Zhou²
¹Shandong Provincial Key Laboratory of Optical Astronomy and Solar-Terrestrial Environment, Institute of Space Sciences, Shandong University, Weihai, People Republic of China.
²Institute of Space Physics and Applied Technology, School of Earth and Space Sciences, Peking University, People Republic of China.

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Key Question 1 What is "nightside distorted TPA"?
"Nightside distorted TPAs" are the dawnside (duskside) TPAs with the nightside ends distorted toward pre- (post-) midnight sector. Because these TPAs look like the shape of an alphabetical letter of "J" or "L", we further distinguished the nightside distorted TPAs from "J"- and "L"-shaped TPAs.
The "J"-shaped TPAs are the dawnside TPA with the nightside end distorted toward the pre-midnight sector. The TPAs in the duskside, whose nightside parts got distorted toward the post-midnight sector, are referred to as "L"-shaped TPA.

Key Question 2 How is the relation with the IMF condition?
In most of cases, the nightside distorted TPAs can dominantly be found under the northward Interplanetary Magnetic Field (IMF) conditions.
Furthermore, when the IMF-By component pointed to the dawnward (duskward) direction, the "J" ("L")-shaped TPAs were frequently observed, suggesting that the relation between the IMF-Bz and By orientations, and the locations of the nightside distorted TPAs would be consistent with that between the IMF conditions and regular TPA, previously reported.

Table with 4 columns: Event #, GSM-X [RE], GSM-Y [RE], GSM-Z [RE]. Contains data for 7 events on September 22nd, 2000.

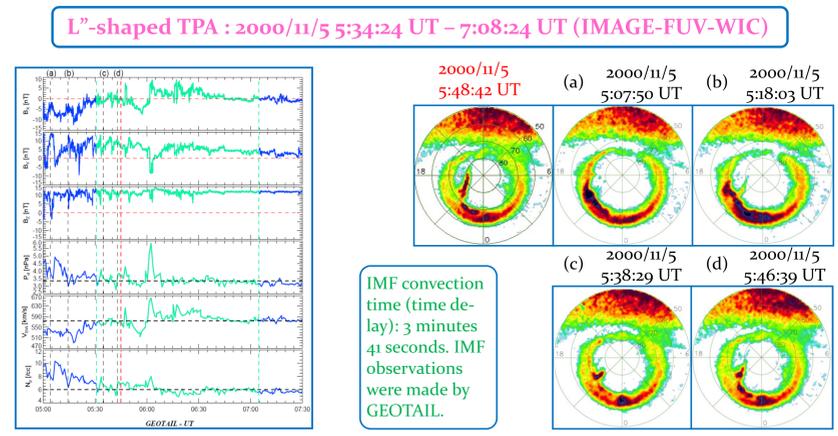
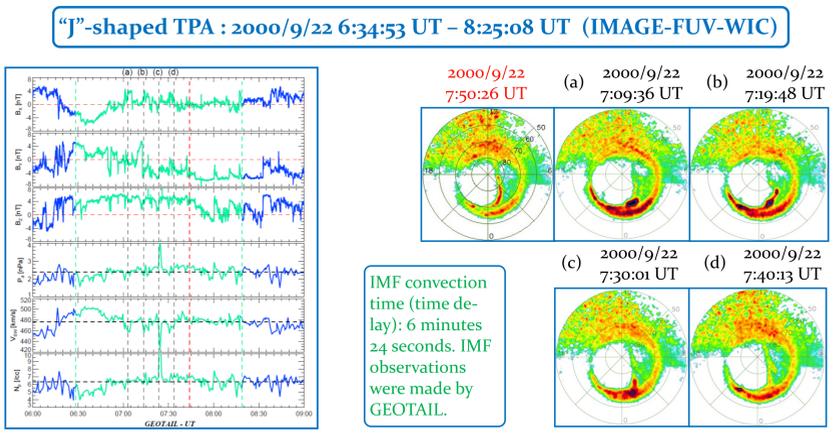
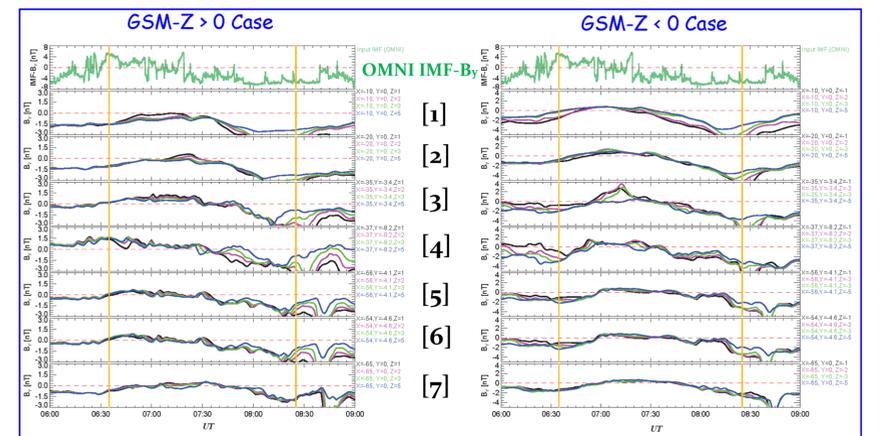
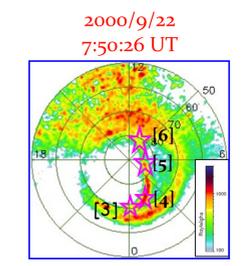
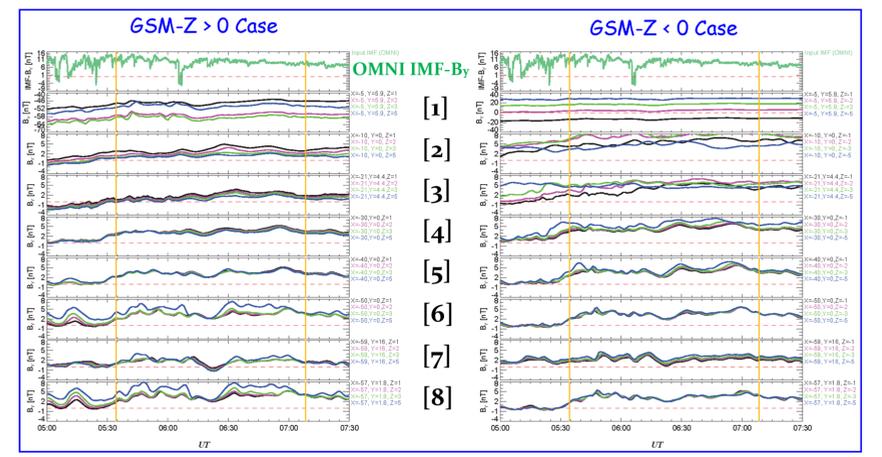
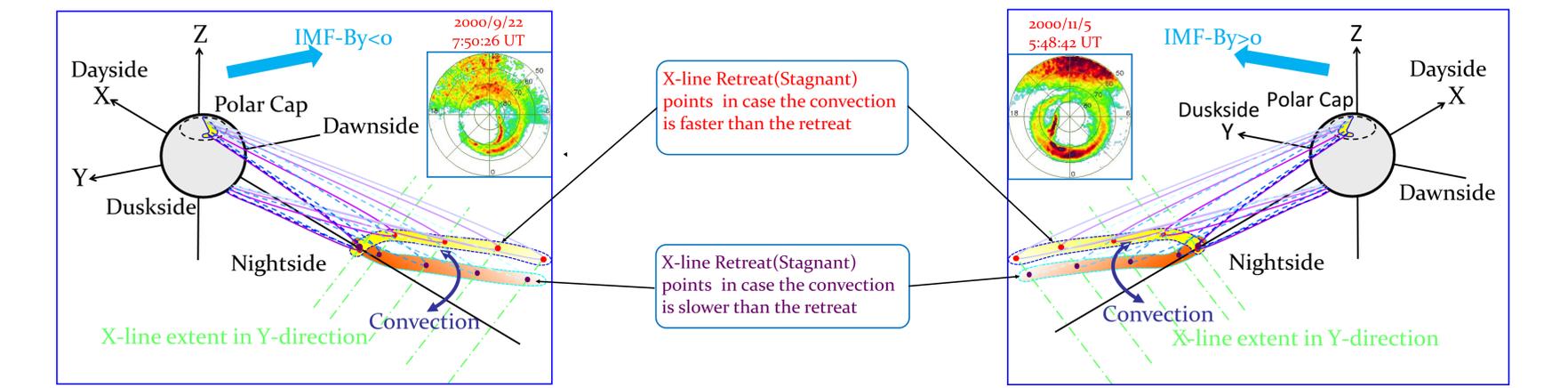
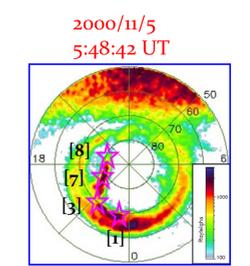


Table with 4 columns: Event #, GSM-X [RE], GSM-Y [RE], GSM-Z [RE]. Contains data for 8 events on November 5th, 2000.



Key Question 3 How are the nightside distorted TPAs formed?

We followed the time sequence of the nightside distorted TPA evolution with the IMAGE FUV-WIC imager data. The "J" and "L"-shaped TPAs mostly started to grow from the nightside main auroral oval, and protruded to the dayside region with being distorted.
Formation process of the nightside distorted TPAs would basically be explained by "nightside magnetic reconnection model", which was proposed by Milan +2005?

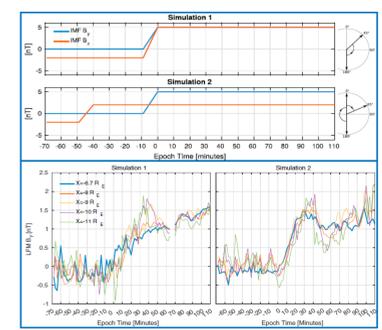
Key Question 4 How do you verify that the formation processes of the "J" and "L"-shaped TPAs could be explained by "nightside magnetic reconnection" model?

No clear "in-situ" observational evidence for magnetotail reconnection during the intervals of the nightside distorted TPA brightening could be obtained. The observational examples, where the low-latitude orbiters were crossing over the distorted parts of the TPA, cannot also be found.
Even though performing an MHD simulation, it is hard to specify the locations where nightside magnetic reconnection occurs (e.g., Kullen and Janhunen +2004). However, if the nightside distorted TPA formation was followed by the models proposed, the magnetotail magnetic field profiles would be controlled by the IMF-By components.

Supportive Evidence

IMF-By penetration to the magnetotail should occur during the nightside distorted TPA formation. ->Verifying the IMF-By control to the magnetotail By profile based on an MHD simulation using the BATS-R-US code.
The IMF penetration to the near-earth tail was confirmed by Tenford +2018 based on an LFM simulation.

Tenford +2018



Conclusion

- 1. New morphological type of transpolar arc, that is, nightside distorted TPA ("J"- and "L"-shaped TPAs) is found.
2. Formation process of the nightside distorted TPA can basically be addressed by the nightside magnetic reconnection model. The nightside end of the TPA might get "distorted" due to the "crooked" X-line retreats, whose lines were convected dawn- or duskward.
3. With a help of the MHD simulations using the BATS-R-US code, the IMF-By component controlled the By profiles in the magnetotail; the IMF-By penetration to the tail was evident, implicitly verifying that the reconnection-formed closed flux (TPA-associated flux) convected dawn- or duskward during the nightside distorted TPA intervals.

A Significant Finding of New Morphological Type of Transpolar Arc: Nightside Distorted Transpolar Arc

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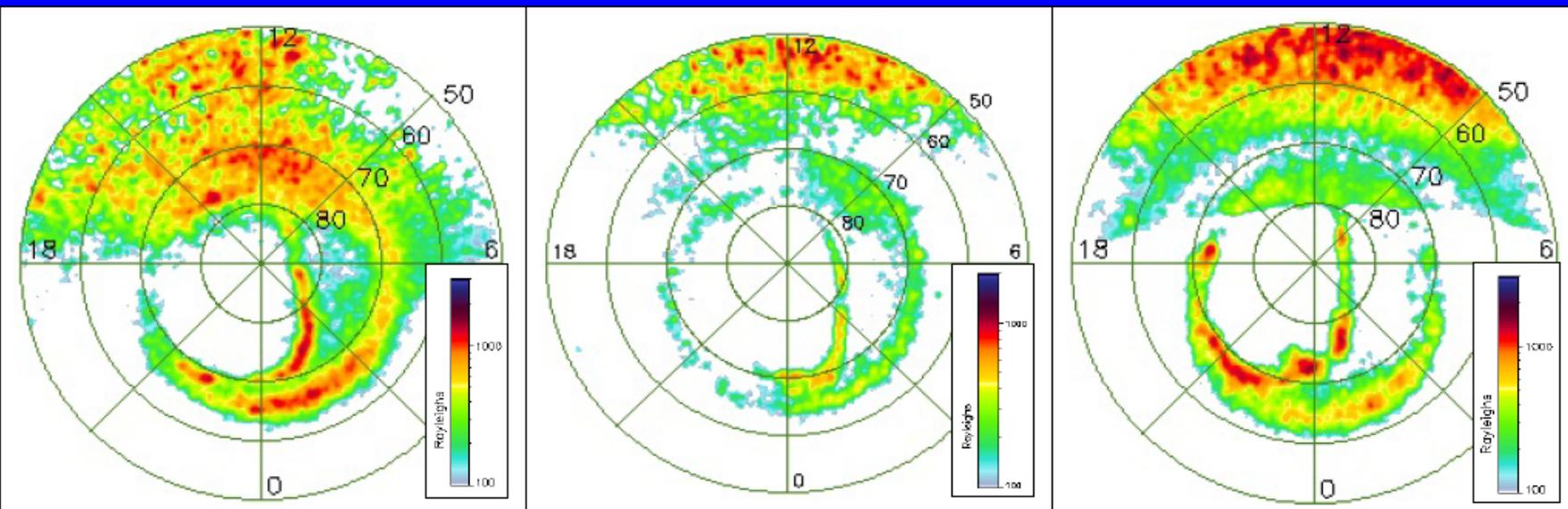
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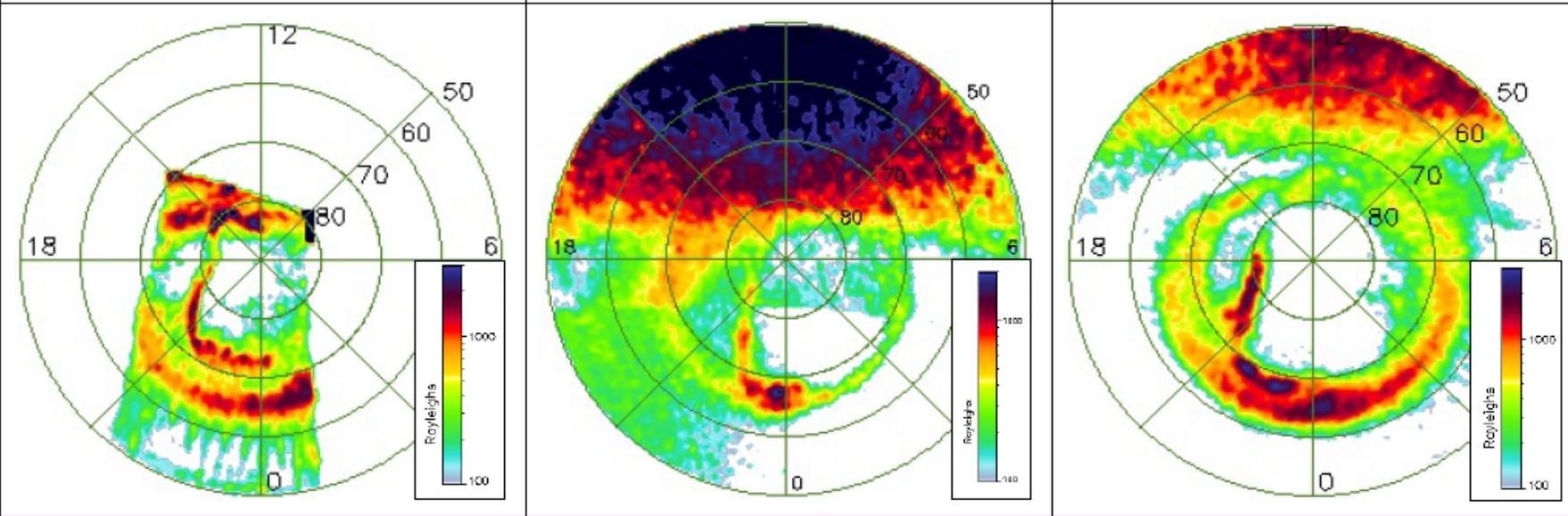
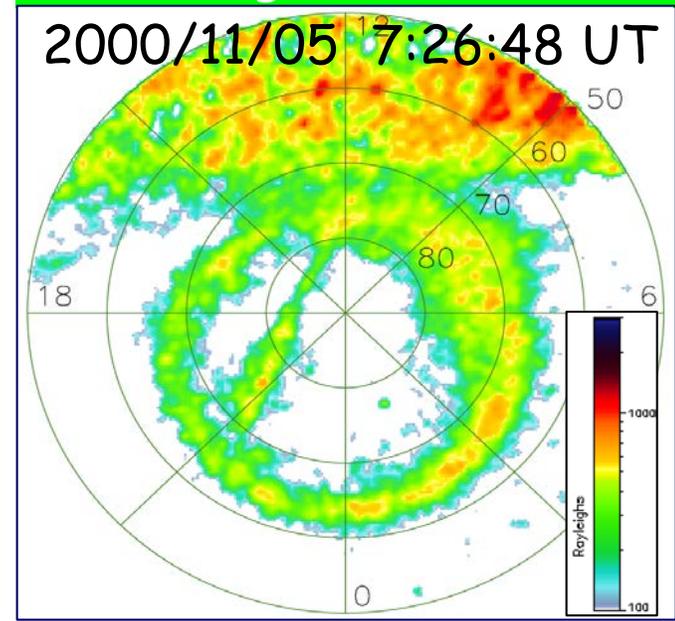


(a) 2000/9/22 7:50:26 UT (b) 2000/12/27 23:50:07 UT (c) 2001/12/31 11:11:49 UT

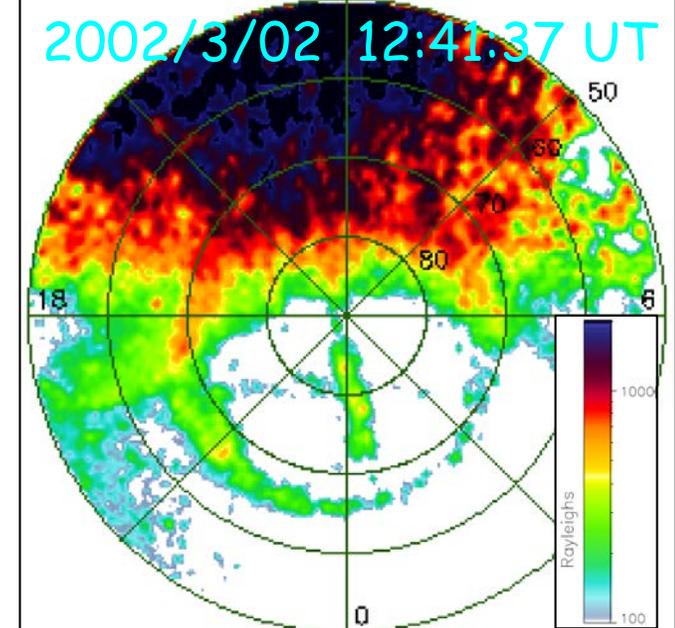
"J"-Shaped Transpolar Arc



Regular TPA



Regular TPA



"L"-Shaped Transpolar Arc

(d) 2003/10/28 14:09:42 UT (e) 2002/3/12 1:20:43 UT (f) 2000/11/5 5:48:42 UT

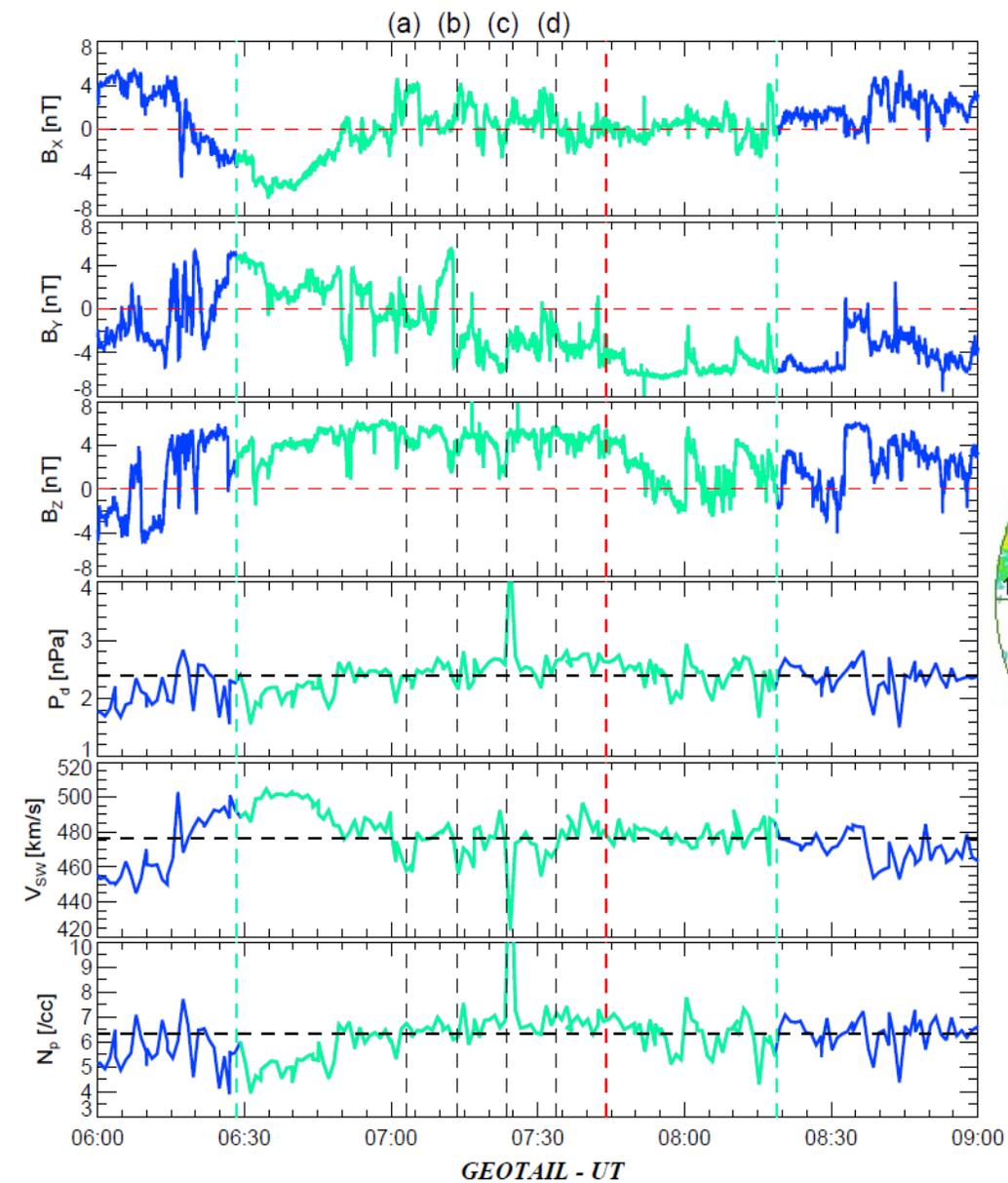
Key Question 1. What is "nightside distorted TPA"?

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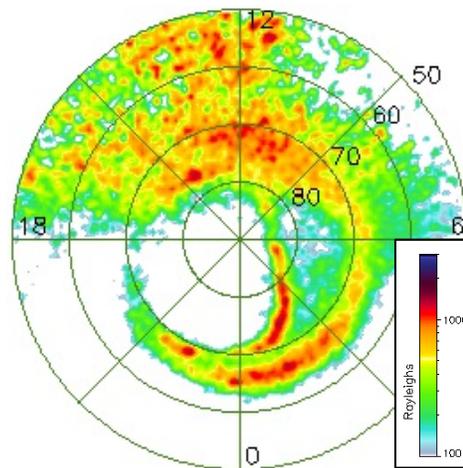
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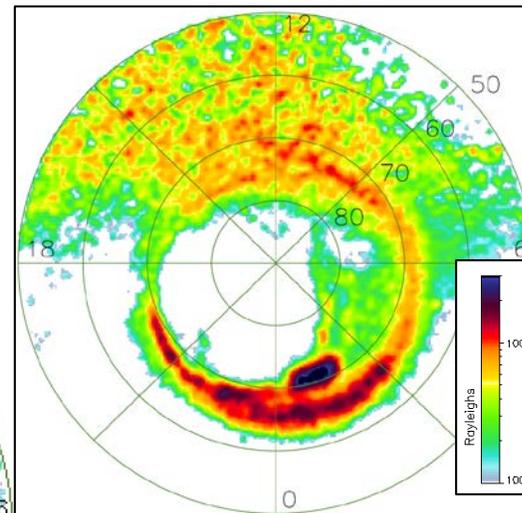
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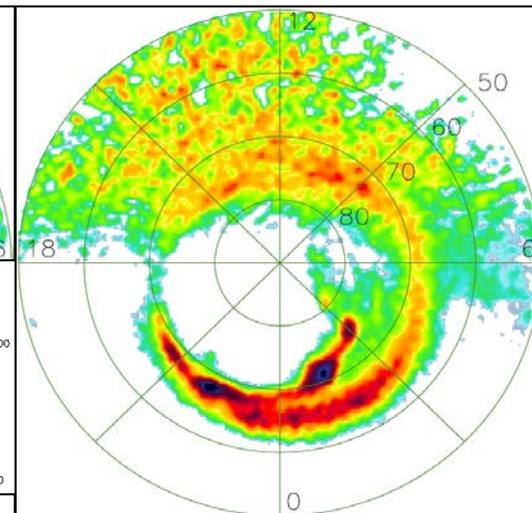
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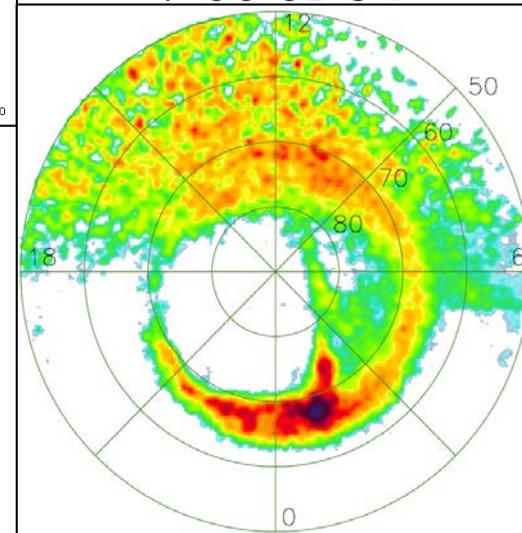
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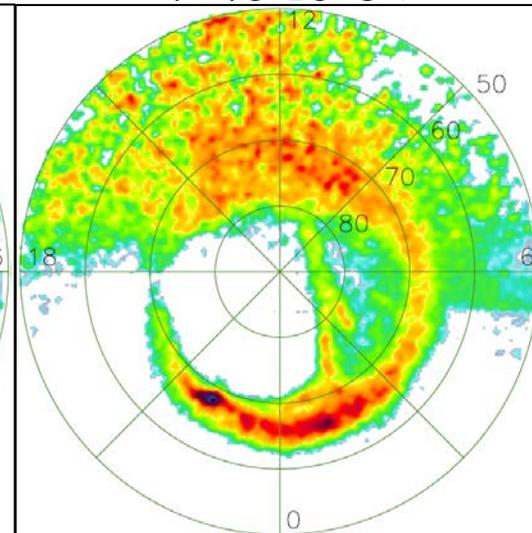
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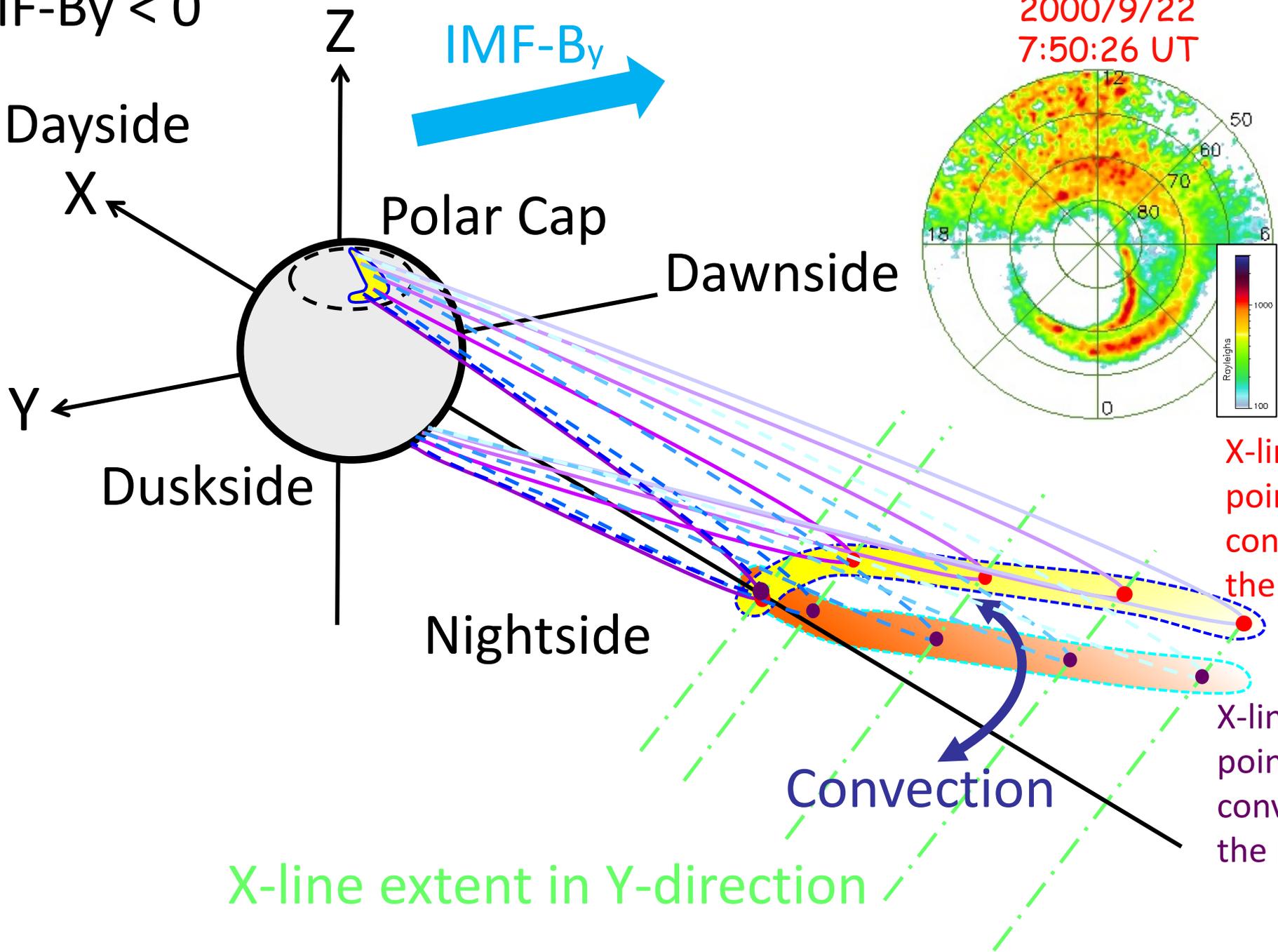


(d) 2000/9/22
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IMF convection time (time delay): 6 minutes 24 seconds. IMF observations were made by GEOTAIL.

(a) IMF-By < 0



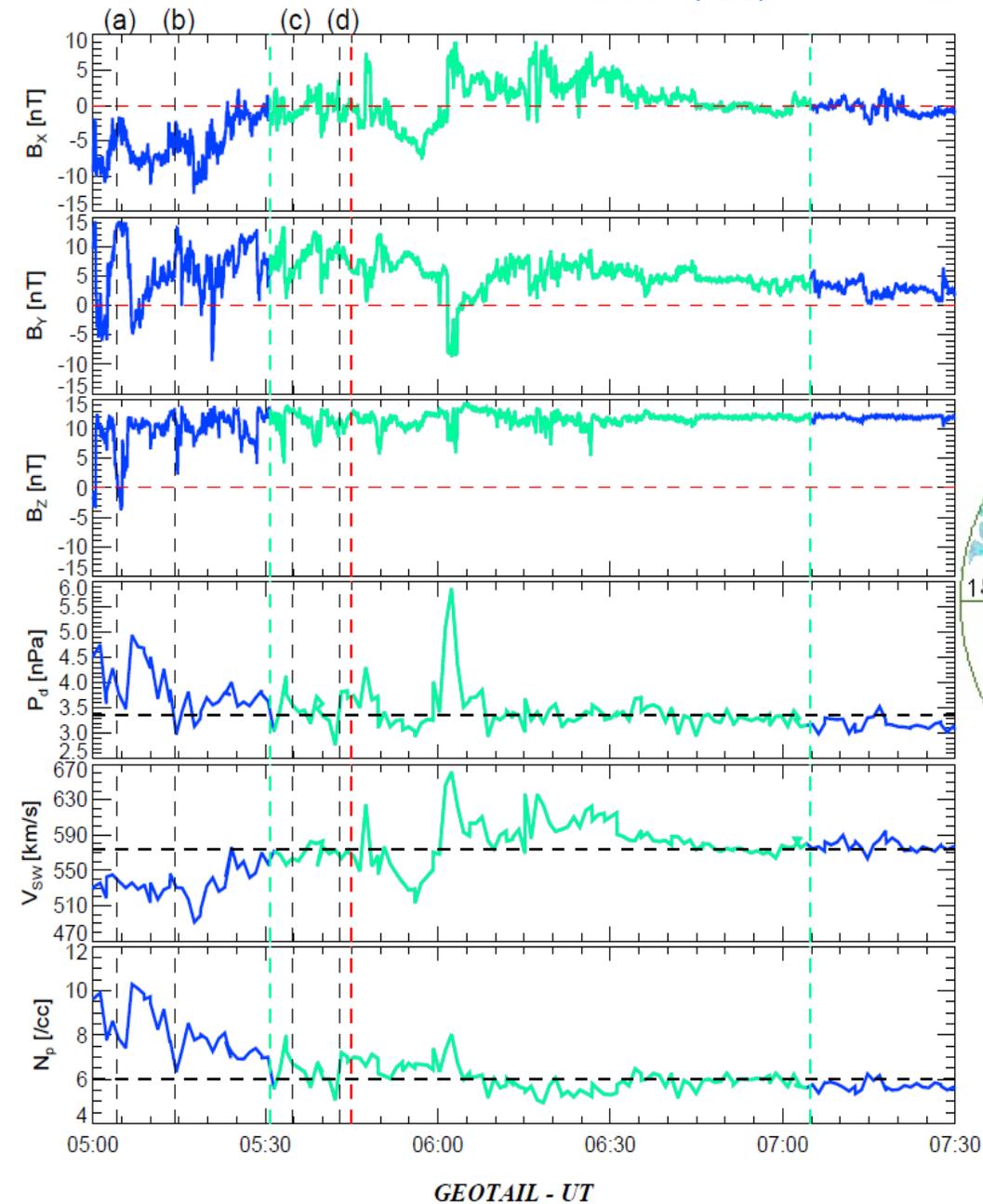
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X-line Retreat(Stagnant) points in case the convection is faster than the retreat

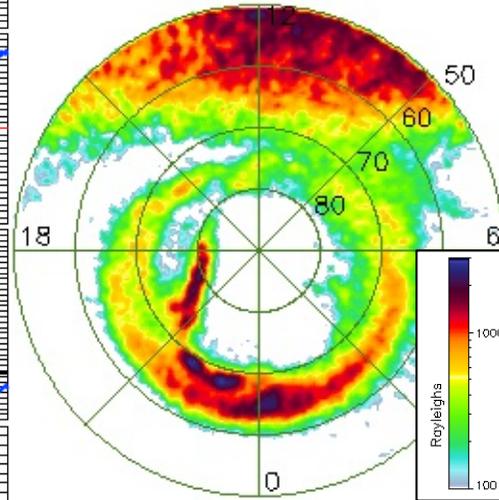
X-line Retreat(Stagnant) points in case the convection is slower than the retreat

X-line extent in Y-direction

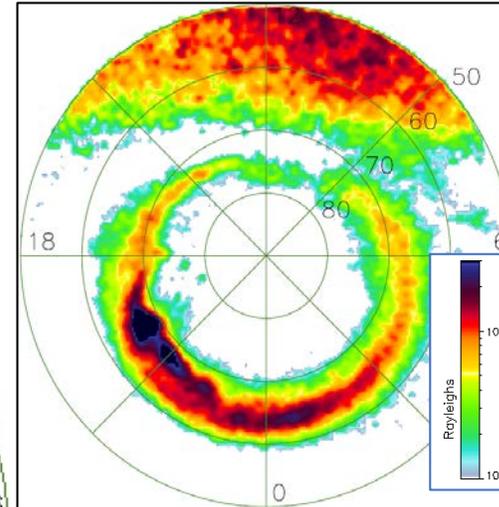
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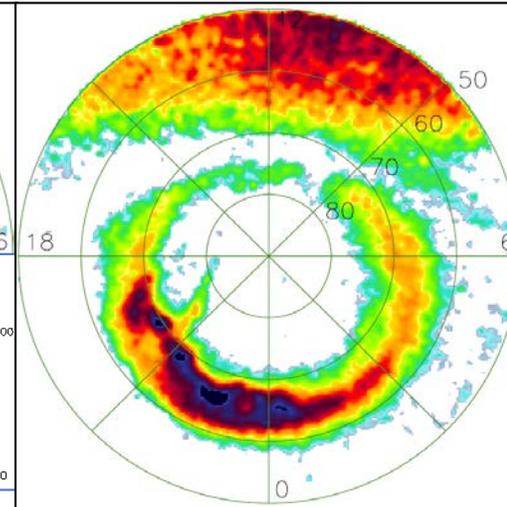
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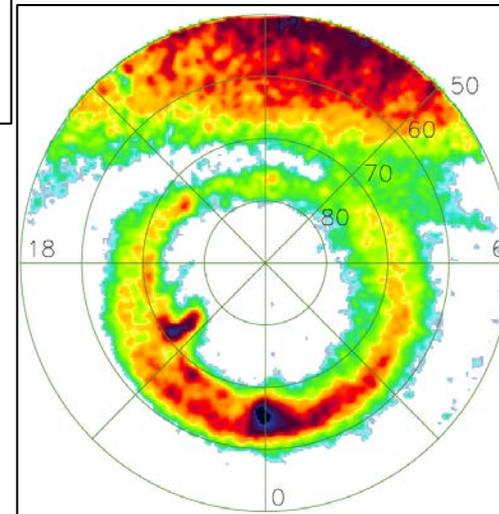
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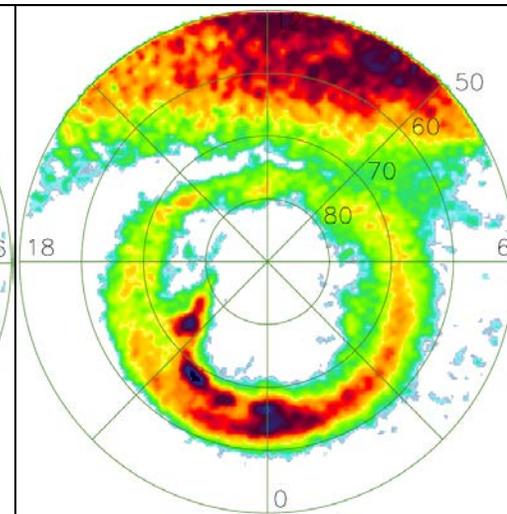
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(c) 2000/11/5
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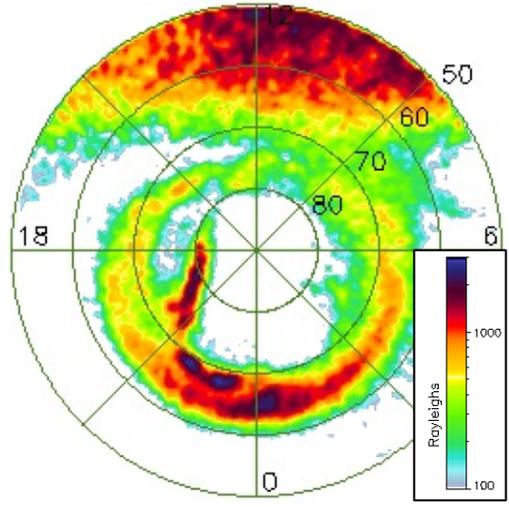
(d) 2000/11/5
5:46:39 UT



IMF convection time (time delay): 3 minutes 41 seconds. IMF observations were made by GEOTAIL.

(b) IMF-By > 0

2000/11/5
5:48:42 UT



IMF-By

Z

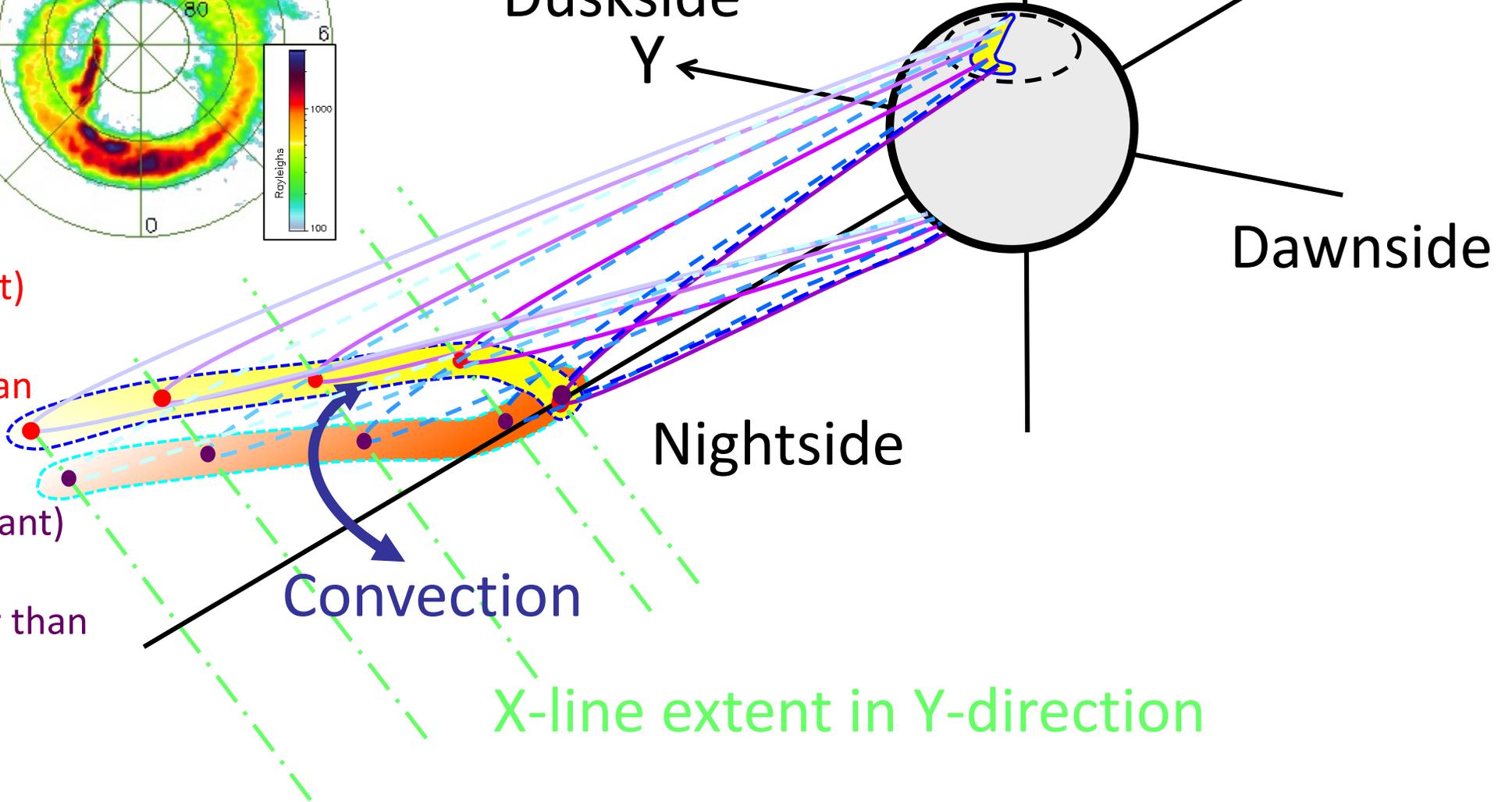
Dayside

X

Duskside Polar Cap
Y

Dawnside

X-line Retreat(Stagnant)
points in case the
convection is faster than
the retreat



X-line Retreat(Stagnant)
points in case the
convection is slower than
the retreat

Nightside

X-line extent in Y-direction

Key Question 3. How are the nightside distorted TPAs formed ?

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→ Formation process of the nightside distorted TPAs would basically be explained by "nightside magnetic reconnection model", which was proposed by Milan +2005 ?

Key Question 4. How do you verify that the formation processes of the "J" and "L"-shaped TPAs could be explained by "nightside magnetic reconnection" model ?

No clear "in-situ" observational evidence for magnetotail reconnection during the intervals of the nightside distorted TPA brightening could be obtained. The observational examples, where the low-latitude orbiters were crossing over the distorted parts of the TPA, cannot also be found.

→ Even though performing an MHD simulation, it is hard to specify the locations where nightside magnetic reconnection occurs (e.g., Kullen and Janhunen +2004). However, if the nightside distorted TPA formation was followed by the models proposed, the magnetotail magnetic field profiles would be controlled by the IMF- B_y components.

Tenfjord +2018

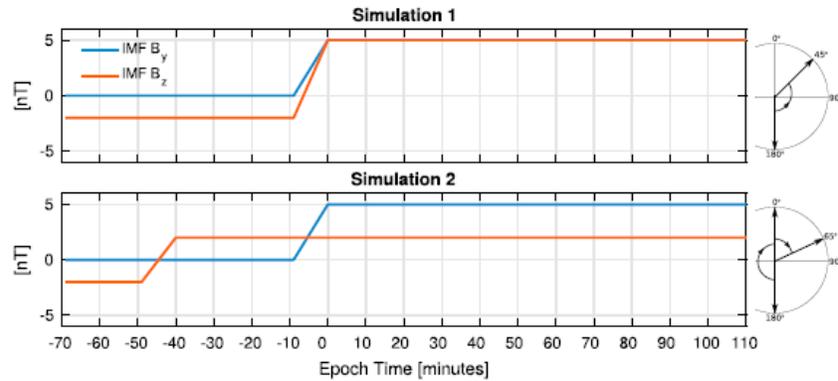


Figure 1. Interplanetary magnetic field (IMF) conditions for the two magnetohydrodynamic simulations and illustration of clock angle regimes. Epoch time = -70 min corresponds to simulation time $t = 0$.

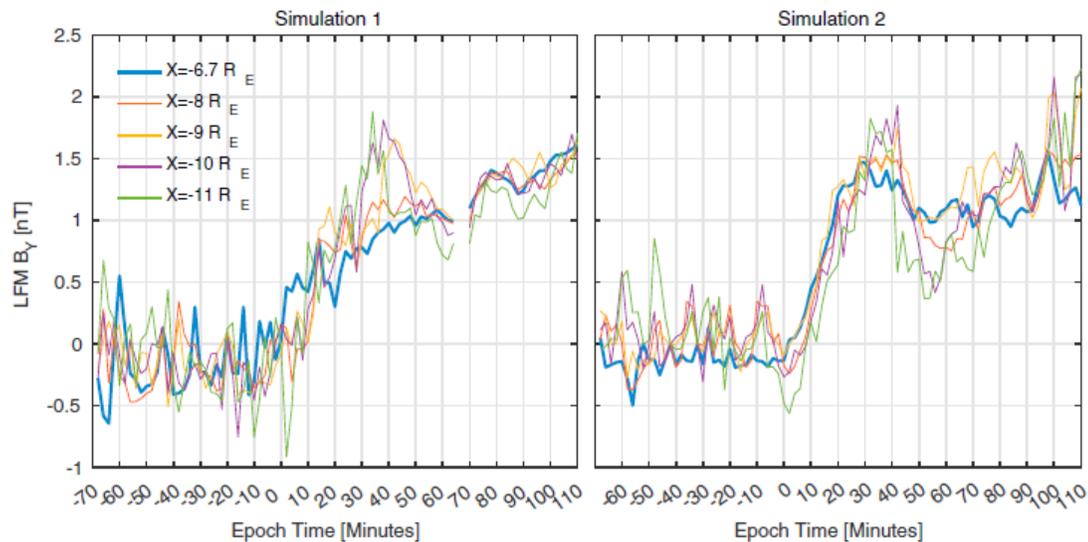


Figure 6. Radial dependence of induced B_y on closed field lines for both simulations. The values are taken at $Y = Z = 0$.

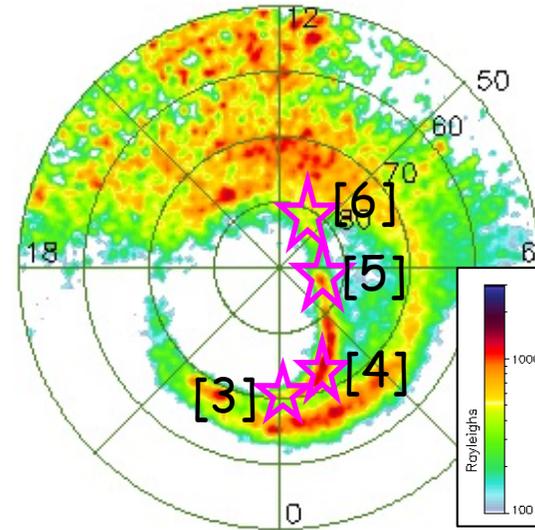
Supportive Evidence:
IMF- B_y penetration to the magnetotail should occur during the nightside distorted TPA formation \rightarrow Verifying the IMF- B_y control to the magnetotail B_y profile based on an MHD simulation using the BATS-R-US code.

The IMF penetration to the near-earth tail was confirmed by Tenfjord +2018 based on an LFM simulation.

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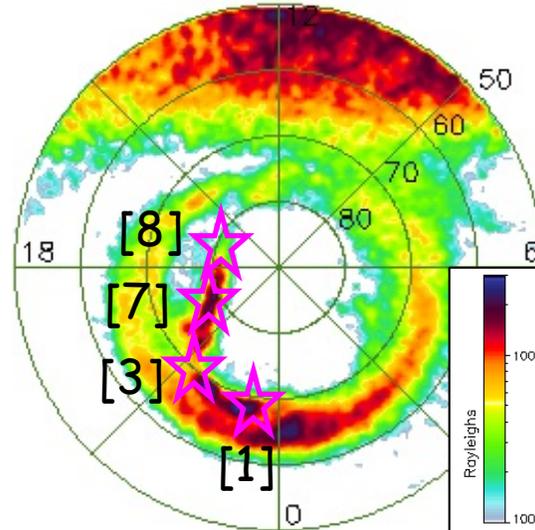
"J"-Shaped TPA Event on September 22 nd 2000			
Event #	GSM-X [R _E]	GSM-Y [R _E]	GSM-Z [R _E]
[1]	-10	0	±1,2,3,5
[2]	-20	0	±1,2,3,5
[3]	-35	-3.4	±1,2,3,5
[4]	-37	-8.2	±1,2,3,5
[5]	-56	-4.1	±1,2,3,5
[6]	-54	-4.6	±1,2,3,5
[7]	-65	0	±1,2,3,5

2000/9/22
7:50:26 UT



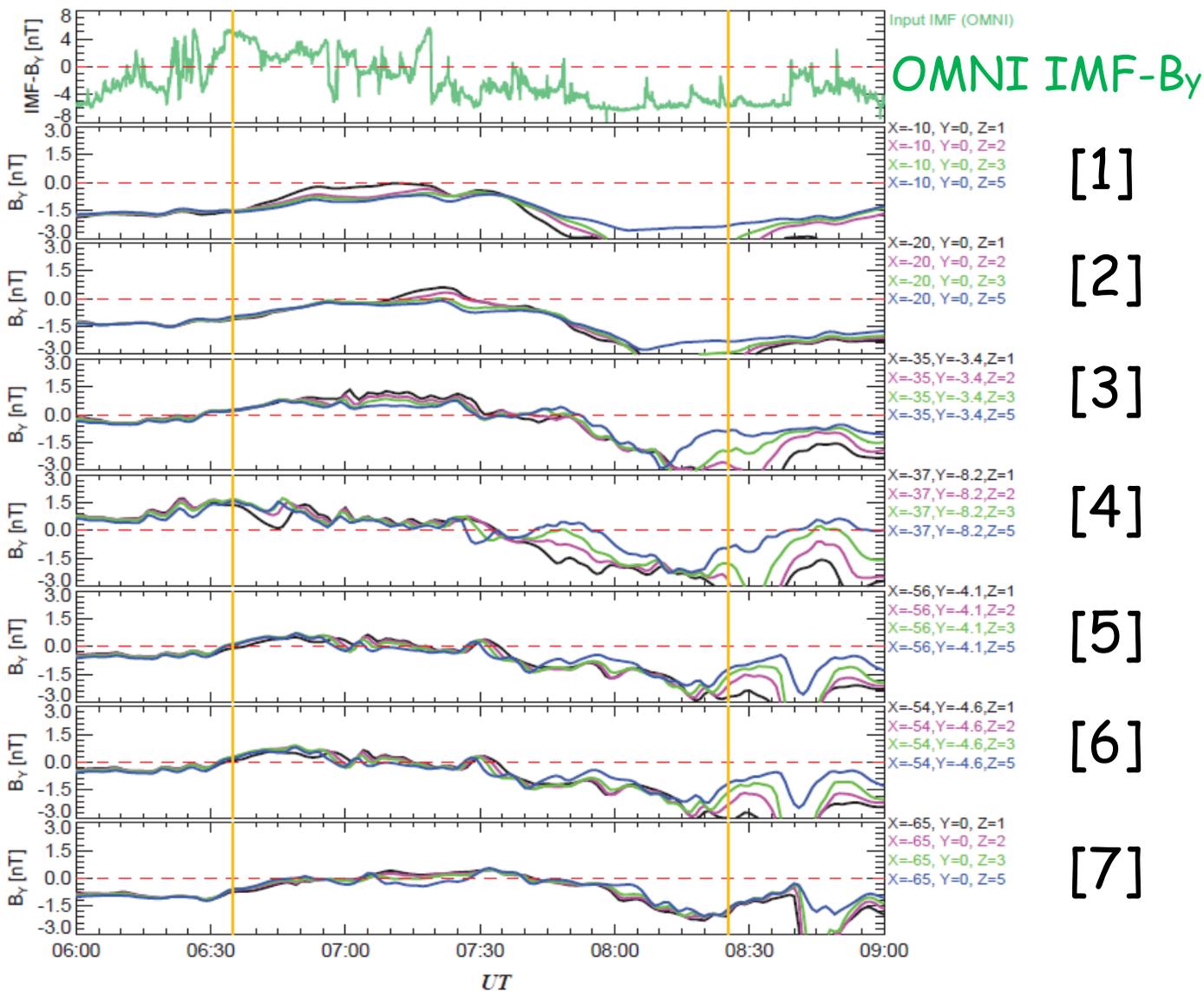
"L"-Shaped TPA Event on November 5 th , 2000			
Event #	GSM-X [R _E]	GSM-Y [R _E]	GSM-Z [R _E]
[1]	-5.0	5.9	±1,2,3,5
[2]	-10	0	±1,2,3,5
[3]	-21	4.4	±1,2,3,5
[4]	-30	0	±1,2,3,5
[5]	-40	0	±1,2,3,5
[6]	-50	0	±1,2,3,5
[7]	-59	16	±1,2,3,5
[8]	-57	1.8	±1,2,3,5

2000/11/5
5:48:42 UT

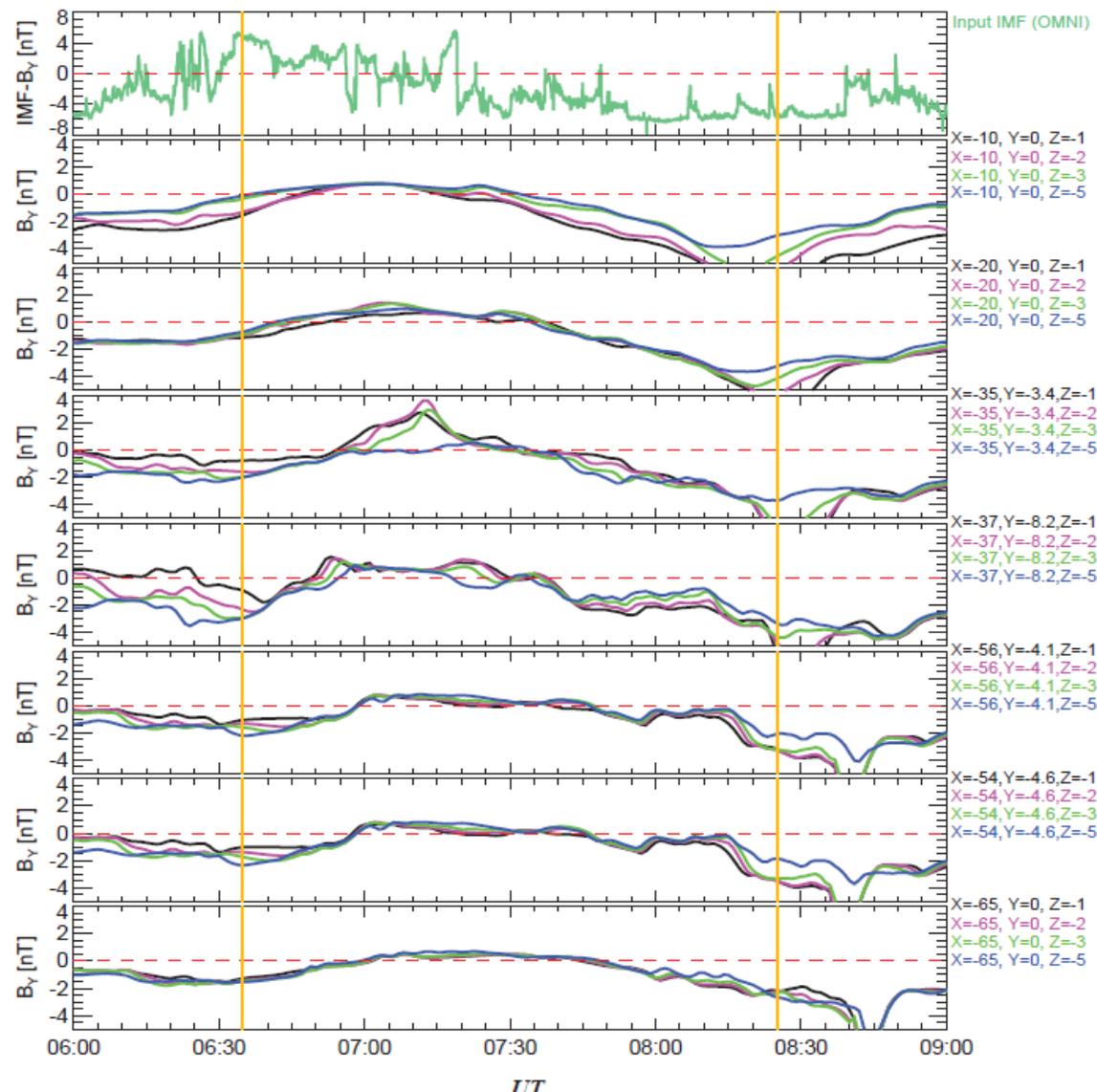


2000/9/22 "J"-Shaped TPA

GSM-Z > 0 Case



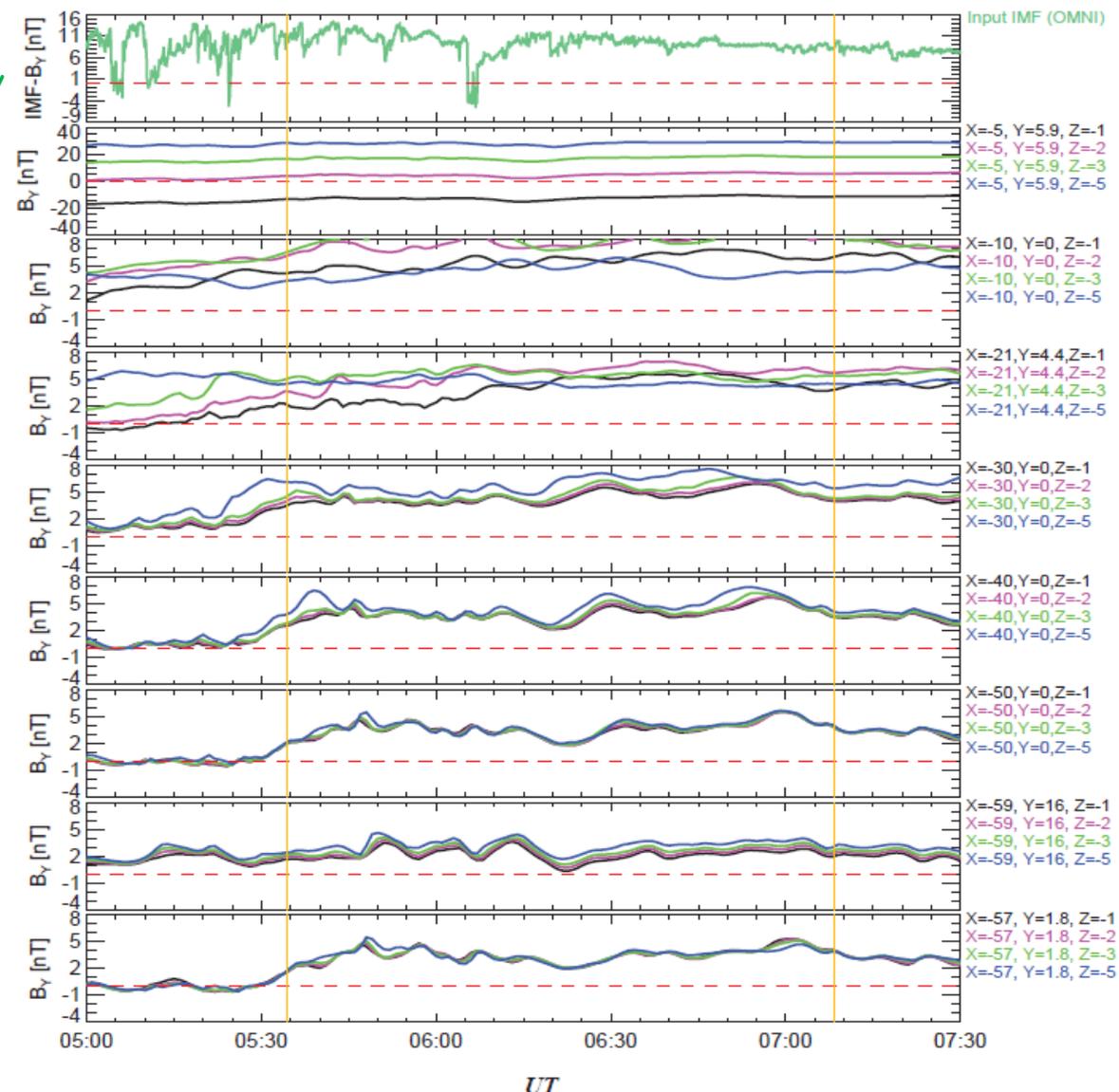
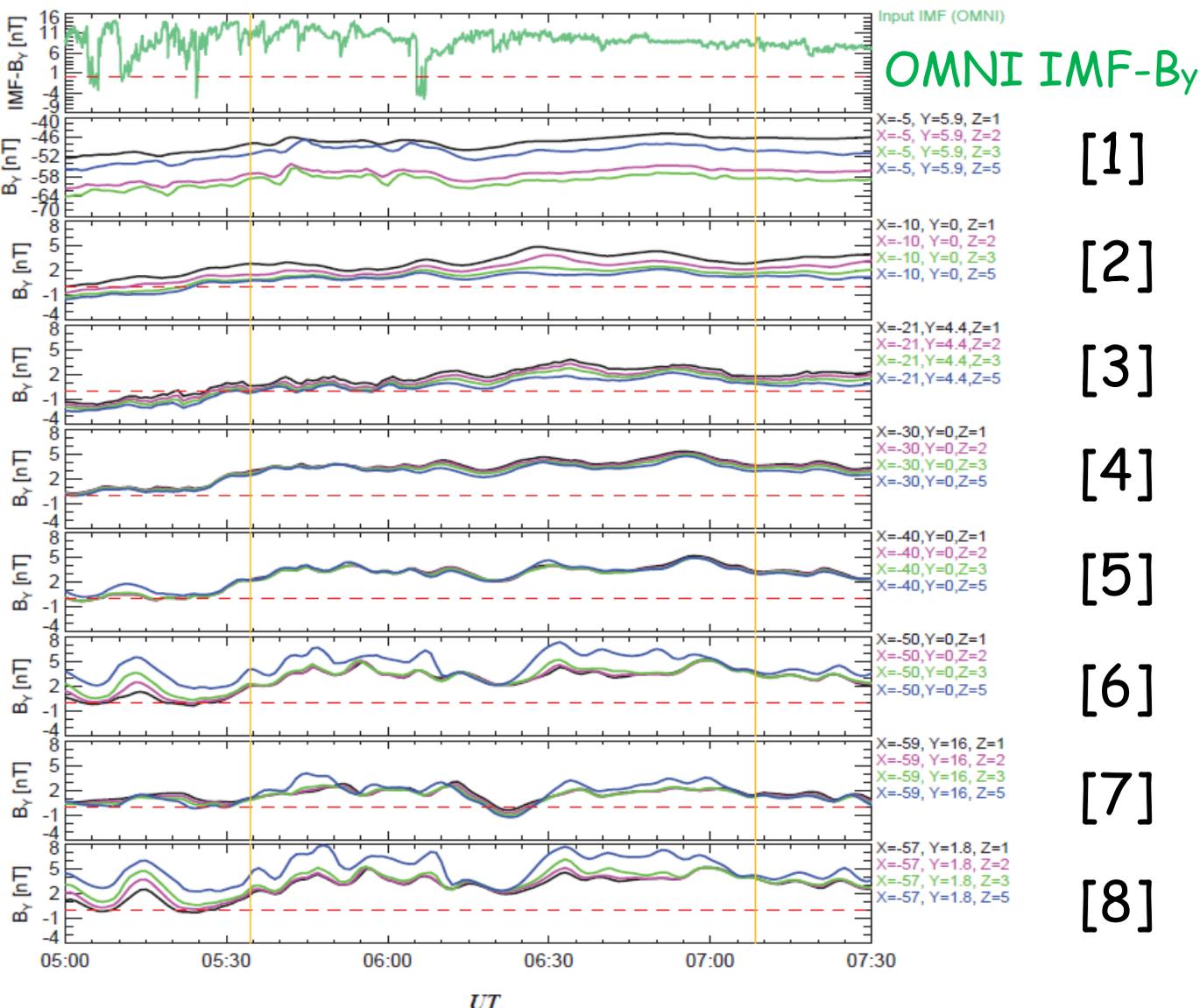
GSM-Z < 0 Case



2000/11/5 "L"-Shaped TPA

GSM-Z > 0 Case

GSM-Z < 0 Case



Conclusion

1. New morphological type of transpolar arc, that is, nightside distorted TPA ("J"- and "L"-shaped TPAs) is found.
2. Formation process of the nightside distorted TPA can basically be addressed by the nightside magnetic reconnection model. The nightside end of the TPA might get "distorted" due to the "crooked" X-line retreats, whose lines were convected dawn- or duskward.
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