

# Magnetospheric dynamics under northward IMF conditions surveyed by concurrent observations of TPA and aurora spirals (Original Title: Magnetospheric dynamics under northward IMF conditions surveyed by concurrent observations of TPA and omega-band aurora)

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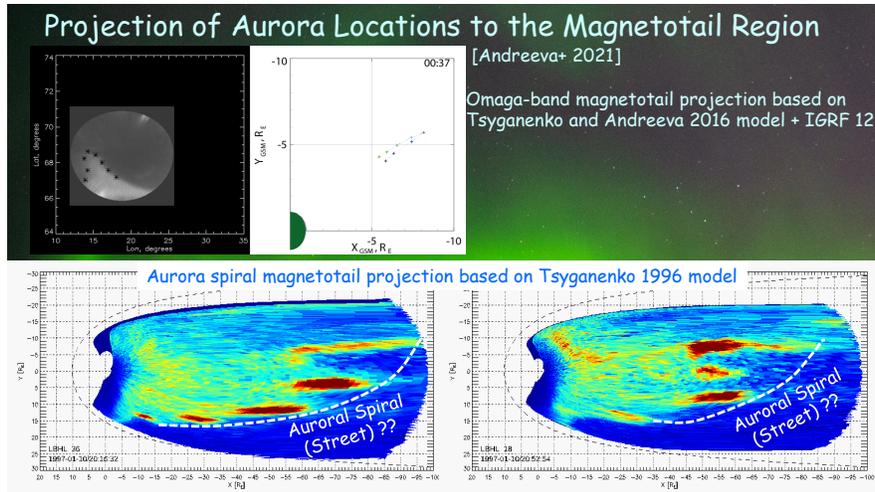
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November 26, 2022

## Abstract

Nightside magnetospheric processes (dynamics) directly reflect to auroral morphology and type. By investigating type of auroras and the auroral morphological changes, we can expect to understand what physical processes would take place in the magnetotail. Under northward Interplanetary Magnetic Field (IMF) conditions, transpolar arcs (TPAs) and aurora spiral can be observed. A source of TPA is considered as field-aligned currents induced by the plasma flow shear (including the plasma flow vortices) between the fast plasma flows generated by magnetotail magnetic reconnection and slower background magnetospheric plasma flows. On the other hand, it is well-known that aurora spiral is also likely to be formed by the field-aligned current induced by the flow shear in the magnetotail, such as the Kelvin-Helmholtz instabilities. Based on the contemporaneous observations of TPA and aurora spiral, we try to investigate (diagnose) how the plasma and its energy are transported in the nightside magnetosphere toward ionosphere under northward IMF conditions. On January 10th, 1997, transpolar arc (TPA) and aurora spiral contemporaneously occurred for about 5.5 hours between 17:58 UT and 22:23 UT even when Interplanetary Magnetic Field (IMF) orientation changed from weakly southward to northward at  $\sim$ 21:00 UT. Because no in-situ magnetotail observations were unfortunately found in this day, we performed global MHD simulations based on the Open Geospace General Circulation Model (Open GGCM) distributed in the Community Coordinated Modeling Center (CCMC), and discussed the physical relation between two different auroral appearances and nightside magnetospheric processes. In this simulation, after the IMF-Bz orientation turned from weakly southward to northward, clear flow shear between fast earthward plasma flows triggered by magnetotail reconnection and slower tailward background magnetospheric flows was seen around Xgsm  $\sim$  -40 Re in the dawn sector, being consistent with the TPA and aurora spiral brightening. These flow shears may be a “source” of field-aligned currents to form the TPA. Furthermore, they bifurcated toward dawn and dusk, and showed stronger vortices in the dusk region than those in the dawnward sector. These vortex(-like) structures, bifurcated duskward, and associated field-aligned currents would be linked to the formation of the aurora spiral. In this presentation, we will discuss further the relation between the variations of these flow shear (vortex) structures, TPA and aurora spiral formations under northward IMF conditions, followed by weak southward IMF intervals.



### Hosted file

additional\_info\_movie.gif available at <https://authorea.com/users/526898/articles/606337-magnetospheric-dynamics-under-northward-imf-conditions-surveyed-by-concurrent-observations-of-tpa-and-aurora-spirals-original-title-magnetospheric-dynamics-under-northward-imf-conditions-surveyed-by-concurrent-observations-of-tpa-and-omega-band-aurora>

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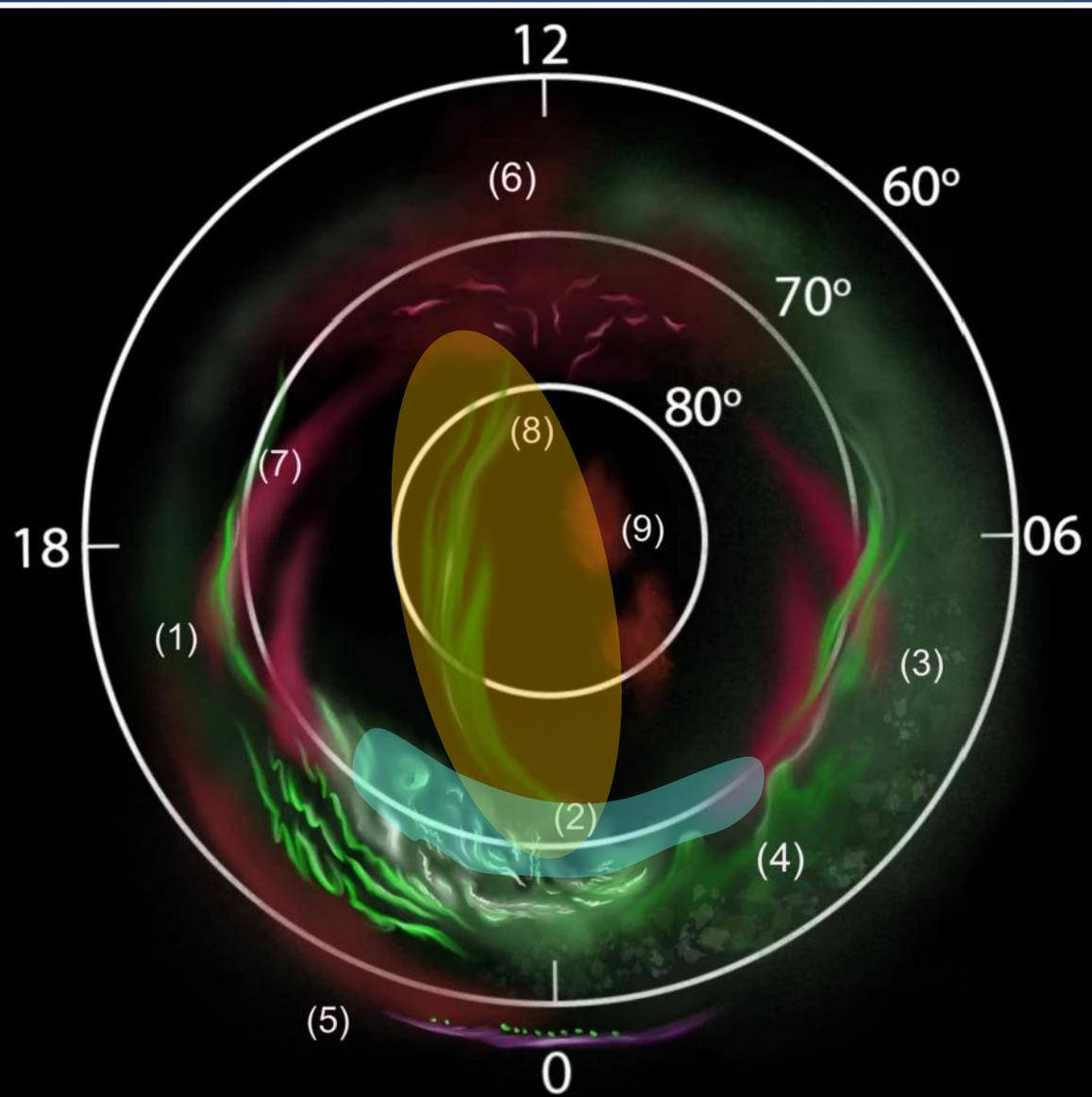
3. Korea University of Science and Technology, Daejeon, South Korea

# Polar cap arc: TPA

+

## Aurora Spirals

- Morphology and appearance location between TPA and Aurora spirals are clearly different.
- Suggesting that some (different) physical processes to form them are occurring in the magnetotail.
- Can diagnose the magnetospheric states under corresponding IMF conditions ?



[Knudsen+ 2021]

# Aurora Spirals: Auroras with spiral form

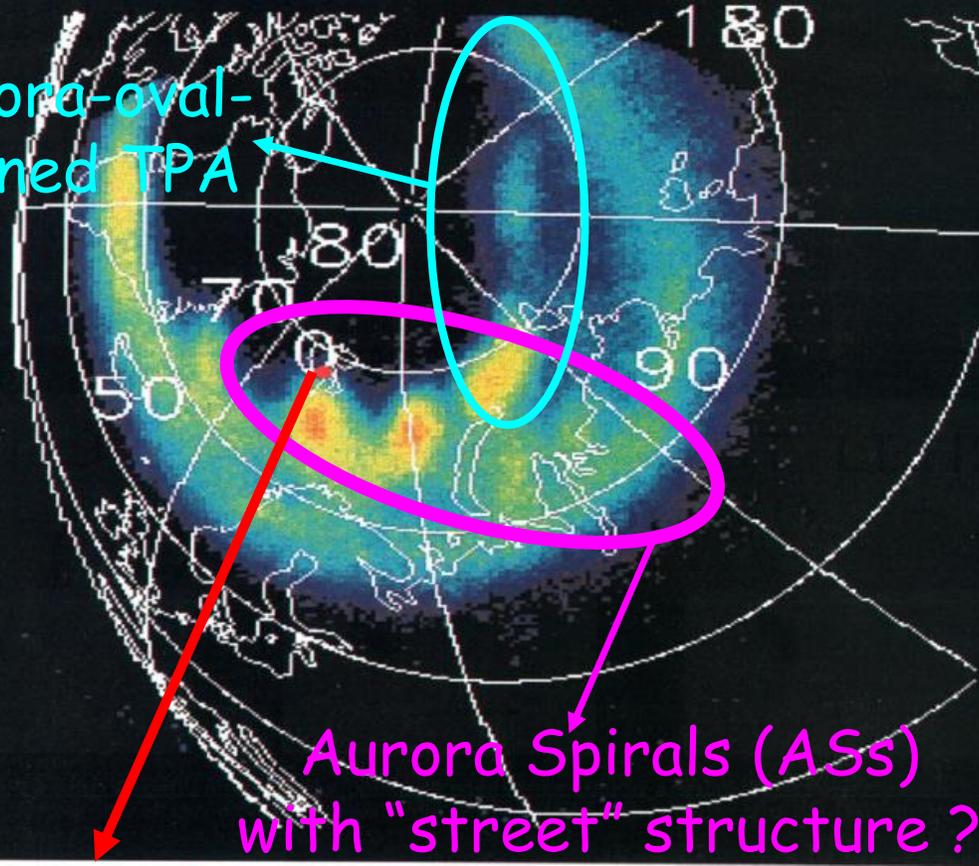
2021/4/7 1AM AKDT, corresponding to 09 UT , Fairbanks, AK



A shot at Thingvallavatn Lake in Iceland, 2016

UVI 970110 2106:14 UT LBHS

Aurora-oval-aligned TPA



Aurora Spirals (ASs) with "street" structure?



Plate 1. (top) A spiral street at the poleward edge of the oval in a Polar UVI image together with (bottom) simultaneous ASC images from Longyearbyen. The red spot in the UVI image shows the location of the Longyearbyen station on Svalbard.

[Partamies+ 2001]

## Statistical characteristics of aurora spirals

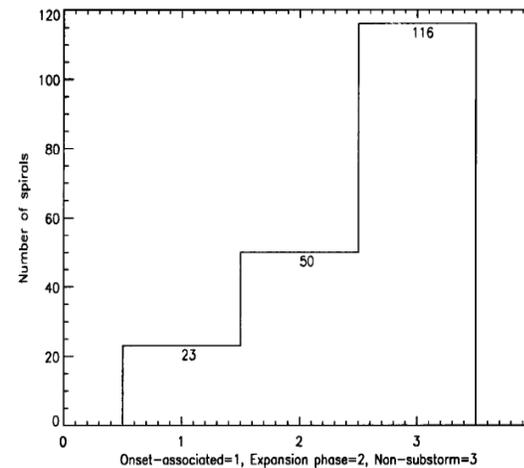
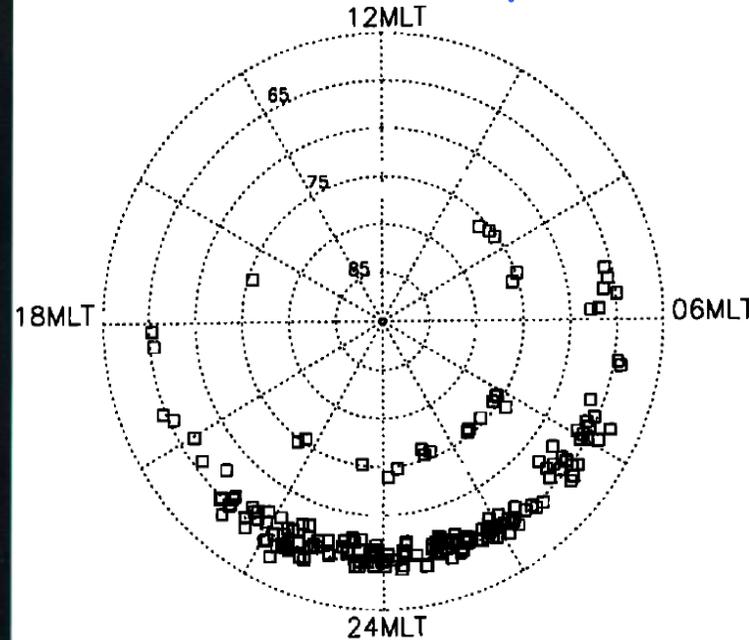
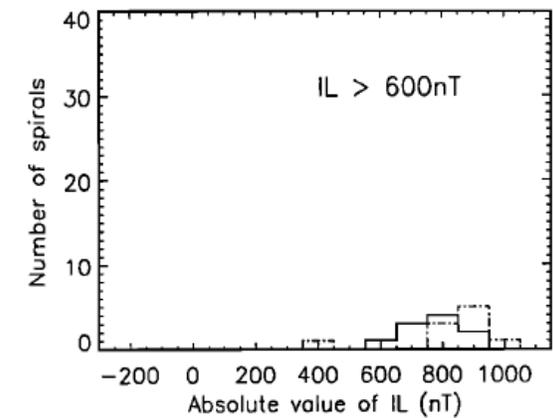
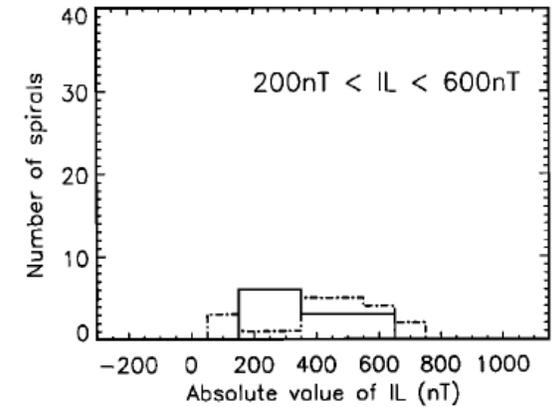
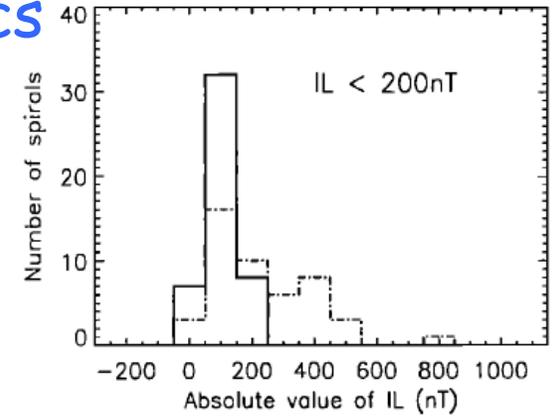


Figure 12. Distribution of substorm phases related to spirals: onset-associated spirals, expansion phase spirals, and nonsubstorm spirals (for definitions, see text).



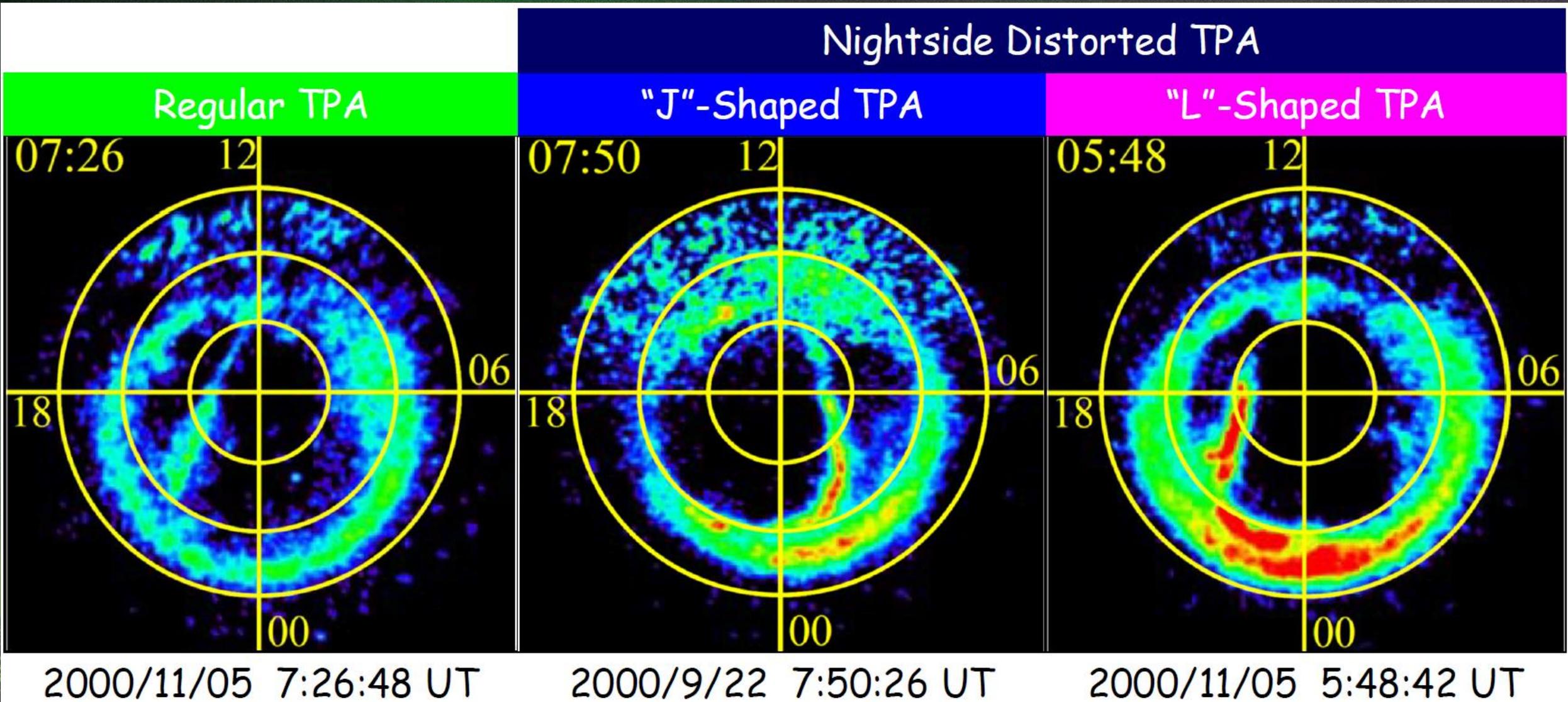
## Aurora Spirals (Statistical Characteristics)

- Aurora spirals are distributed around  $\sim 65$  degrees in MLat whose MLT range is between 18h and 6h, and around  $\sim 70$  degrees in MLat with the MLT range from 22h to 4h.
- Aurora spirals tends to occur under relatively geomagnetical quiet conditions, suggesting that the IMF- $B_z$  orientation is northward or weakly stable southward. Their occurrence peak is seen at  $\sim 100$  nT in  $IL$  (particular  $AL$  index values, covering the UT range [21:00 UT - 02:00 UT] of the IMAGE magnetic observatory chain [c.f. Kauristie+ 1996]).
- They are also seen frequently during non-substorm intervals.

## Aurora Spirals (Essentially Unraveled Points)

- Aurora spirals are distributed over the two difference MLat regions in the nightside MLT. However, do these spirals all have the same characteristics; spiral sense, relative locational relation between the aurora spirals and main auroral oval/bulges, and their duration time intervals ?
- Aurora spirals are **REALLY** likely to occur under geomagnetically quiet conditions and during non-substorm intervals ? → dependence or independence on the MLT or MLat ? etc...

# Regular (Conventional) Transpolar Arc and Nightside Distorted TPA



[Nowada+ 2021 under review]

# Several Proposed Models for the TPA Formation: Fear and Milan+ 2012

Model	Mechanism	Interaction Region	Response to IMF
Chiu+ 1985 Lyons+ 1985 Sojka+ 1994	Field-Aligned Currents From Reverse Convection	Magnetopause (Tailward-of-the-Cusp)	Prompt (Magnetopause Driver)
Reiff and Burch+ 1985	Closure Of Tail Flux	Magnetotail	Delayed By Convection Time
Makita+ 1991	Tilt or Asymmetry In Plasma Sheet Thickness	Magnetotail	Delayed By Convection Time
Newell and Meng+ 1995	Flow Shears Near Open/Closed Field Boundary	Magnetopause	Promptly After Southward IMF Turning
Rezhenov+ 1995	Plasma Sheet Instability	Magnetotail	Follows Northward IMF Turning
Chang+ 1998	Change in Reconnection Site	Magnetopause	Promptly After $B_z$ or $B_y$ sign Changes
Kullen+ 2000	Twisting Of Magnetotail	Magnetotail	Promptly After $B_y$ Sign Changes
Milan+ 2005	Nightside Reconnection In Twisted Magnetotail	Magnetotail	Time Delayed By Flux Transport Near Magnetotail Current Sheet

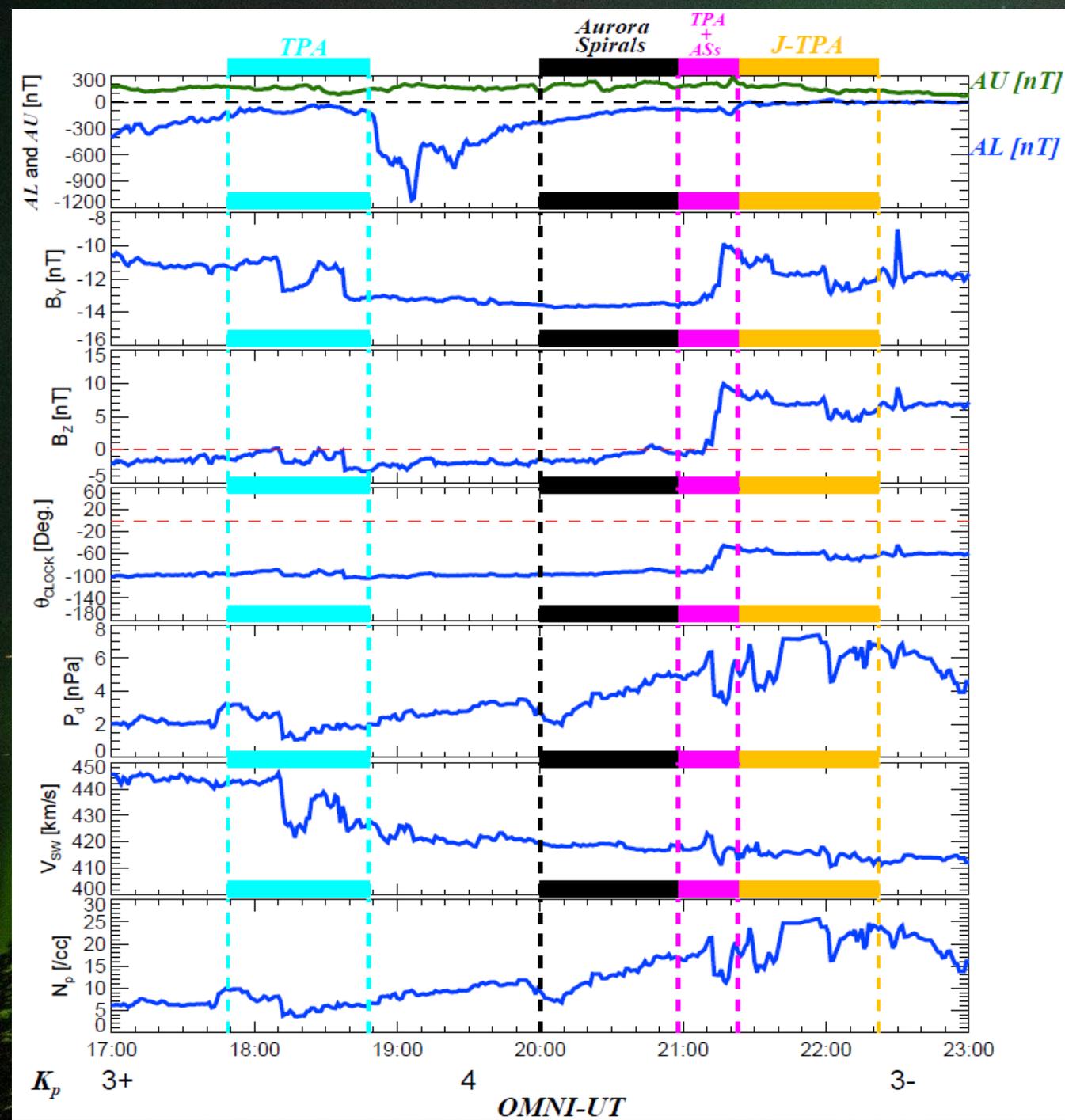
# Transpolar Arcs (Statistical Characteristics)

- TPAs are closely related with the dynamics of the magnetotail and are sometimes associated with those of (tailward-of-) cusp and/or magnetopause.
- TPA location is controlled by the IMF- $B_z$  and  $-B_y$  components.
  - TPAs are frequently occurring under northward IMF- $B_z$  conditions.
  - TPAs appear in the duskside sector (from pre-midnight to post-noon sector) under duskside (positive) IMF- $B_y$  conditions.
  - Also, they can be seen in the dawnside sector (from post-midnight to pre-noon sector) under the dawnside (negative) IMF- $B_y$  conditions.

## "Aurora Spirals + TPA" Phenomena

Useful to diagnose the nightside magnetospheric dynamics under northward and weakly southward IMF- $B_z$  (+ dominant IMF- $B_y$ ), or relatively geomagnetic quiet conditions.





Before the concurrent observations of two different auroras, TPA (theta aurora) and aurora spirals occurred separately, and further "J"-shaped aurora (nightside distorted TPA) was also seen alone after the concurrent aurora spirals and TPA observations.

TPA was seen during geomagnetically quiet state before the main phase of substorm, and the other auroras occurred during the substorm recovery phase.

All aurora events were seen during dominant downward (negative) IMF intervals. In particular, concurrent observations of TPA and aurora spiral are just observed at a significant IMF- $B_z$  jump whose orientation was changing from weakly southward to northward.

# Temporal Changes of Auroral Morphology

Aurora Shape	Time Interval (UT) and Duration (Minutes)	IMF-Bz Conditions
TPA	17:49 - 18:48 59	Weakly southward
Aurora Spirals (Street)	20:00 - 20:58 58	Weakly southward with transient northward
TPA + Aurora Spirals	20:58 - 21:23 25	Turning weakly southward to northward
"J"-shaped TPA	21:23 - 22:22 59	Northward

# Aurora Shape

Time Interval (UT) and  
Duration (Minutes)

IMF-Bz  
Conditions

TPA

17:49 - 18:48  
59

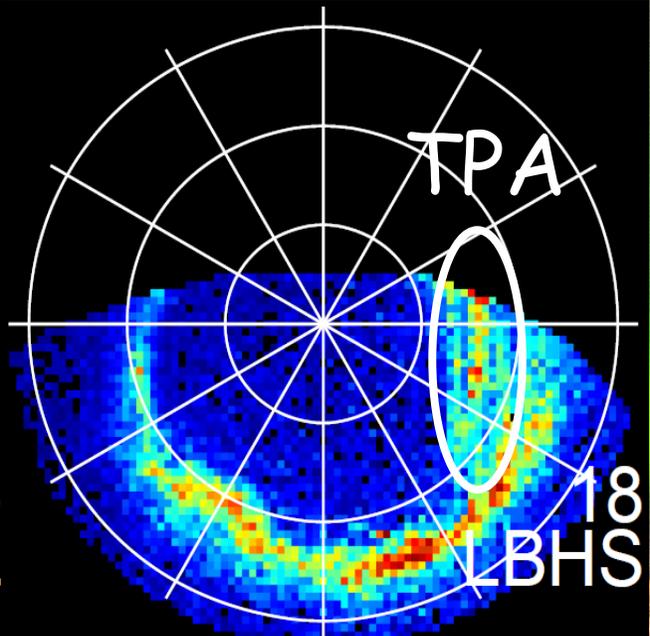
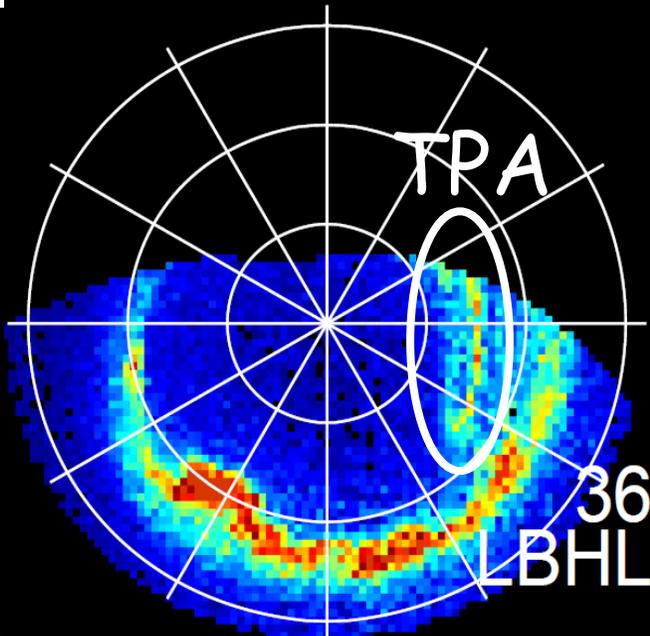
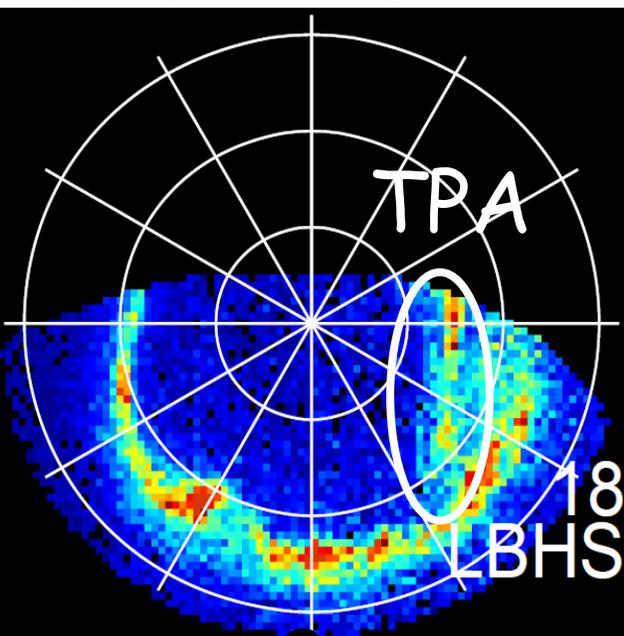
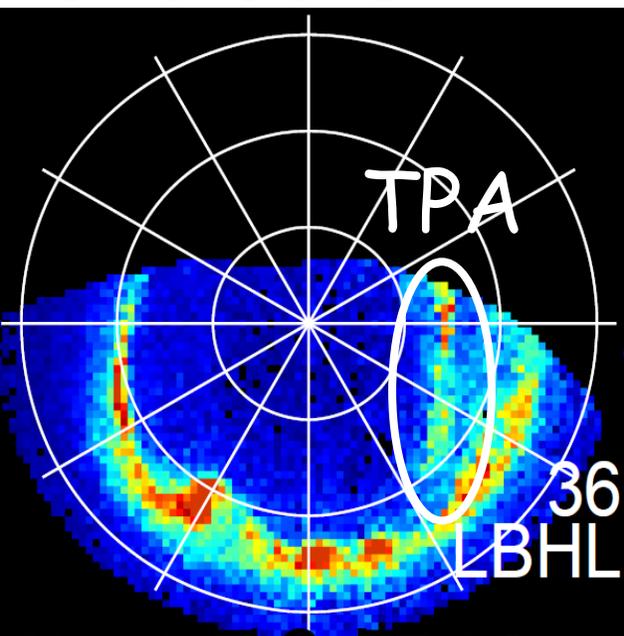
Weakly  
southward

1820:00 UT

1820:47 UT

1826:08 UT

1826:55 UT



Aurora Shape

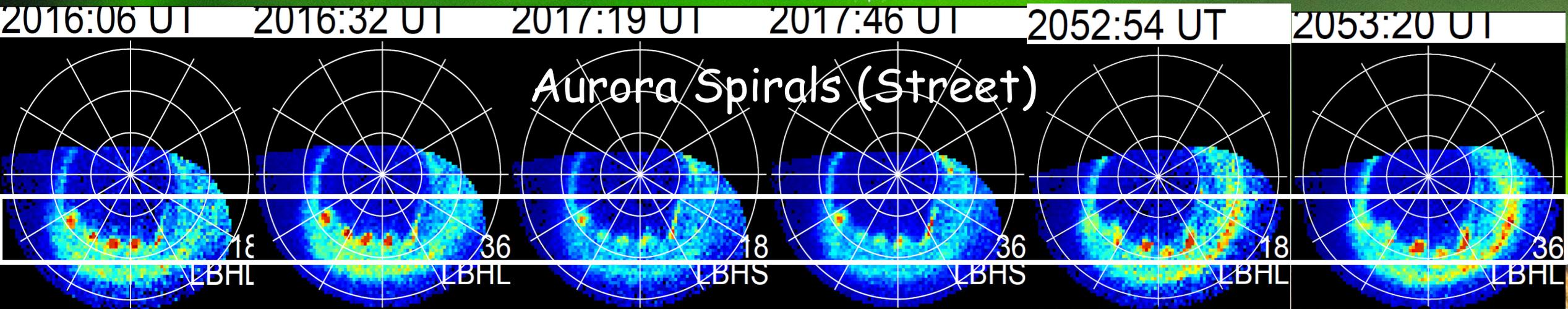
Time Interval (UT) and  
Duration (Minutes)

IMF-B<sub>z</sub>  
Conditions

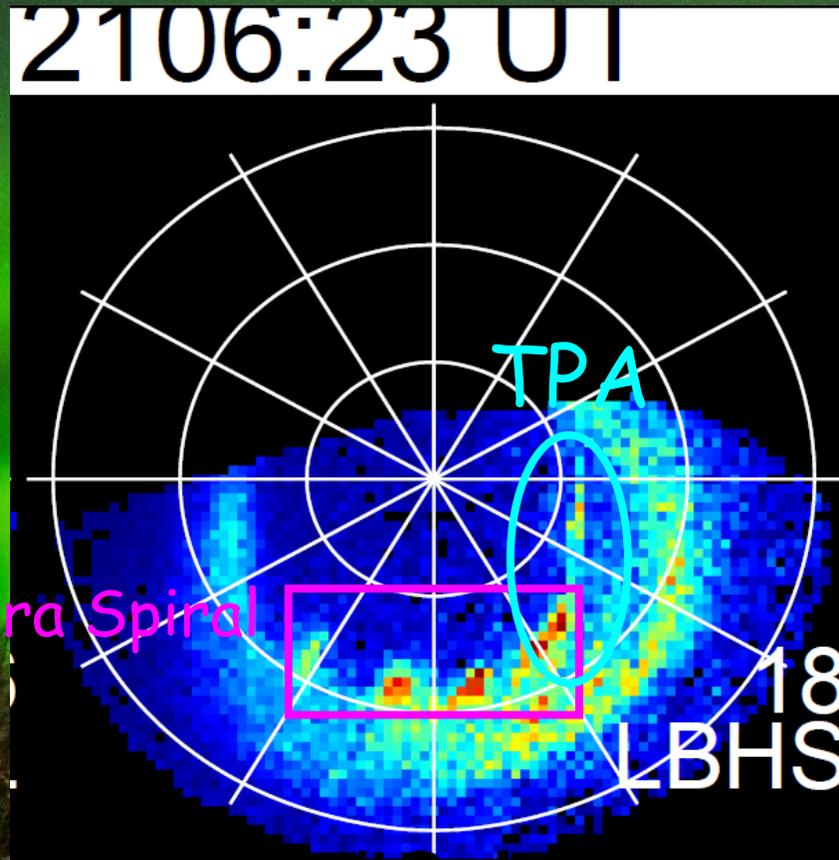
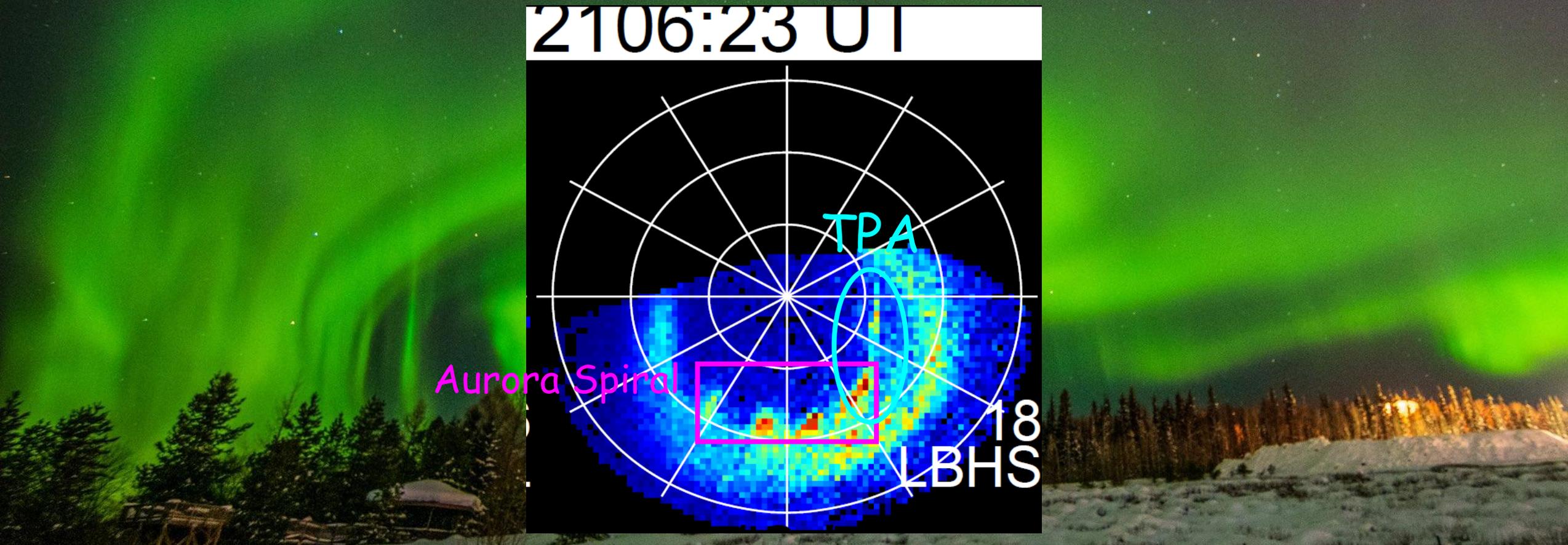
Aurora Spirals (Street)

20:00 – 20:58  
58

Weakly southward  
with transient  
northward



Aurora Shape	Time Interval (UT) and Duration (Minutes)	IMF-Bz Conditions
TPA + Aurora Spirals	20:58 - 21:23 25	Turning weakly southward to northward



# Aurora Shape

Time Interval (UT) and  
Duration (Minutes)

IMF-B<sub>z</sub>  
Conditions

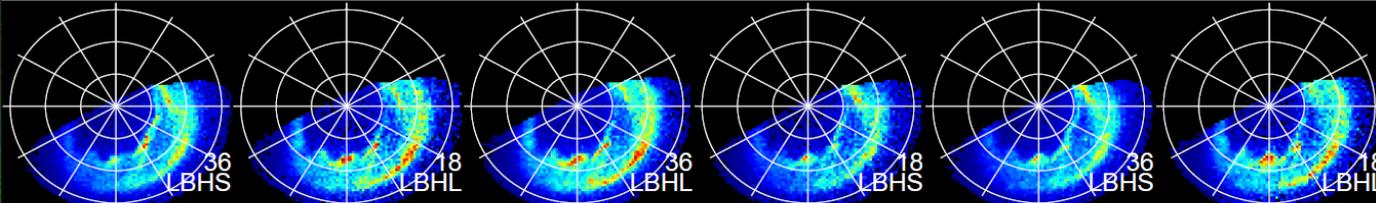
"J"-shaped TPA

21:23 - 22:22

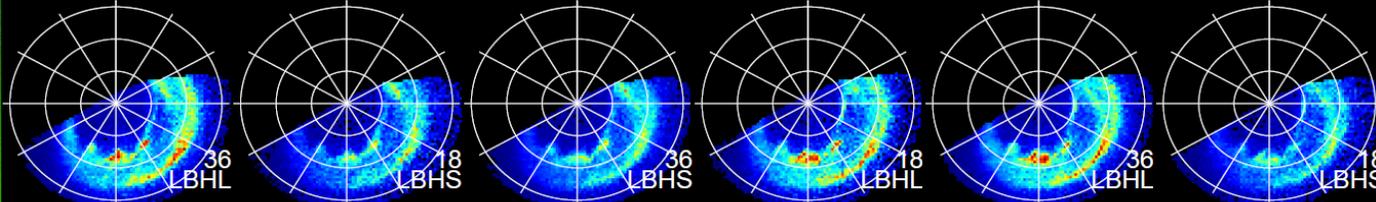
59

Northward

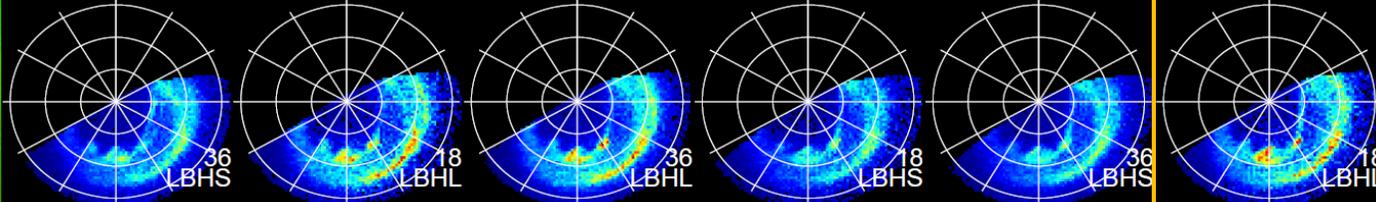
2143:38 UT 2145:02 UT 2145:28 UT 2146:15 UT 2146:42 UT 2148:06 UT



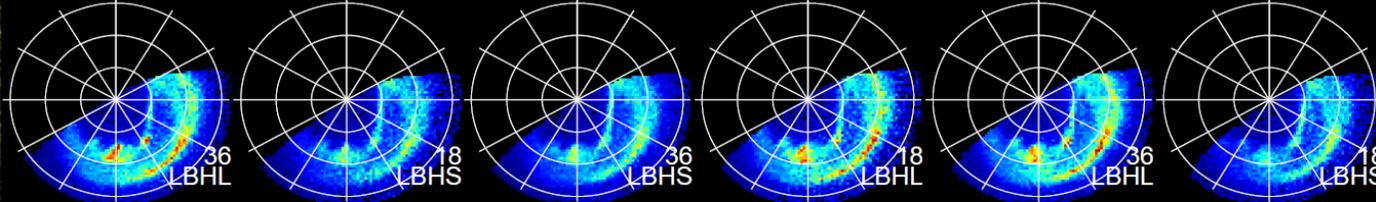
2148:32 UI 2149:19 UI 2149:46 UI 2151:10 UI 2151:36 UI 2152:23 UI



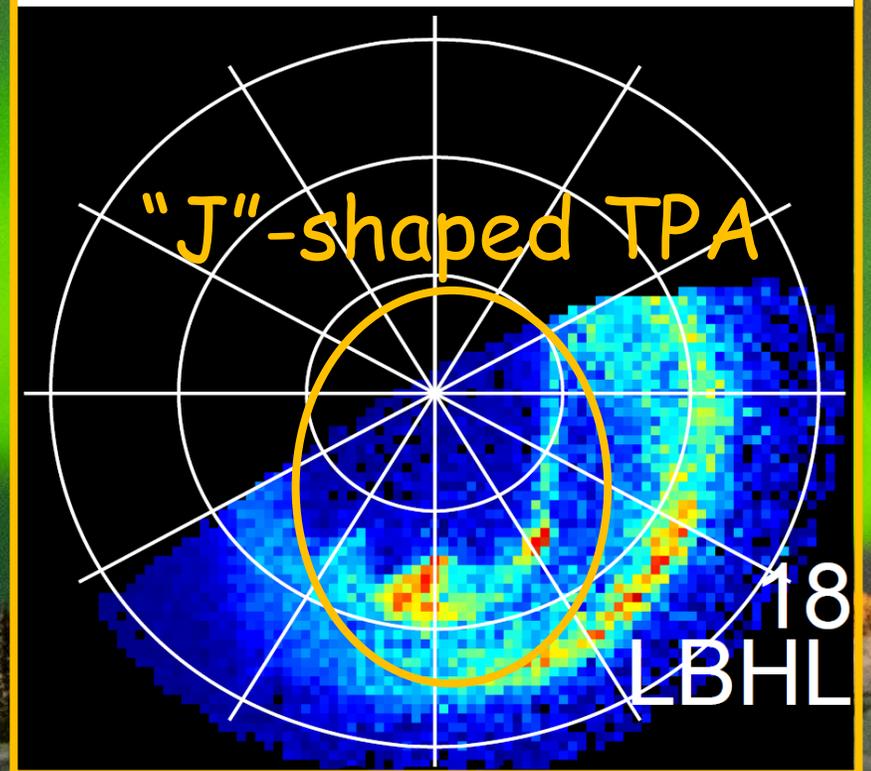
2152:50 UI 2154:14 UI 2154:40 UI 2155:27 UI 2155:54 UI 2157:18 UI



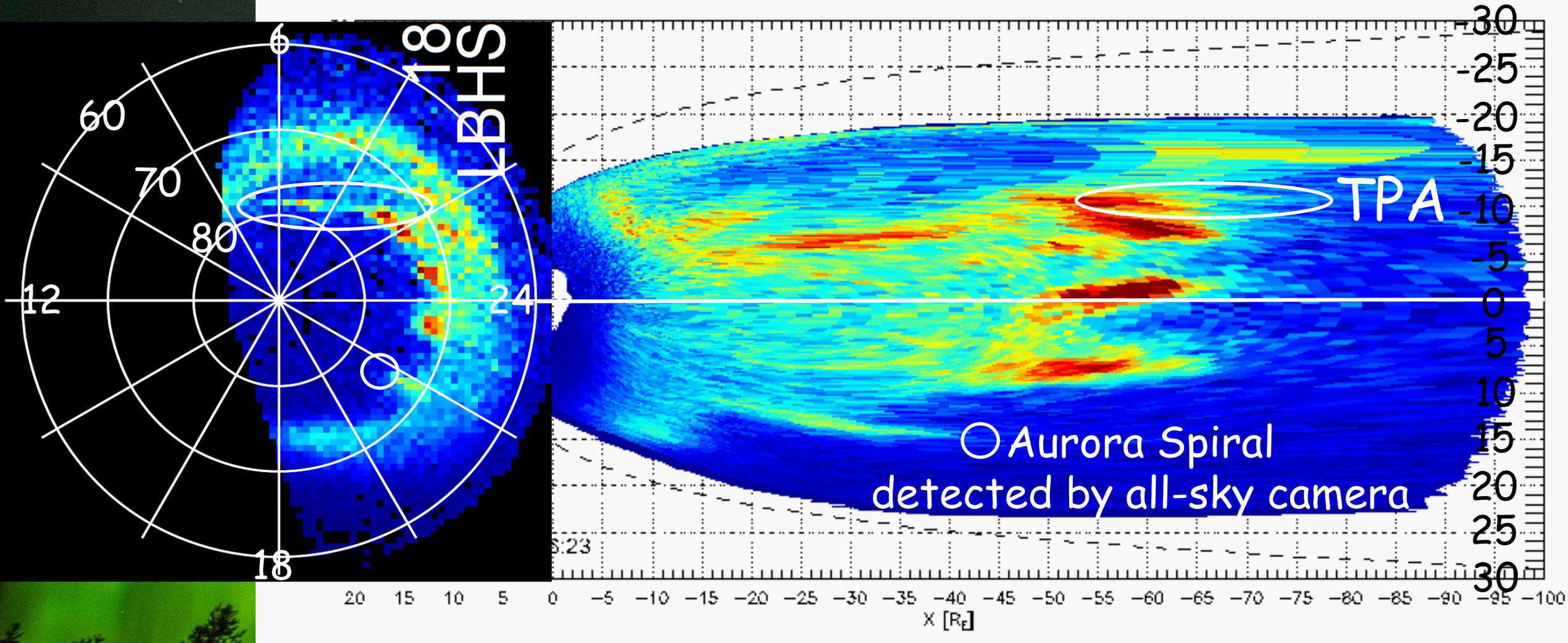
2157:44 UI 2158:31 UI 2158:58 UI 2200:22 UI 2200:48 UI 2201:35 UI



2157:18 UI



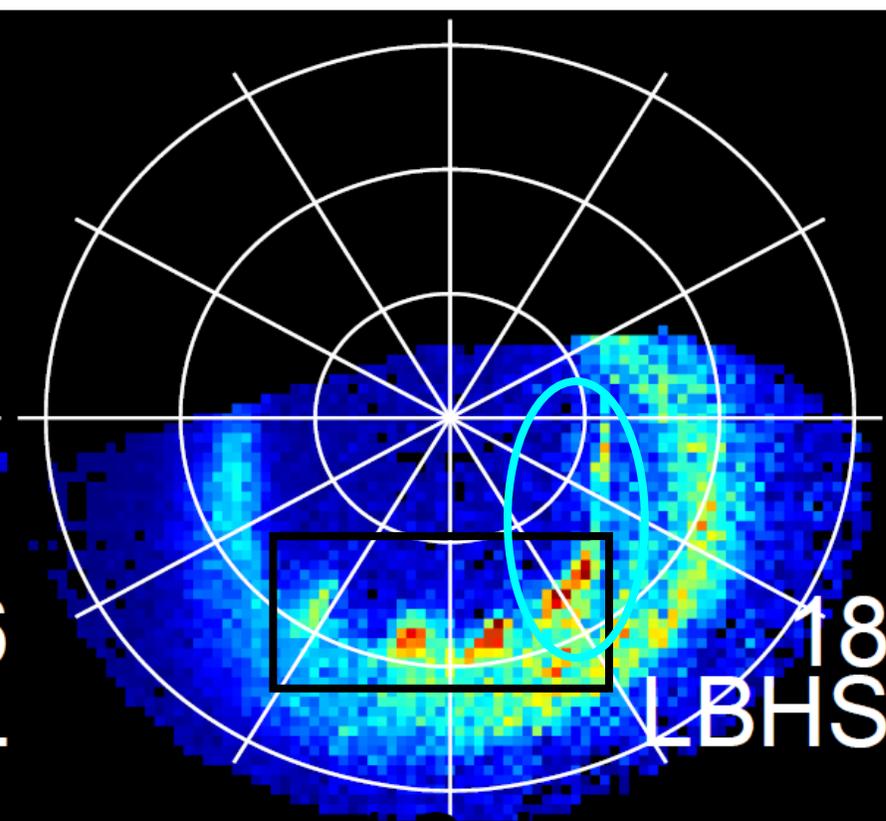
21:06:23 UT (Aurora Spiral + TPA)



Aurora projection (mapping) onto the magnetic equatorial plane based on the Tsyganenko 96 model

# Polar UVI Observation

## 2106:23 UT



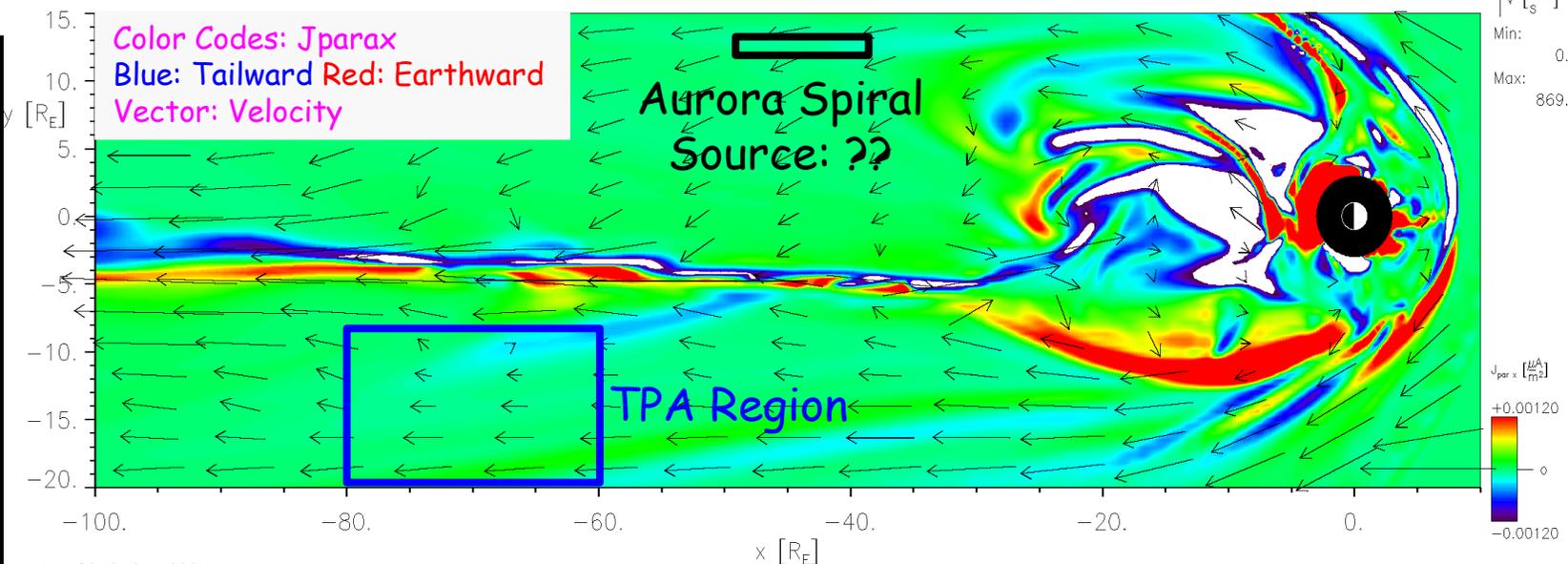
### LBHS 18

### Aurora Spirals + TPA

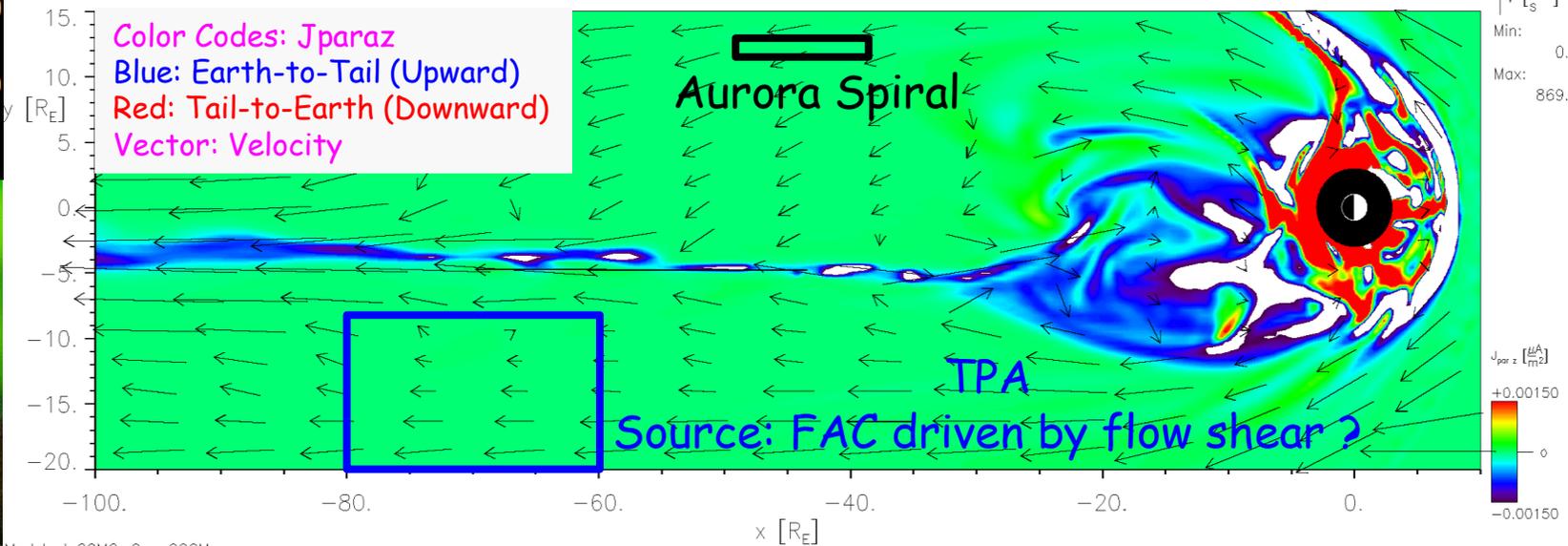


# Global MHD Simulation (Open-GGCM)

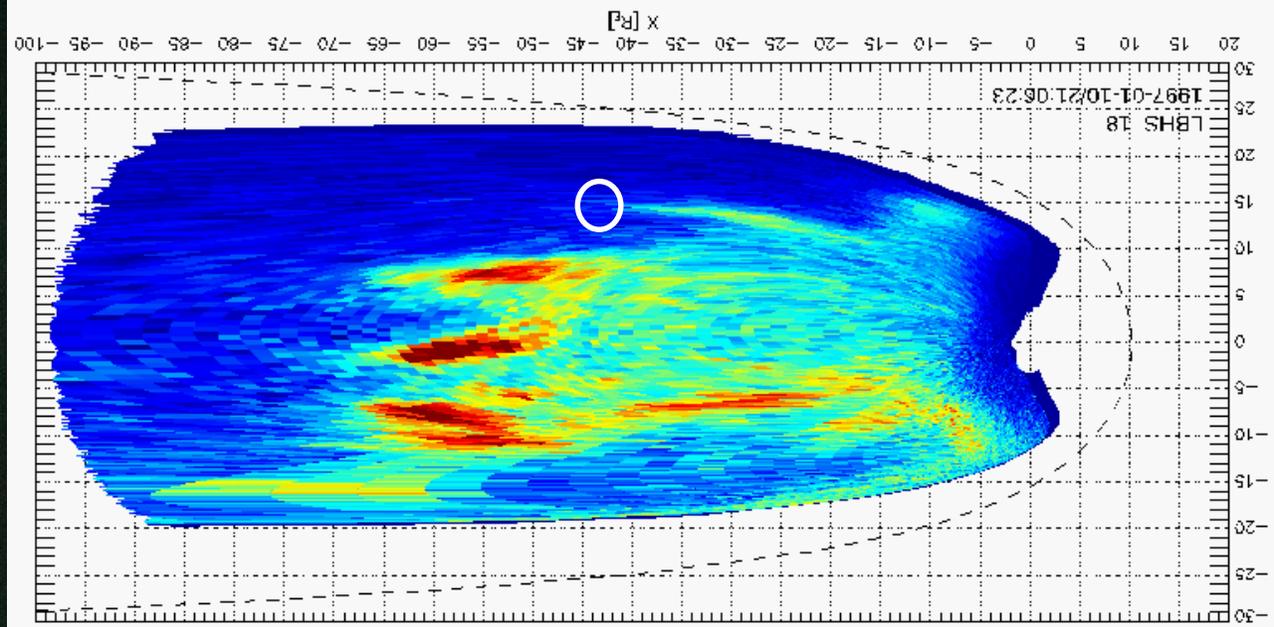
01/10/1997 Time = 21:06:00 UT z = 0.00R<sub>E</sub>



01/10/1997 Time = 21:06:00 UT z = 0.00R<sub>E</sub>



# Field-aligned Current Structures Obtained by Global MHD Simulation (Open-GGCM)



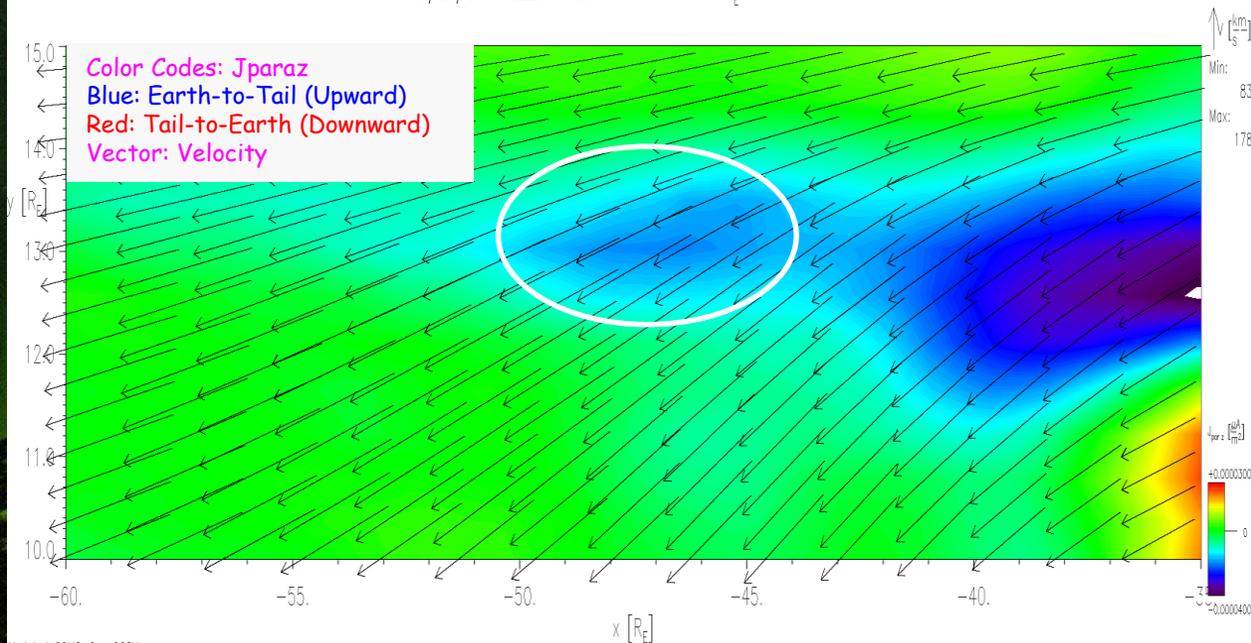
Aurora spiral dominantly consisted of upward field-aligned current (from ionosphere to magnetotail).

However, magnetic reconnection, which causes the fast plasma flows and resultantly generates flow shear, was not found in the simulation.

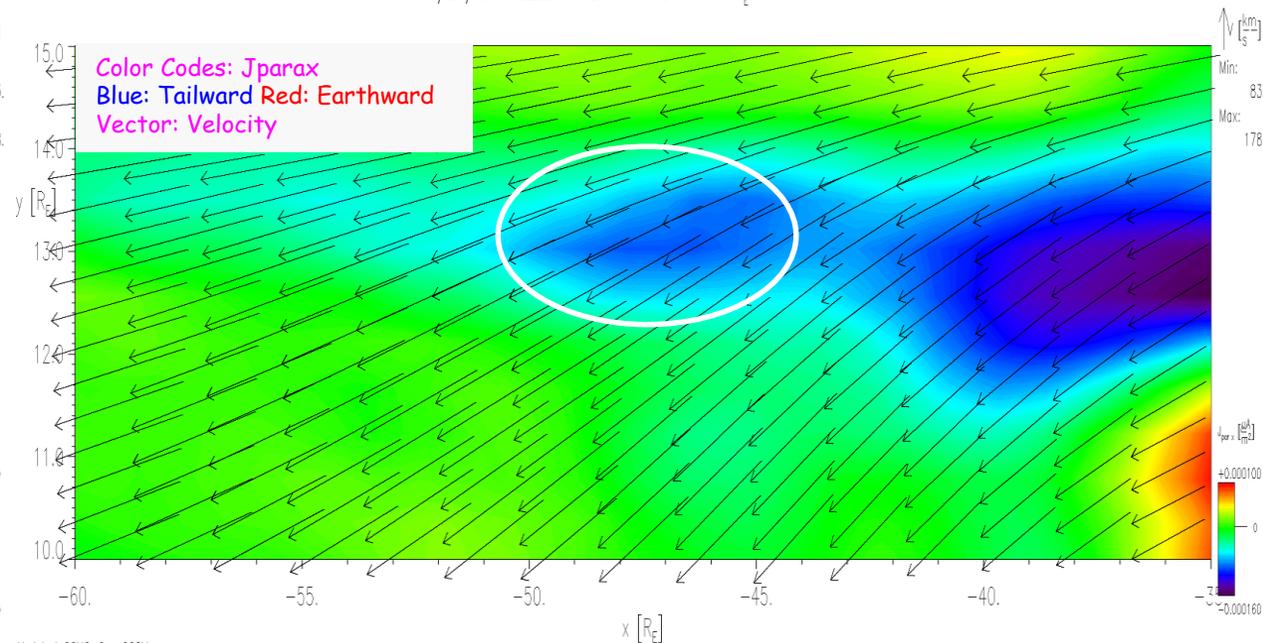
This aurora spiral may be caused by local plasma processes (instabilities) ?

→ Further investigations of magnetic field and plasma parameter variations around the aurora spiral source region are required based on global MHD simulations.

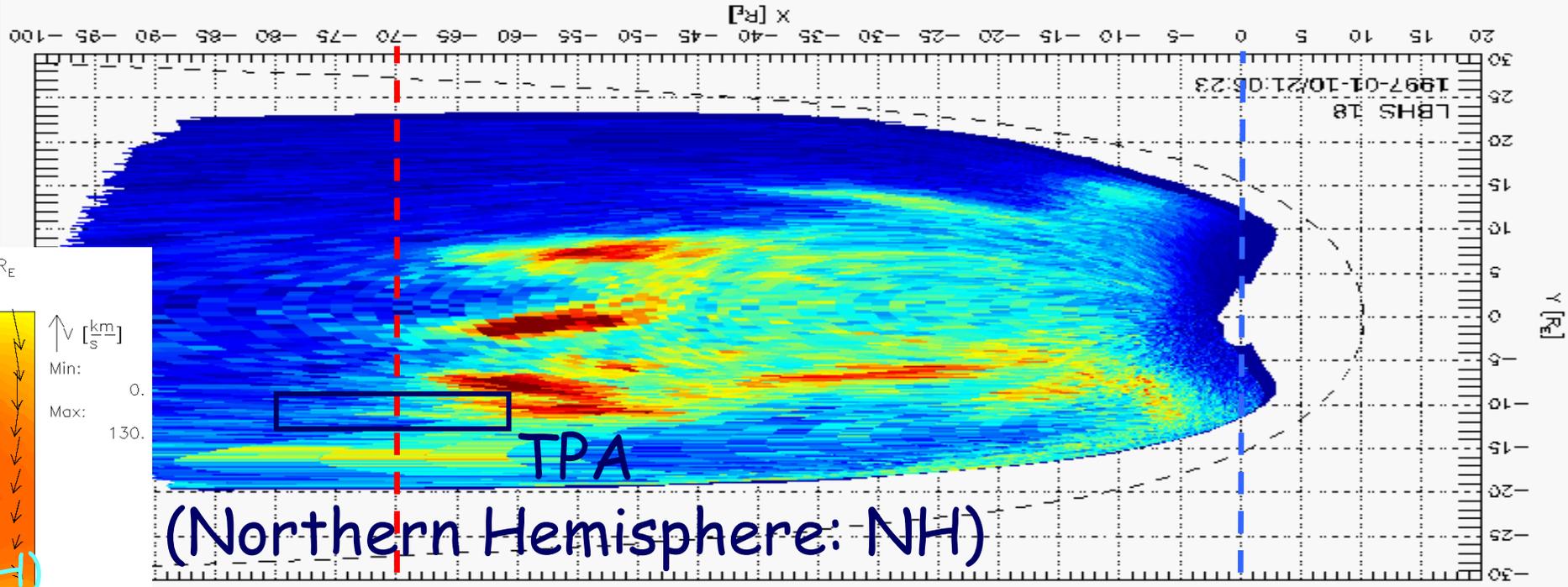
01/10/1997 Time = 21:06:00 UT  $z = 0.00R_E$



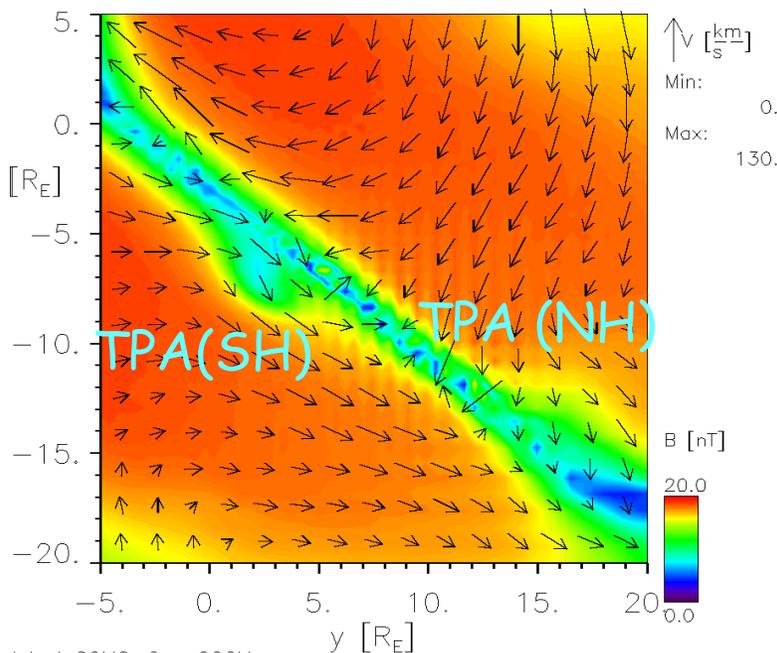
01/10/1997 Time = 21:06:00 UT  $z = 0.00R_E$



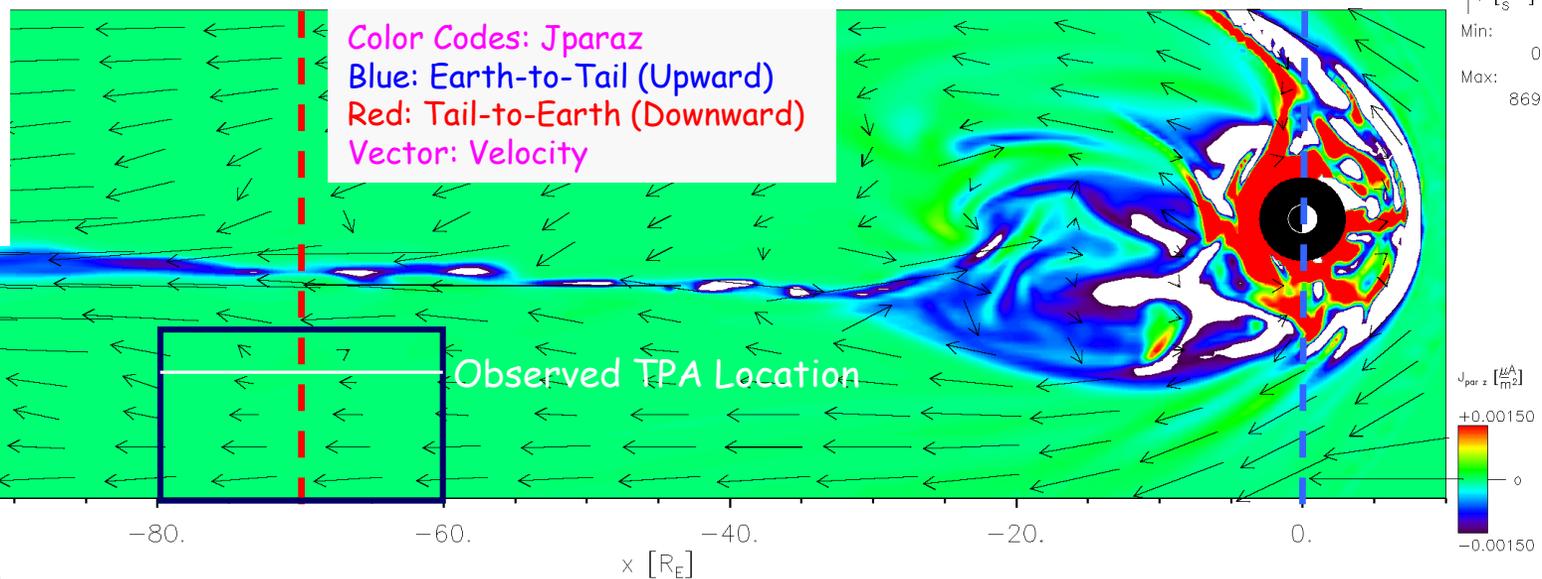
# Comparison of the UVI observations projected onto the equatorial plane with the MHD simulations



01/10/1997 Time = 21:06:00 UT x = -70.0R<sub>E</sub>



01/10/1997 Time = 21:06:00 UT z = 0.00R<sub>E</sub>

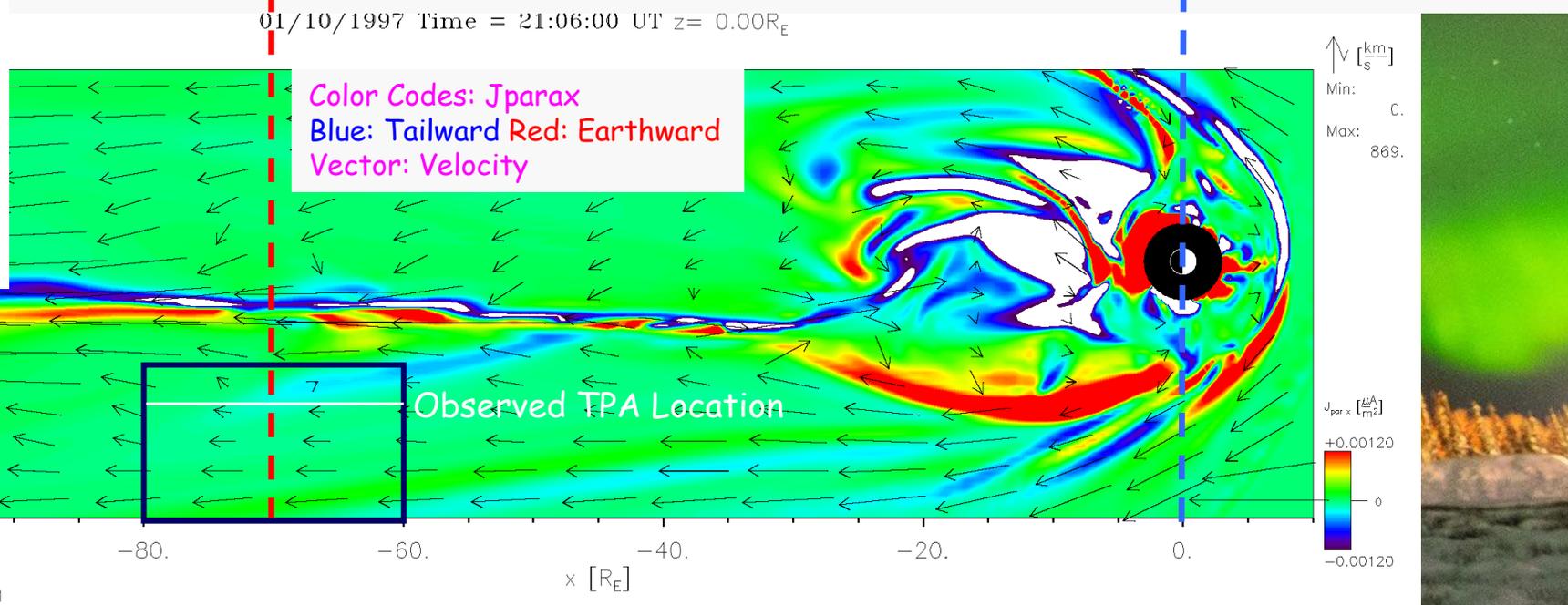
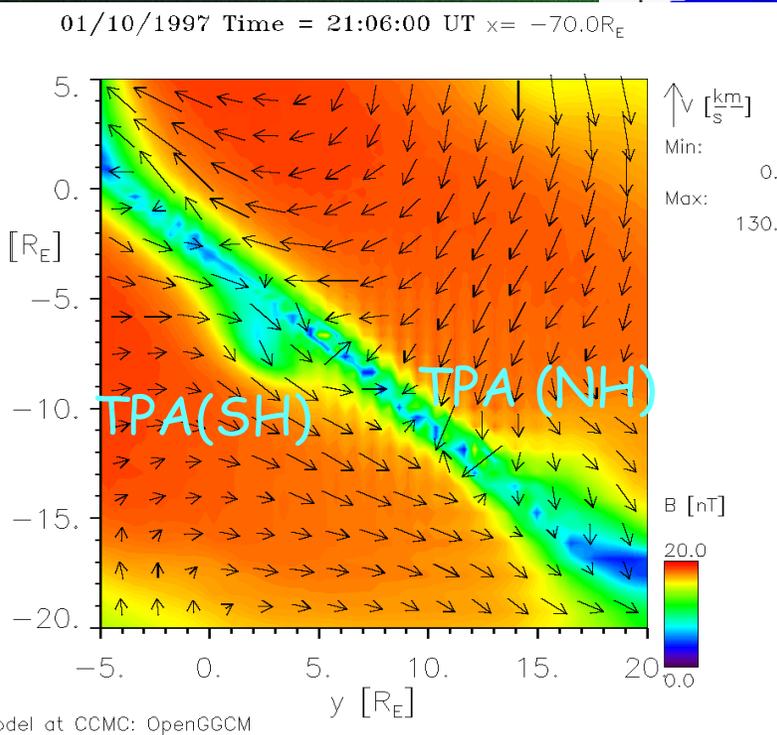
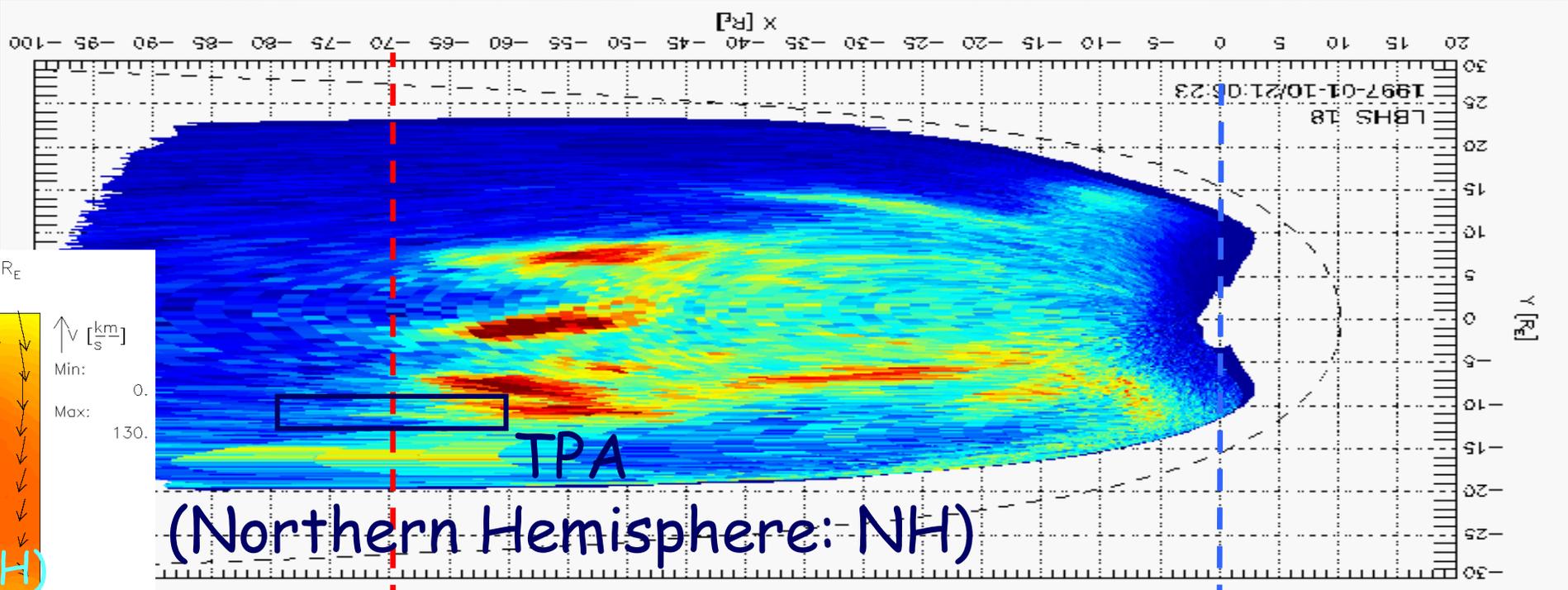


Model at CCMC: OpenGGCM

Model at CCMC: OpenGGCM

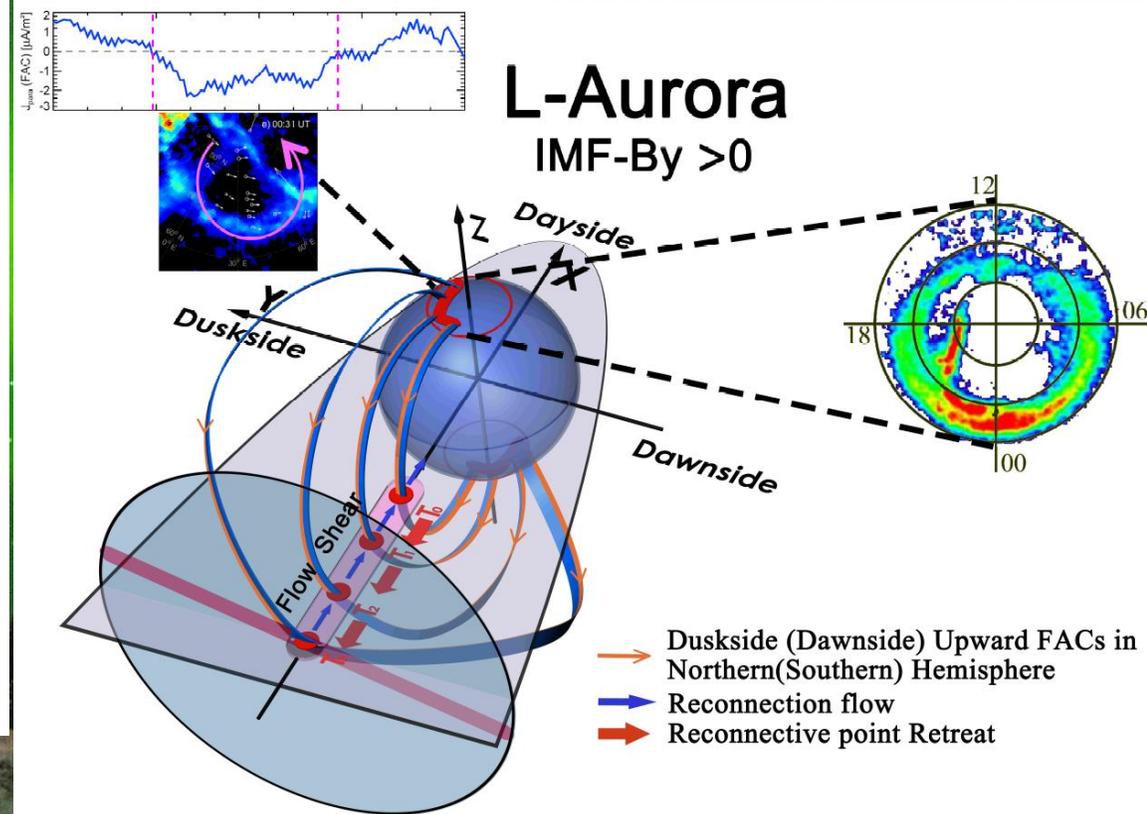
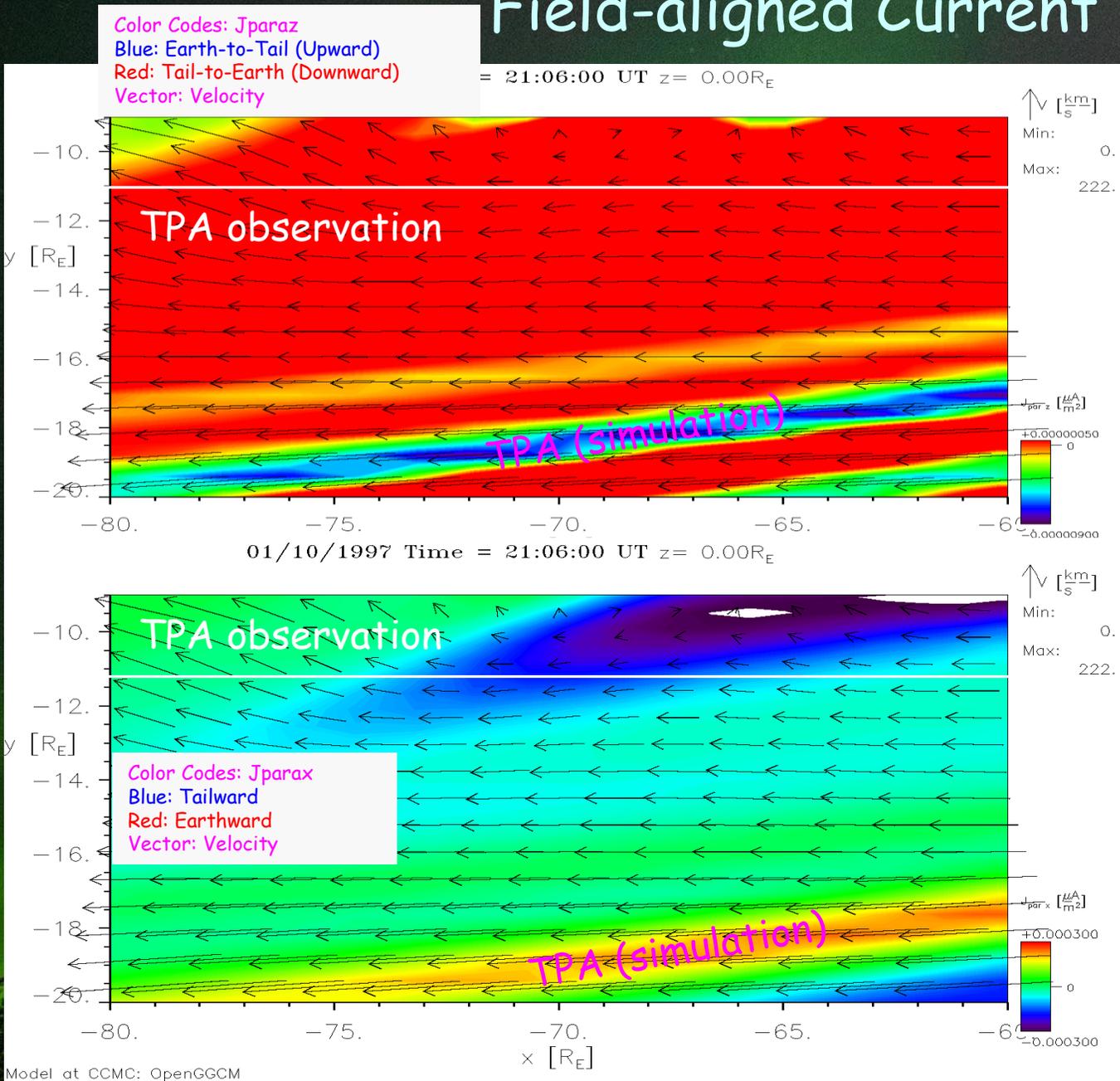


# Comparison of the UVI observations projected onto the equatorial plane with the MHD simulations



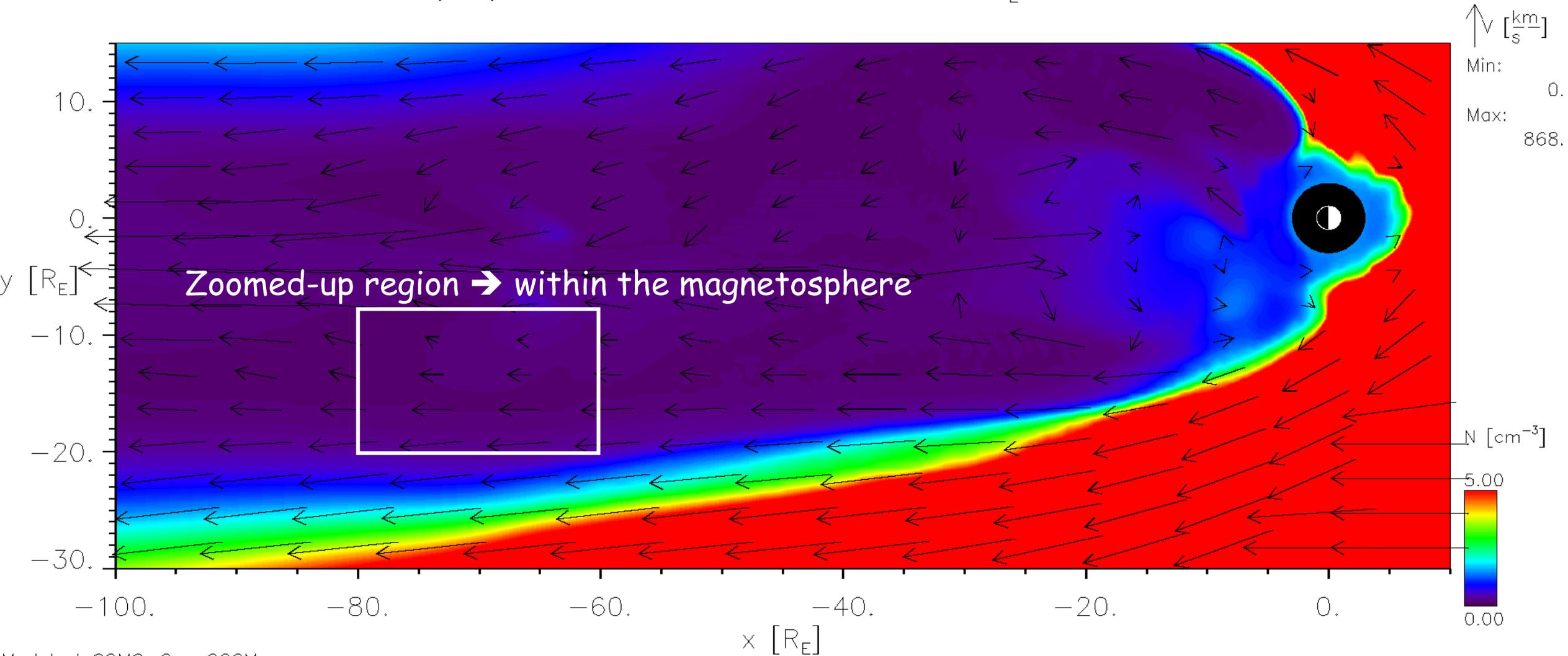
# Field-aligned Current Structure of TPA (Simulation)

TPA was including the component of field-aligned currents from ionosphere to tail (upward FACs).  
 → TPA source and formation process are partially consistent with the TPA formation model proposed by Nowada+ (2020).



# TPA is really identified in the magnetosphere in the simulation ?

01/10/1997 Time = 21:06:00 UT  $z = 0.00R_E$



Color code is assigned according to plasma density

# Conclusions

1. Contemporaneous TPA and aurora spiral were observed by Polar UVI. Furthermore, based on global MHD simulations, magnetotail dynamics associated with TPA and auroral spiral (formations) are estimated.
2. The TPA formation is closely associated with magnetotail magnetic reconnection (large-scale phenomena), which is consistent with the basic part of the TPA formation process which was proposed by Nowada+ 2020.
3. While the aurora spiral is not associated with (large-scale) magnetotail reconnection but may be related with local plasma processes (instabilities).  
→ Further investigations based on global MHD simulations are required.
4. Concurrent observations of two different types of auroras suggest that large- and small-(local) scale dynamics simultaneously occurred in the magnetotail under dominant northward IMF- $B_z$  (with predominant IMF- $B_y$ ) conditions.

# Future Works

1. Based on in-situ observations and global MHD simulations, investigating what finally generates aurora spirals. Small- (Local) or large-scale plasma processes (instabilities)?
2. Investigating the fundamental characteristics of aurora spirals. The other major problems to be clarified, besides two questions raised in "Essentially Unraveled Points":
  - ✓ Dependence of solar wind conditions, such as IMF orientation, on aurora spiral occurrences
  - ✓ Relationship between substorm phases and auroral spiral occurrencesThe location of the aurora spiral appearance was statistically examined by Partamies+ 2001, but above relations are not adequately examined.
3. Improving the accuracy of global MHD simulations.