PEM09-P07

Magnetospheric dynamics under northward IMF conditions surveyed by concurrent observations of TPA and aurora spirals

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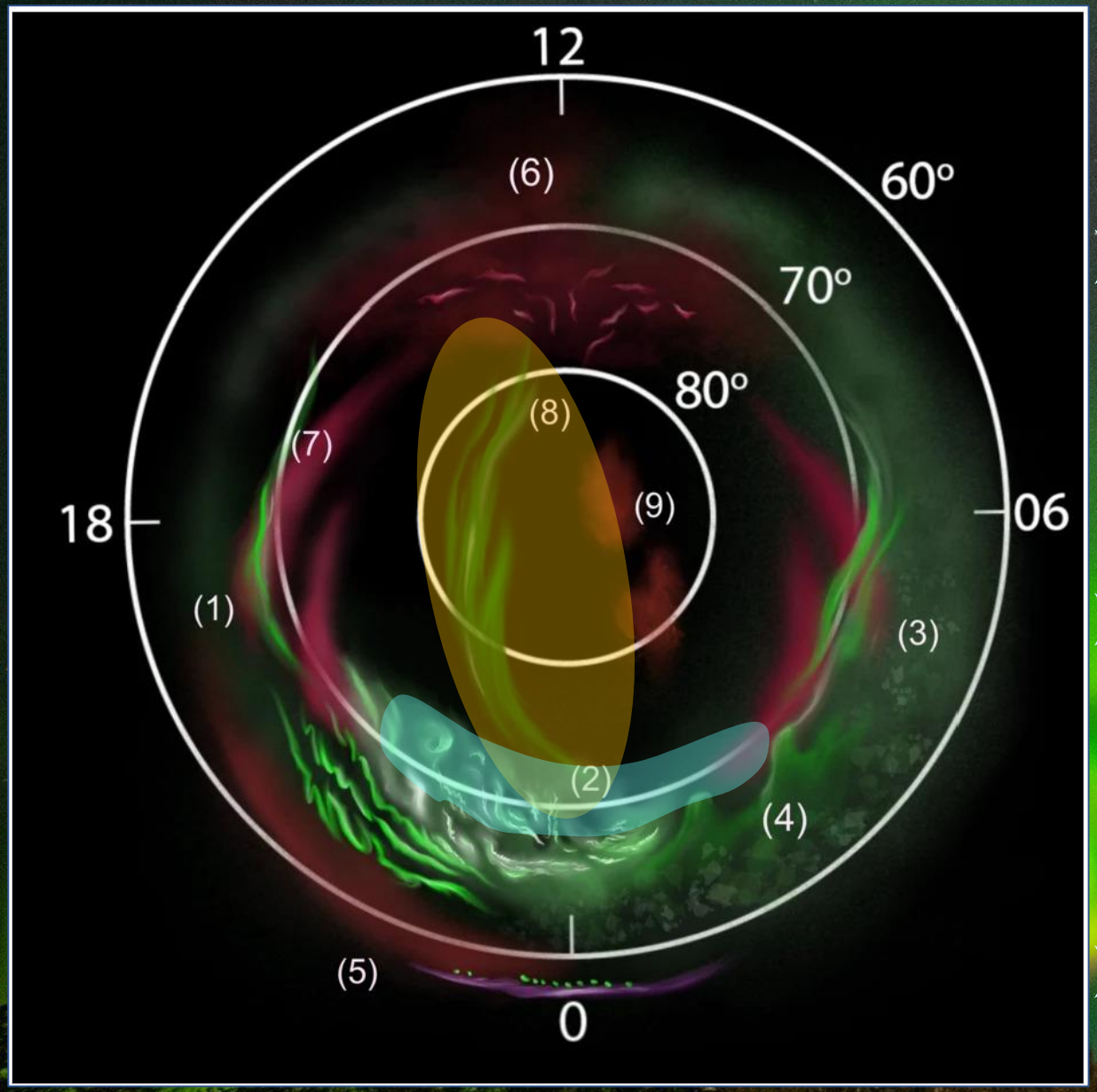


[Knudsen+ 2021]

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 ?

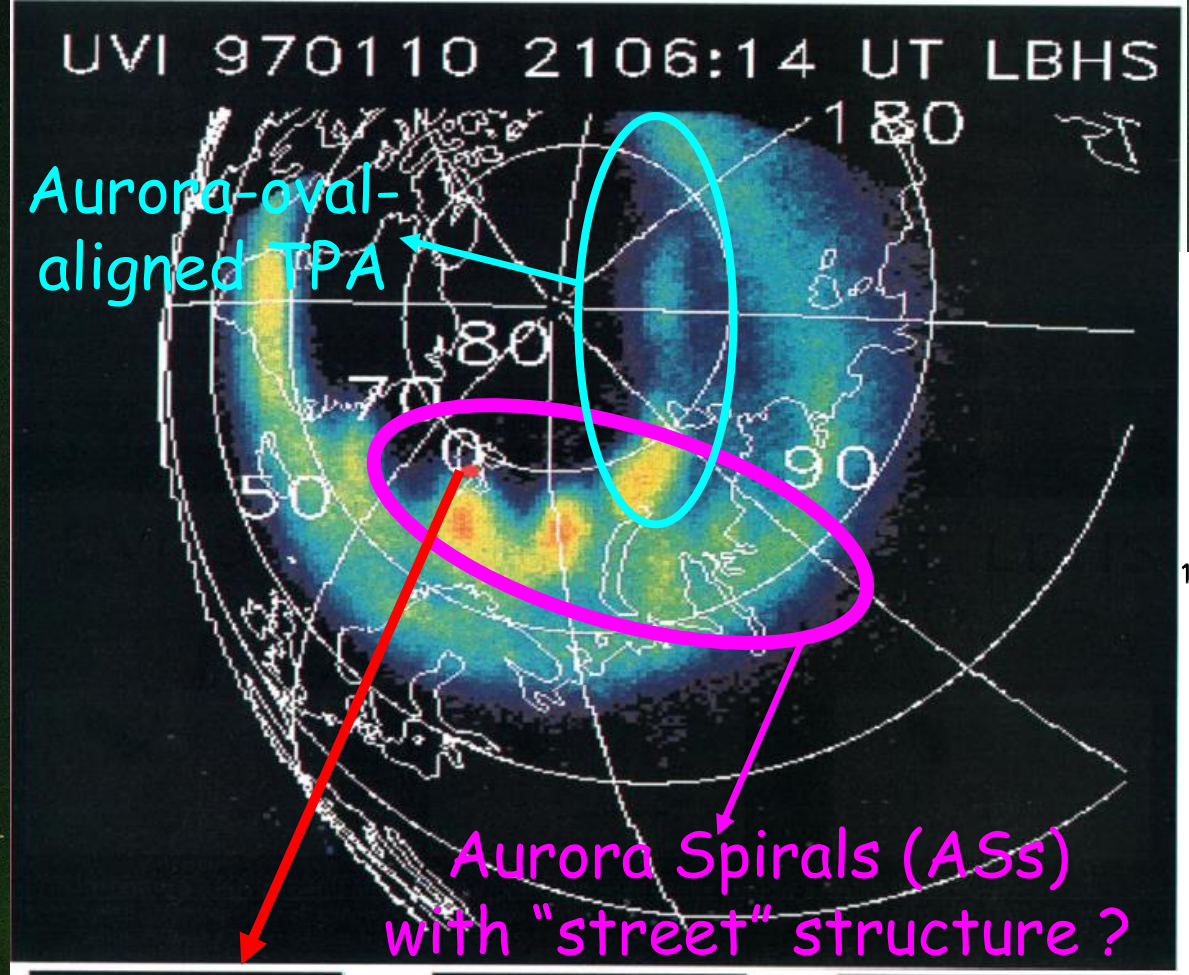
Aurora Spirals: Auroras with spiral form

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

A shot at Thingvallavatn Lake in Iceland, 2016

[Partamies+ 2001]

Statistical characteristics of aurora spirals



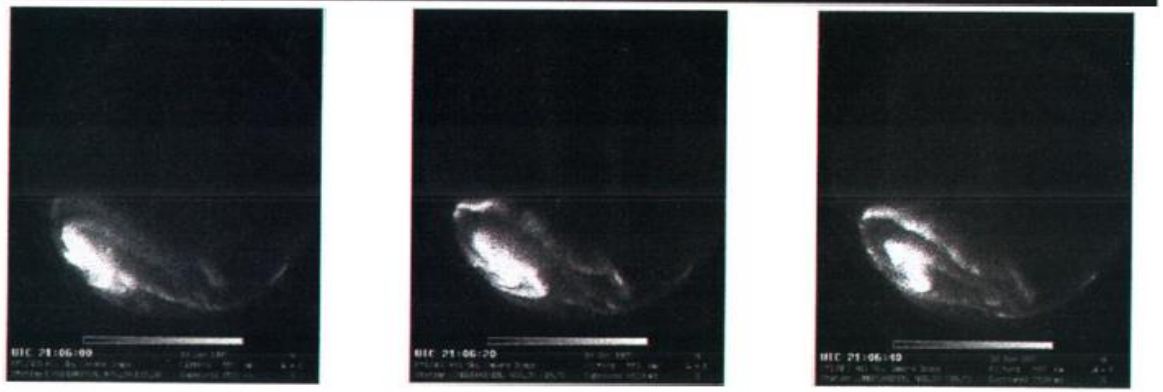


Plate 1. (top) A spiral street at the poleward edge of the oval in a Polar UVI image together with (bottom) simultaneous ASC images from Longyearbyen. The red spot in the UVI image shows the location of the Longyearbyen station on Svalbard.

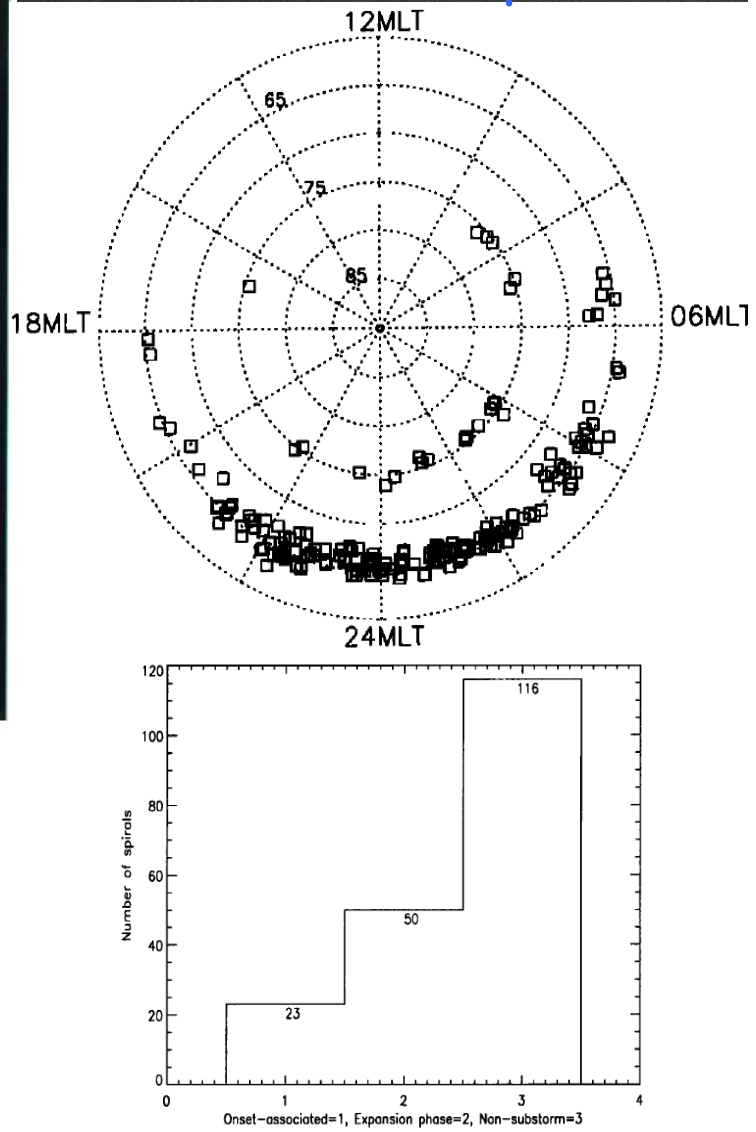
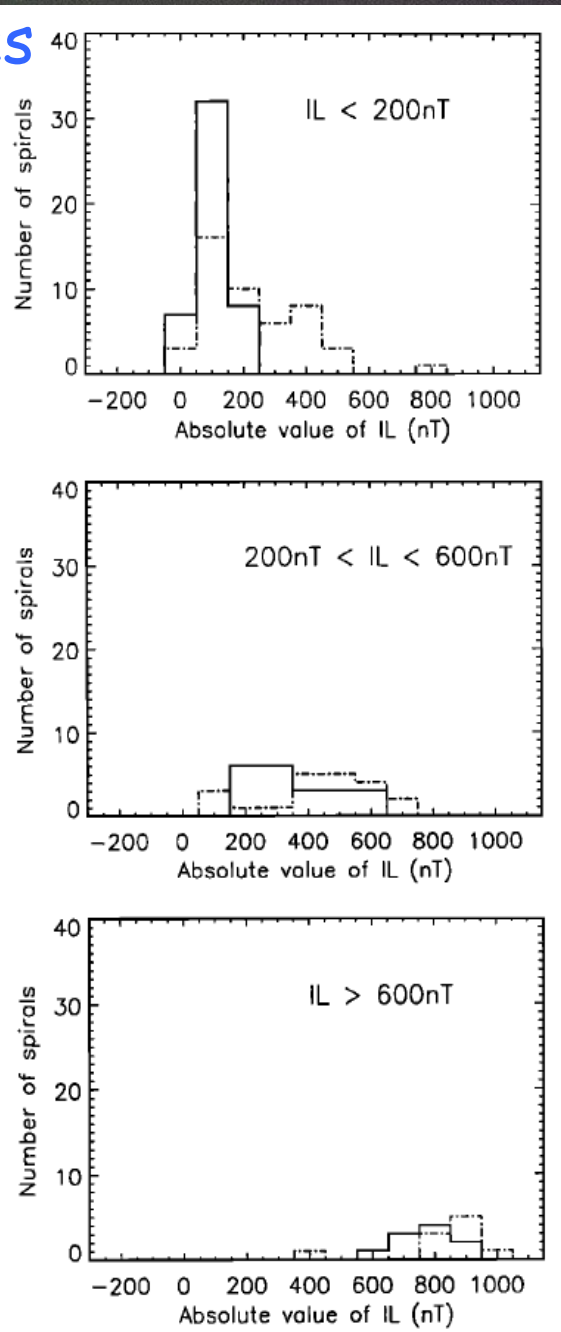


Figure 12. Distribution of substorm phases related to spirals: onset-associated spirals, expansion phase spirals, and nonsubstorm spirals (for definitions, see text).



Aurora Spirals (Statistical Characteristics)

- Aurora spirals are distributed around ~65 degrees in MLat whose MLT range is between 18h and 6h, and around ~ 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-Bz orientation is northward or weakly stable southward**. Their occurrence peak is seen at ~ 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]).

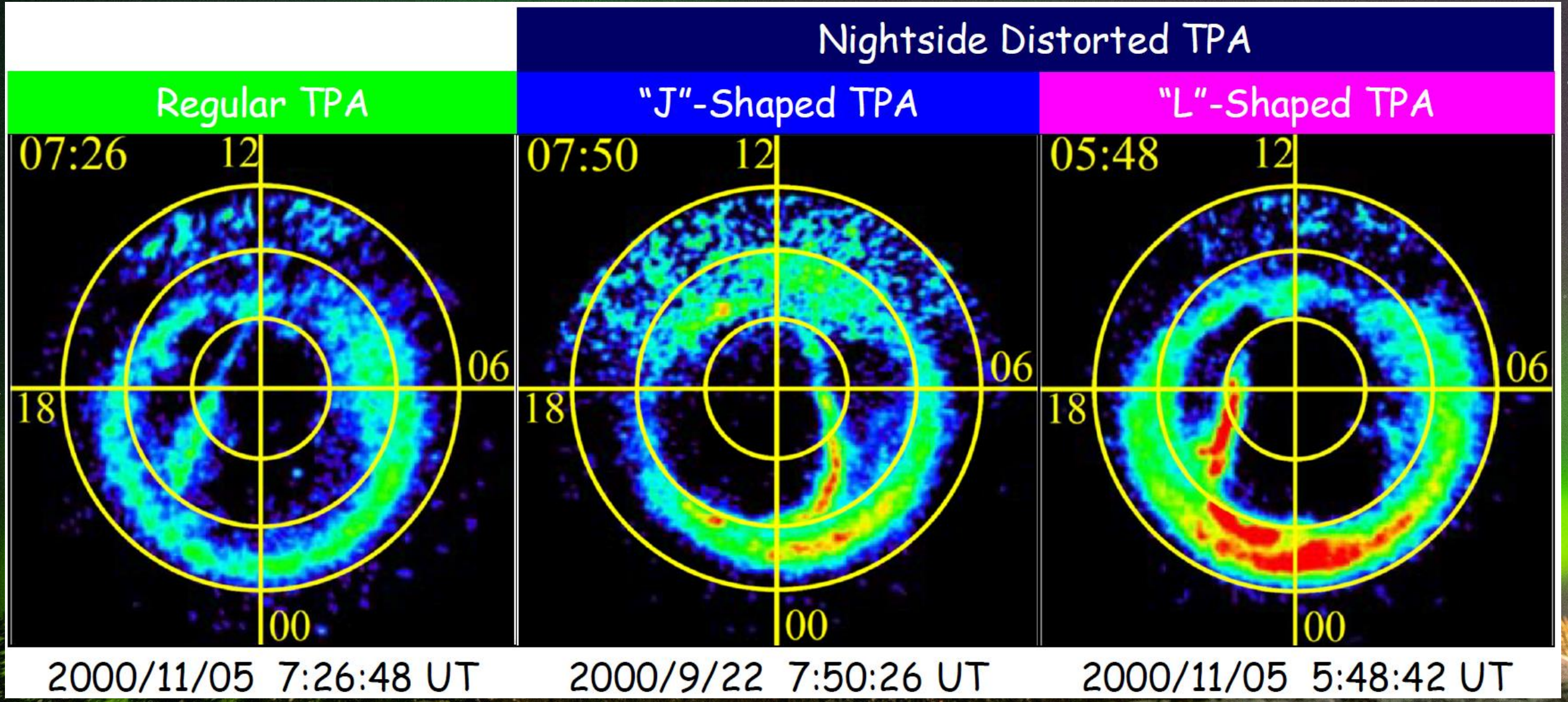
- They are also seen frequently during **non-substorm intervals**.

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

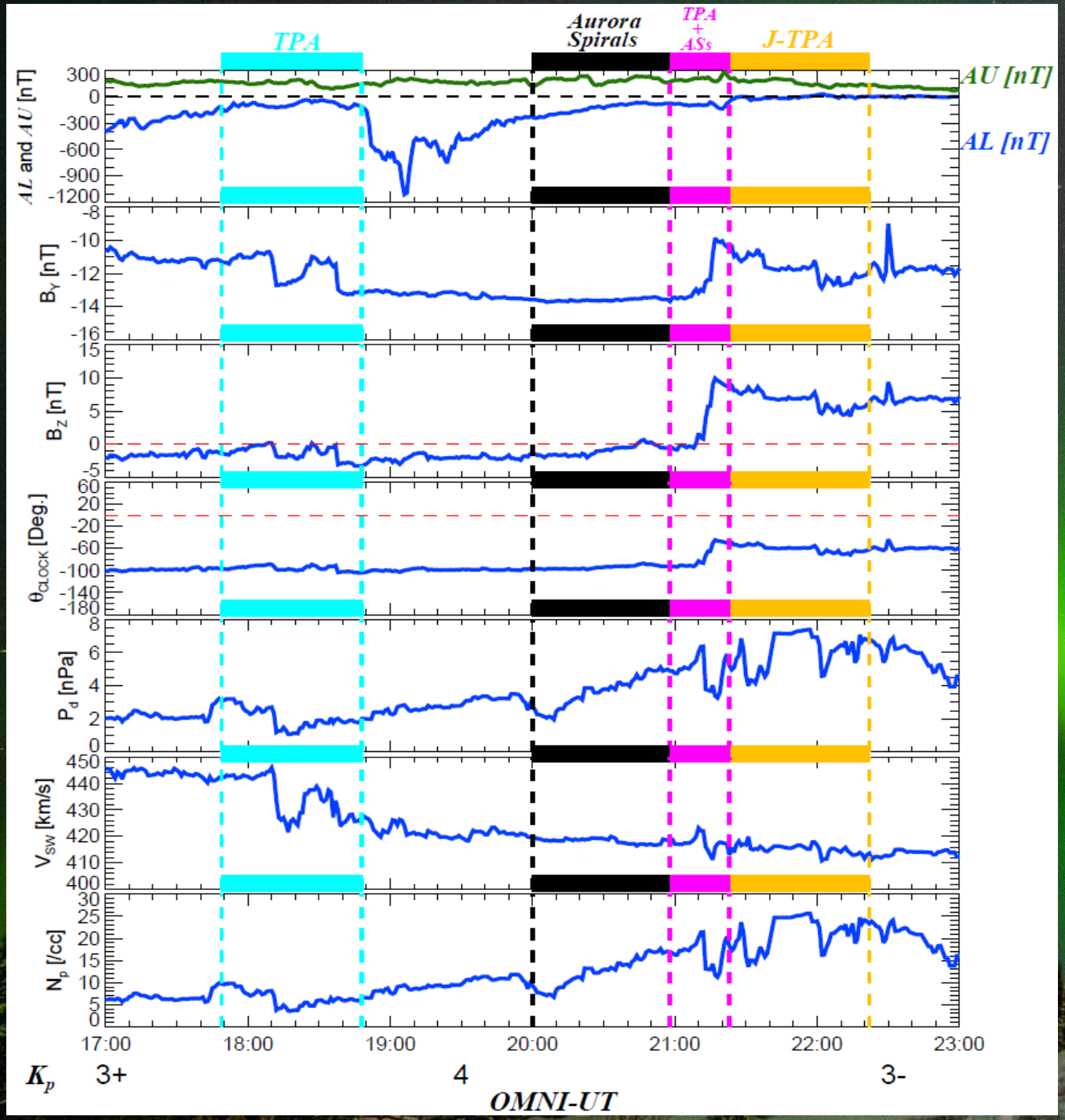
Transpolar Arcs (Statistical Characteristics)

- 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-Bz and -By components.
  - TPAs are frequently occurring under **northward IMF-Bz conditions**.
  - TPAs appear in the duskside sector (from pre-midnight to post-noon sector) under duskside (positive) IMF-By conditions.
  - Also, they can see in the dawnside sector (from post-midnight to pre-noon sector) under the dawnside (negative) IMF-By 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 dawnward (negative) IMF intervals.** In particular, concurrent observations of TPA and aurora spiral are just observed at **a significant IMF-Bz 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

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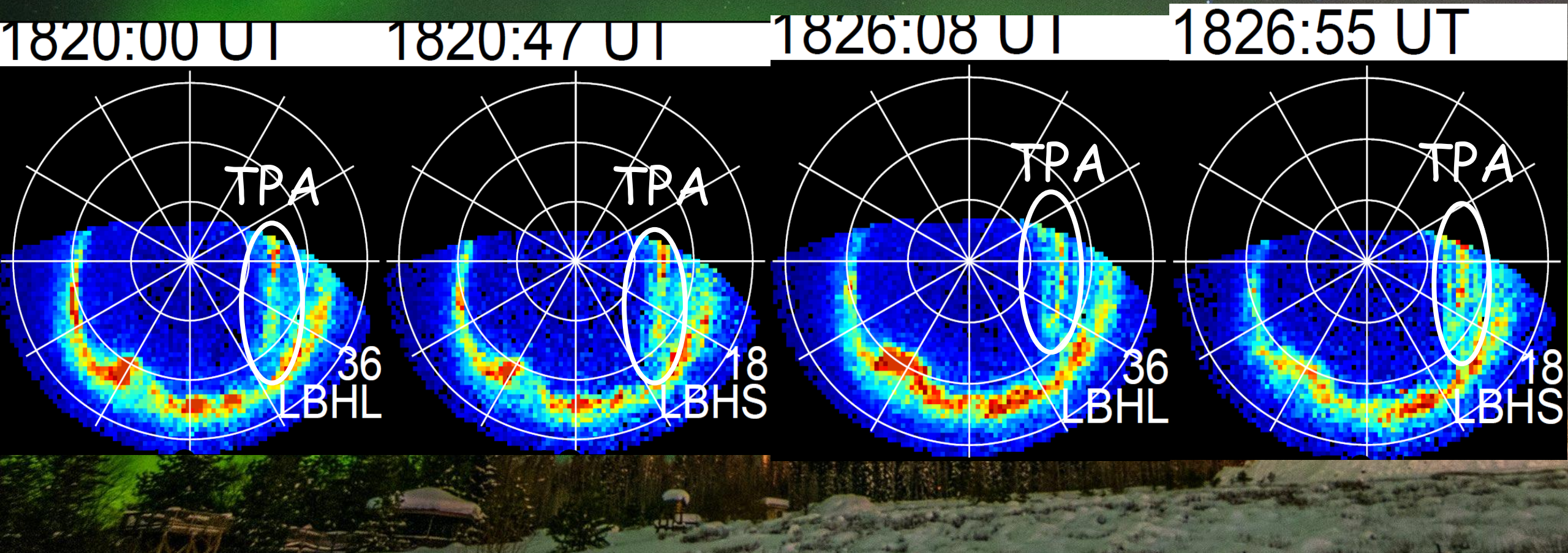

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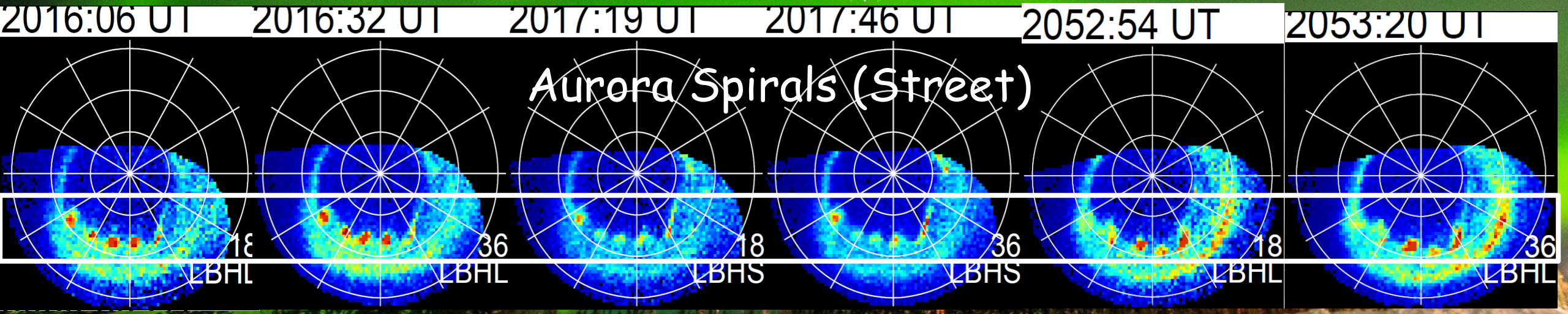

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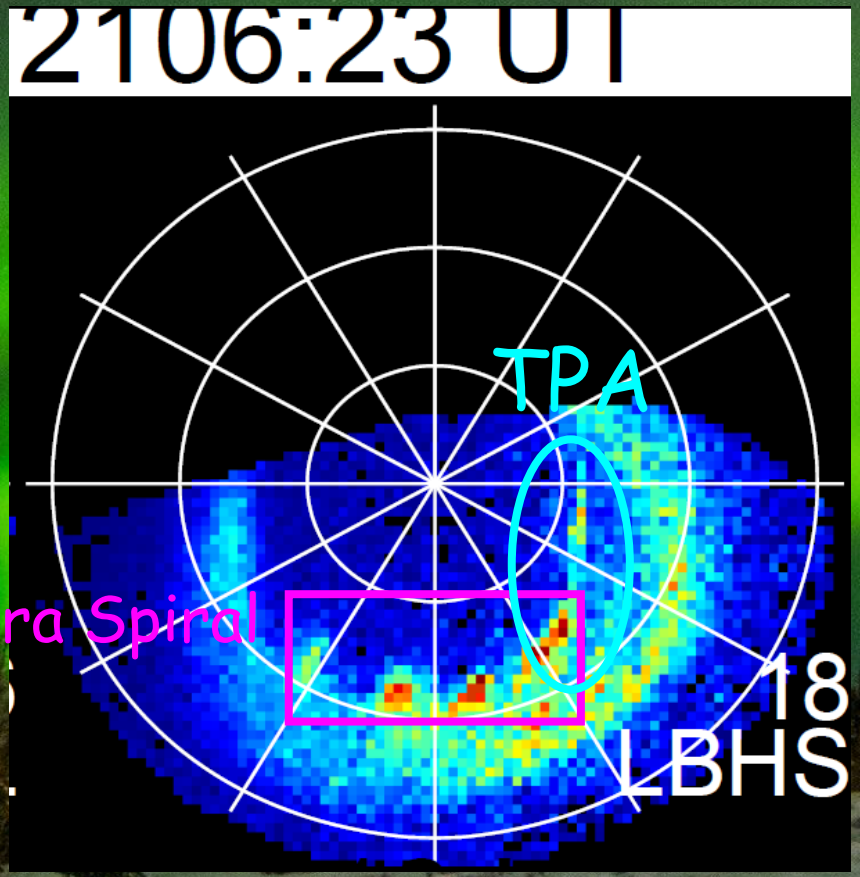
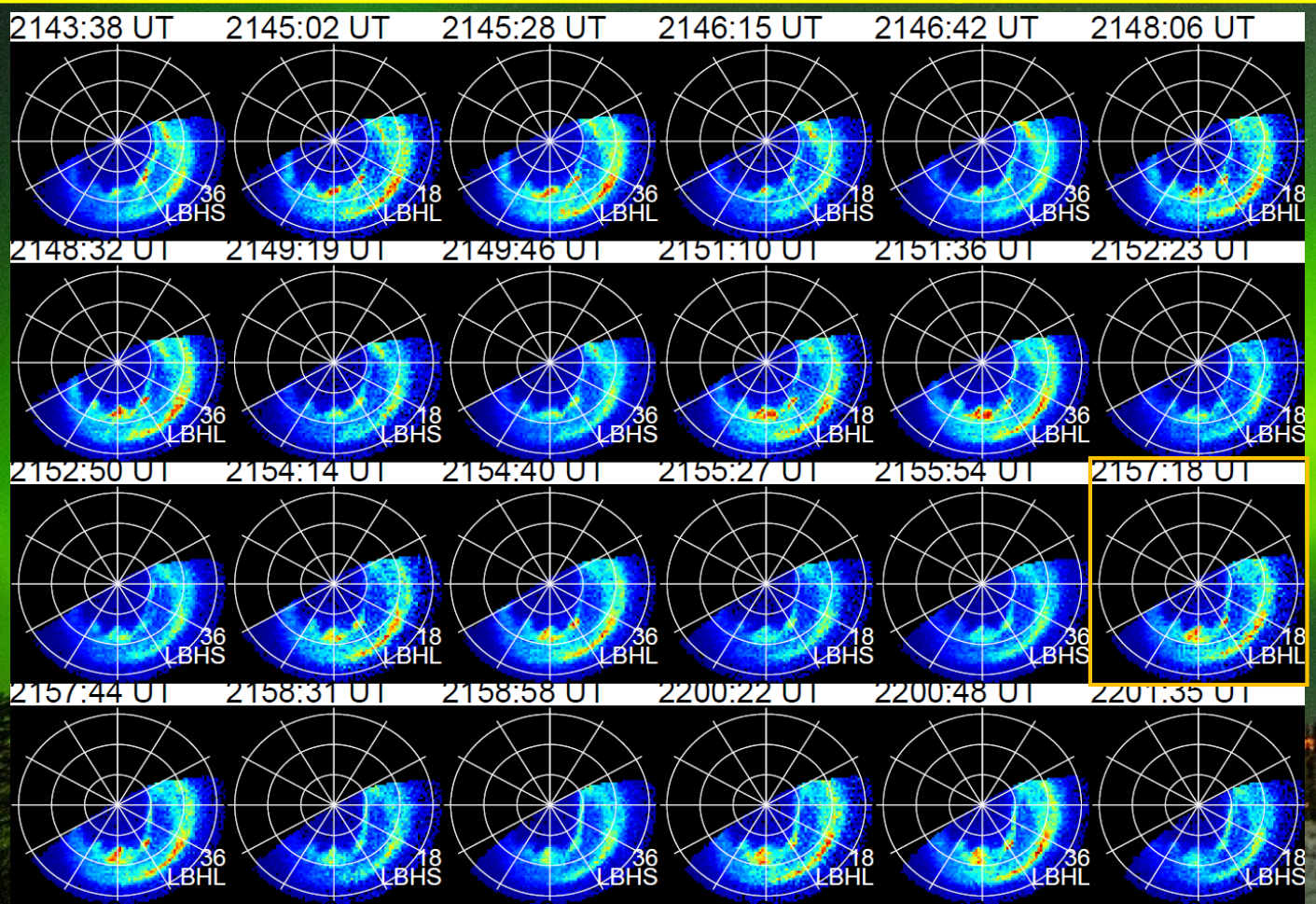
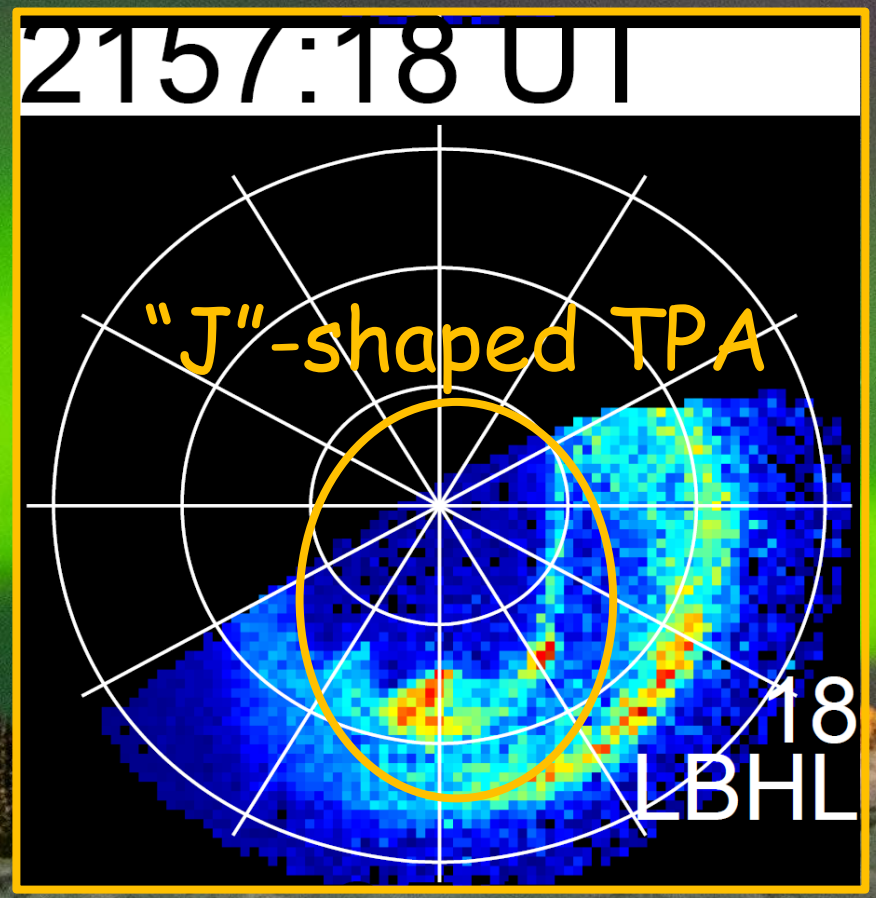
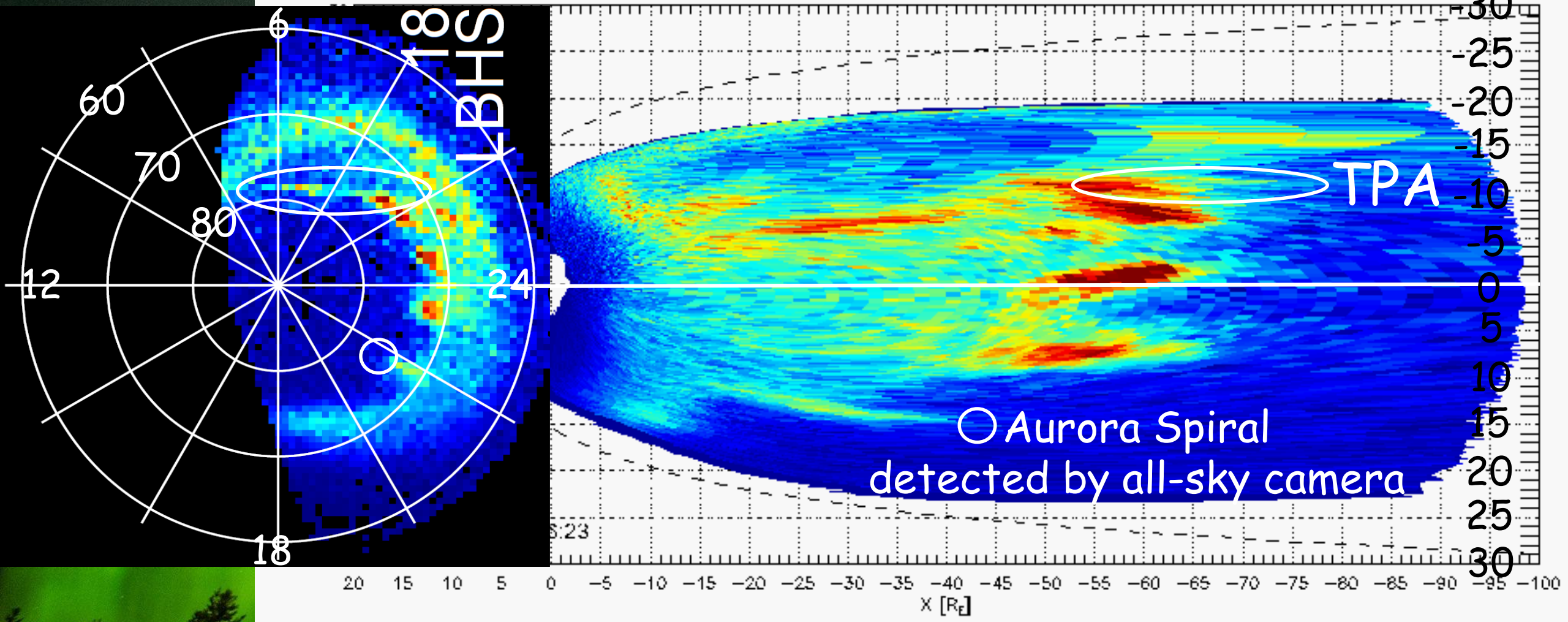


Aurora Shape	Time Interval (UT) and Duration (Minutes)	IMF-Bz Conditions
"J"-shaped TPA	21:23 - 22:22 59	Northward





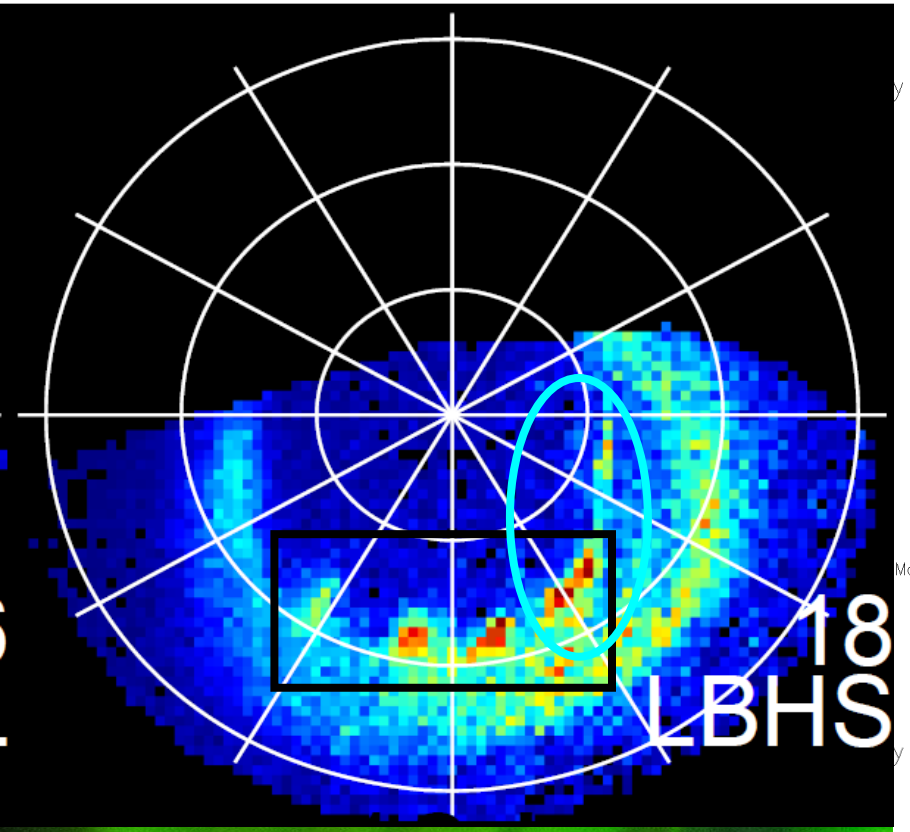
21:06:23 UT (Aurora Spiral + TPA)



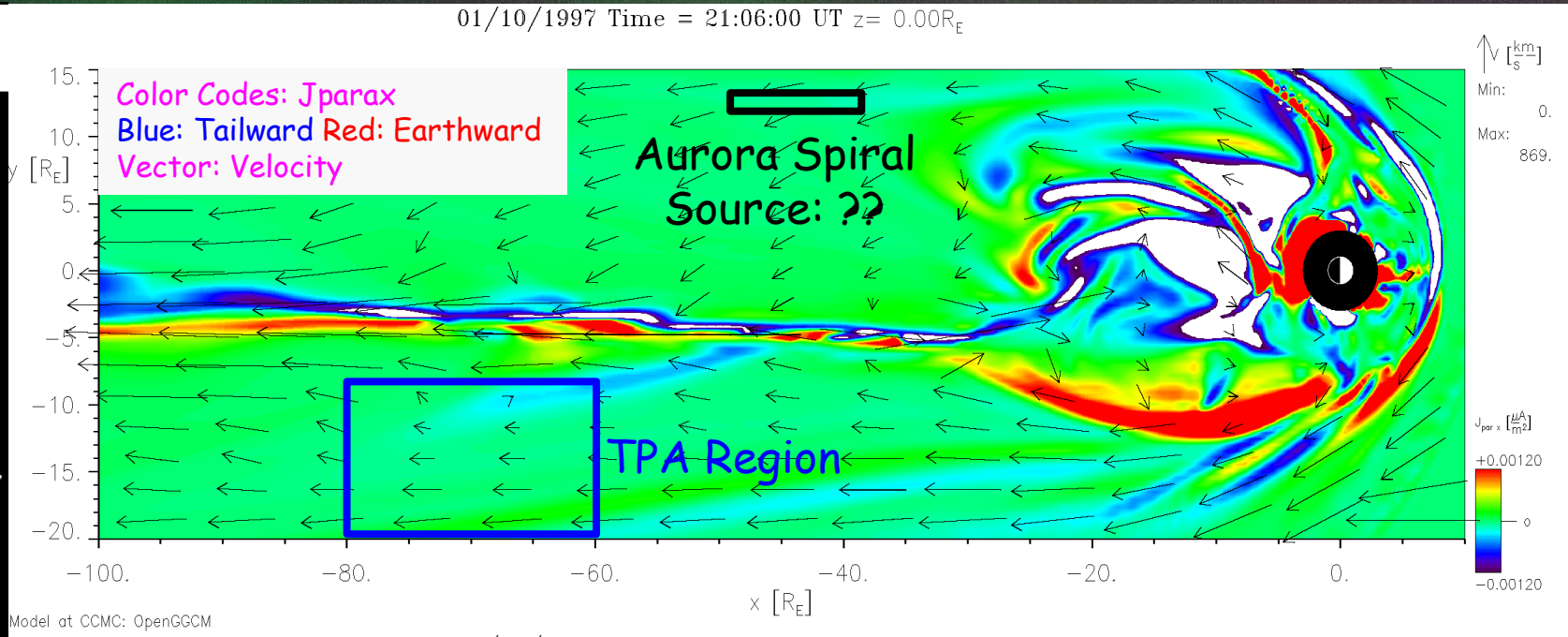
Aurora projection (mapping) onto the magnetic equatorial plane based on the Tsyganenko 96 model

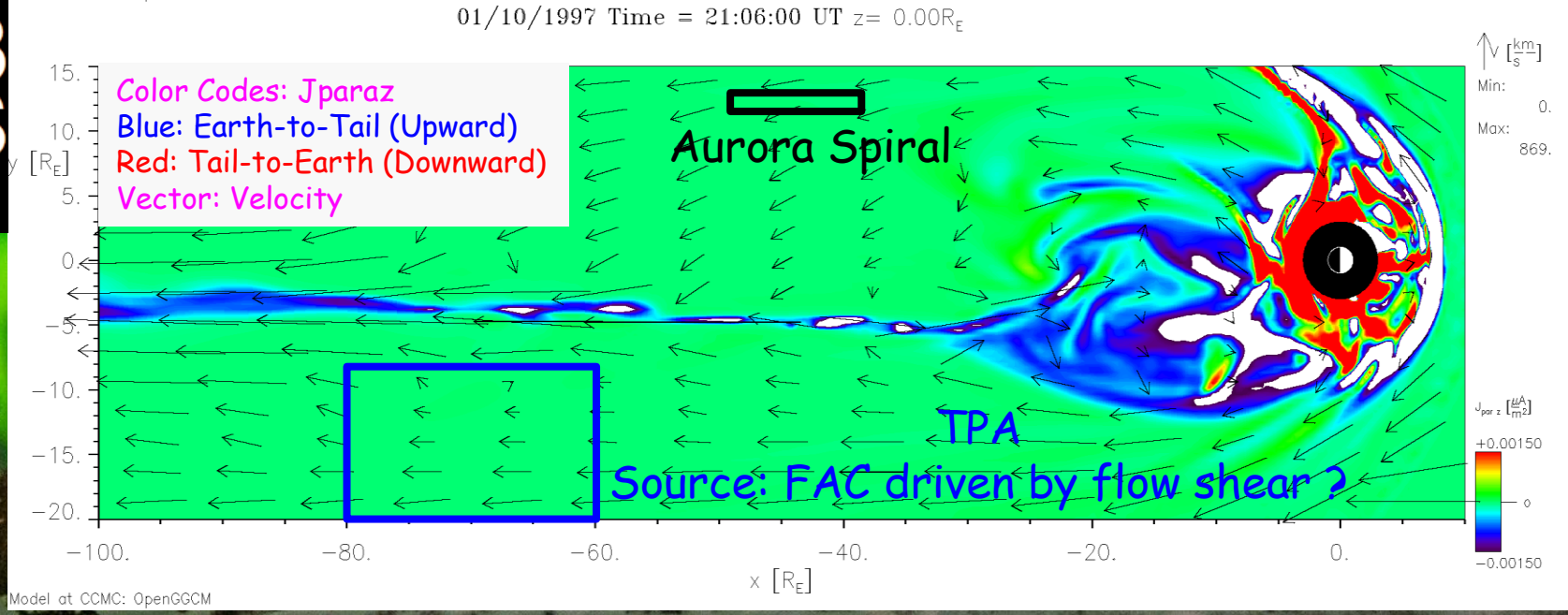
Polar UVI Observation

2106:23 UT

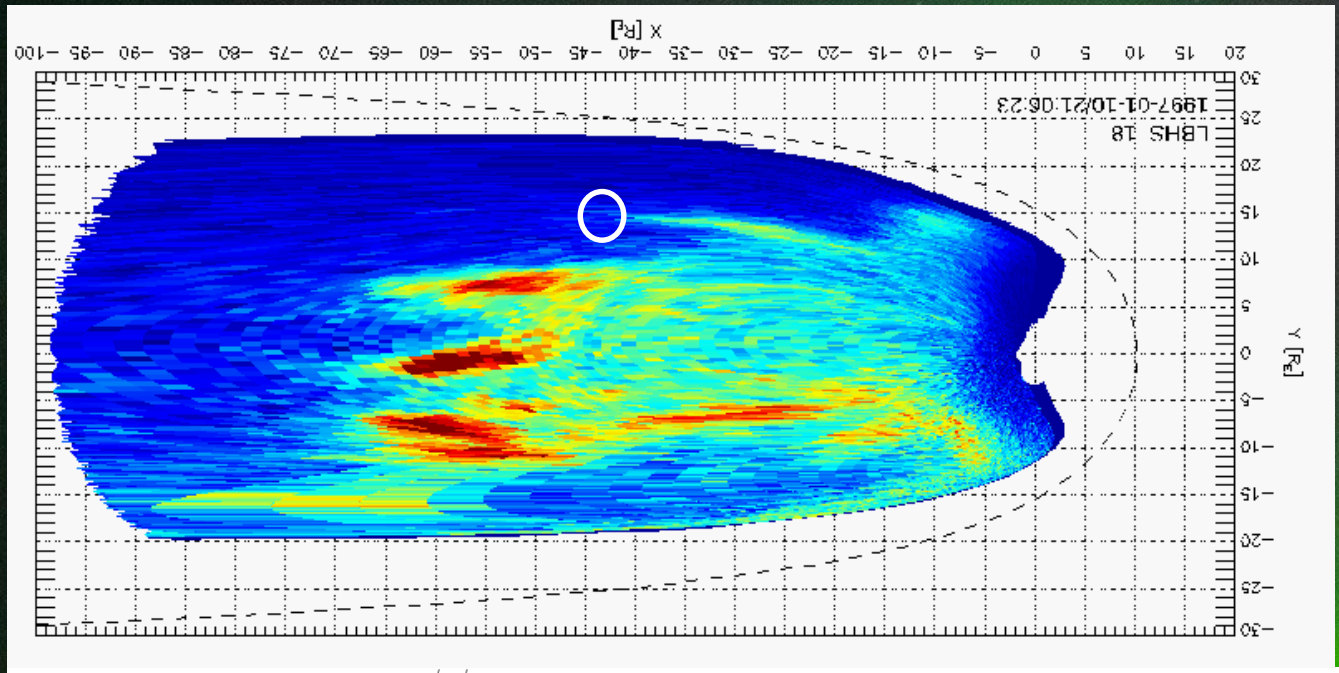


Global MHD Simulation (Open-GGCM)





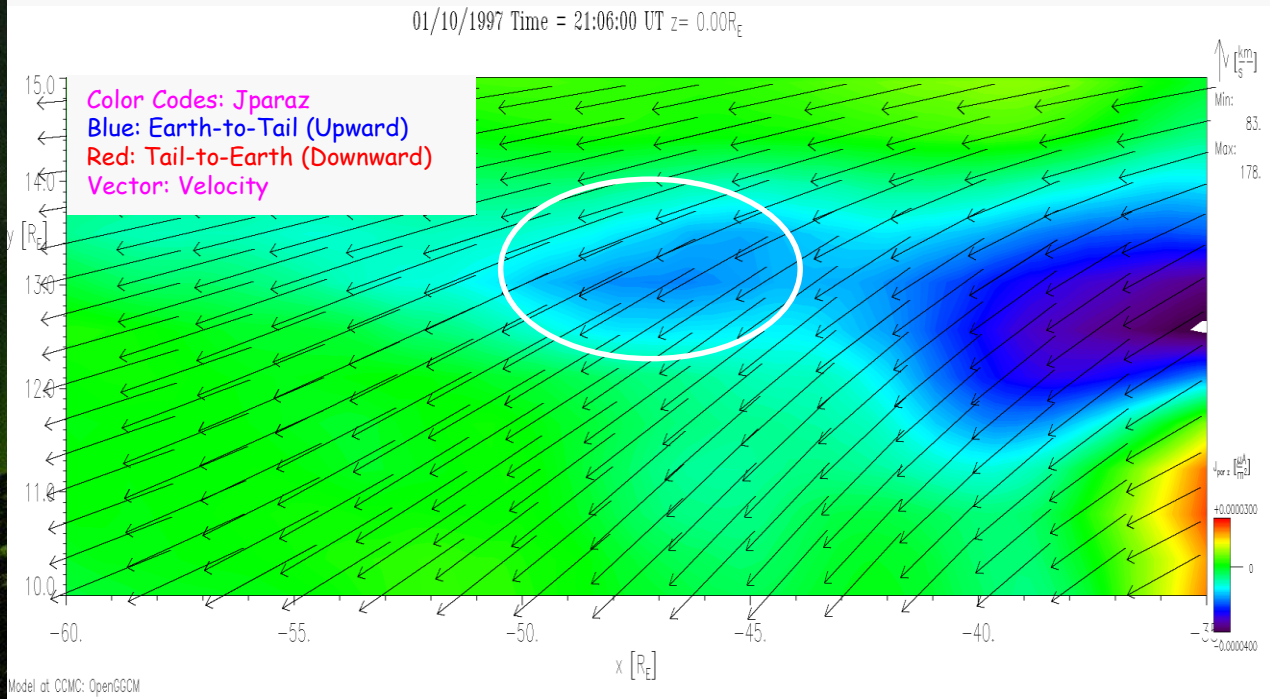
Field-aligned Current Structures Obtained by Global MHD Simulation (Open-GGCM)

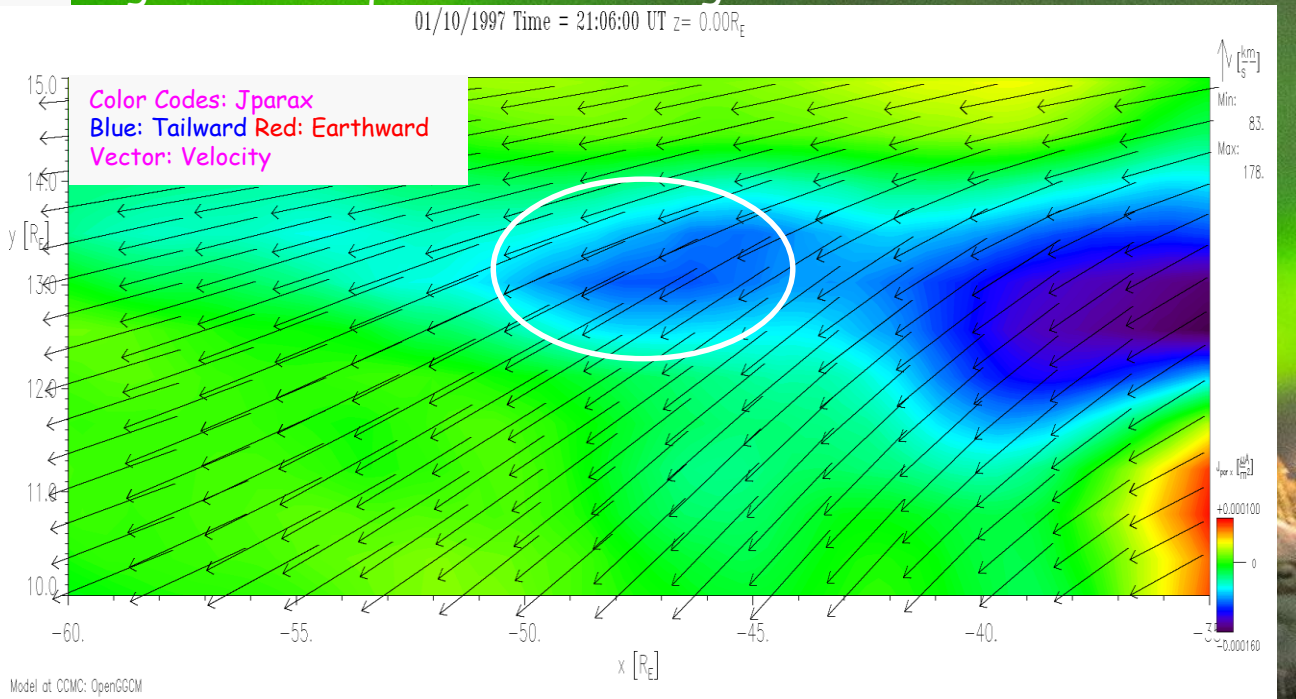


Aurora spiral dominantly consisted of **upward field-aligned current (from ionosphere to magnetotail)**.

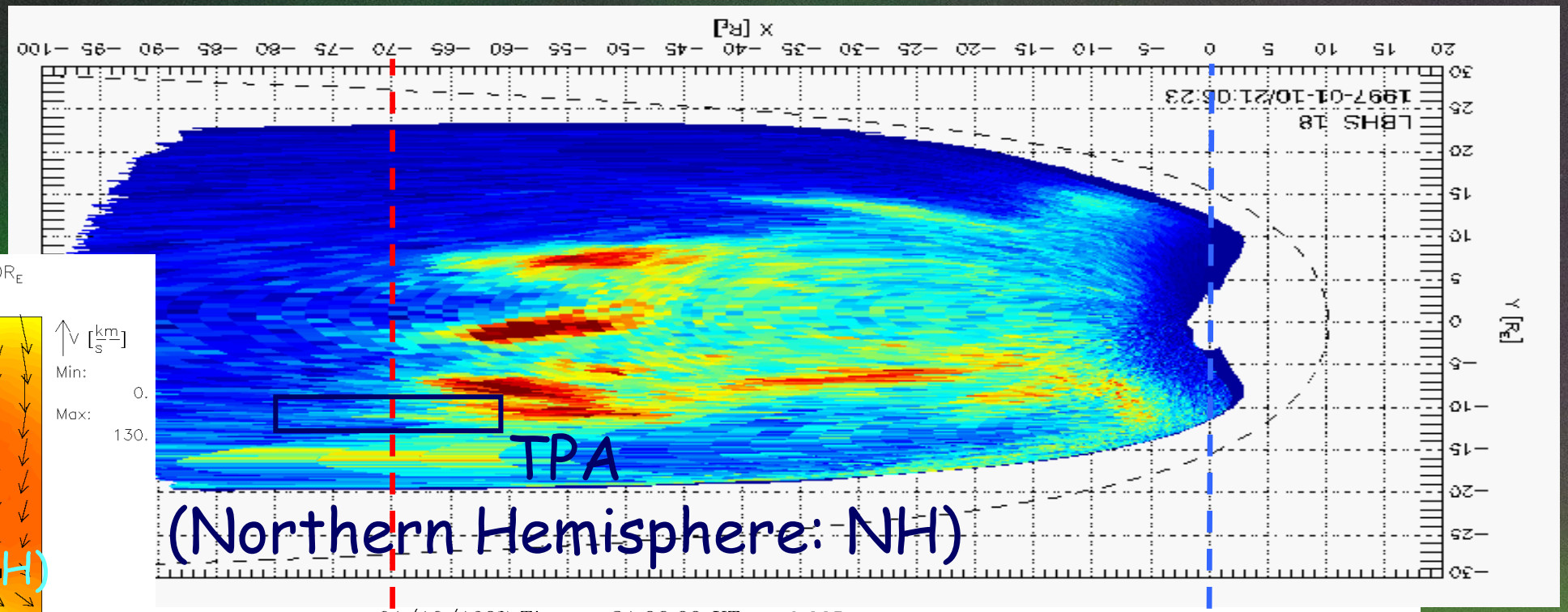
However, magnetic reconnection, which causes the fast plasma flows and resultantly generates flow shear, was **not found** in the simulation.

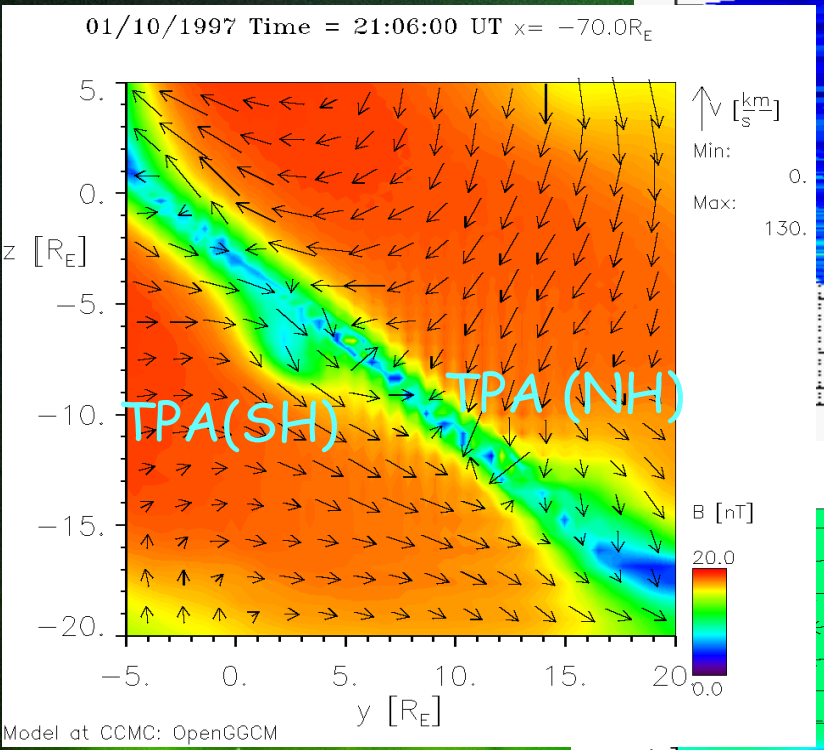
This aurora spiral may be caused by **local plasma processes (instabilities)** ?
→ Further investigations of magnetic field and plasma parameter variations around the aurora spiral source region are required based on global MHD simulations.

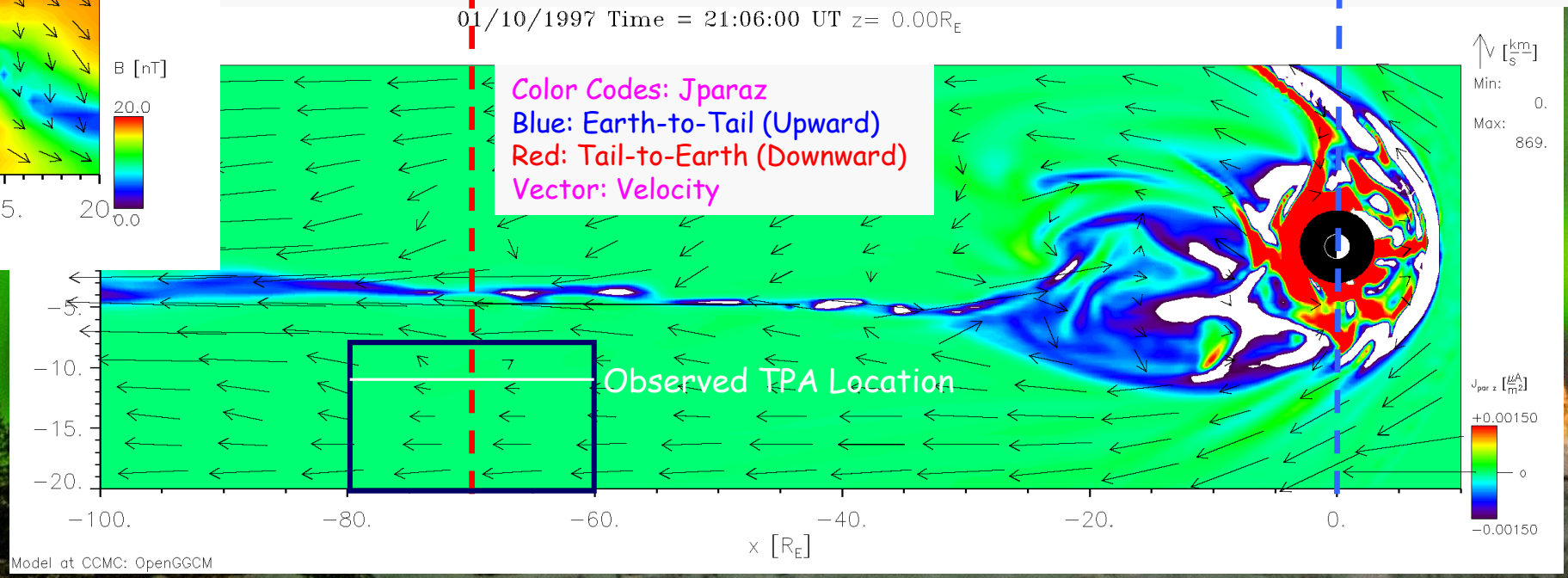




Comparison of the UVI observations projected onto the equatorial plane with the MHD simulations







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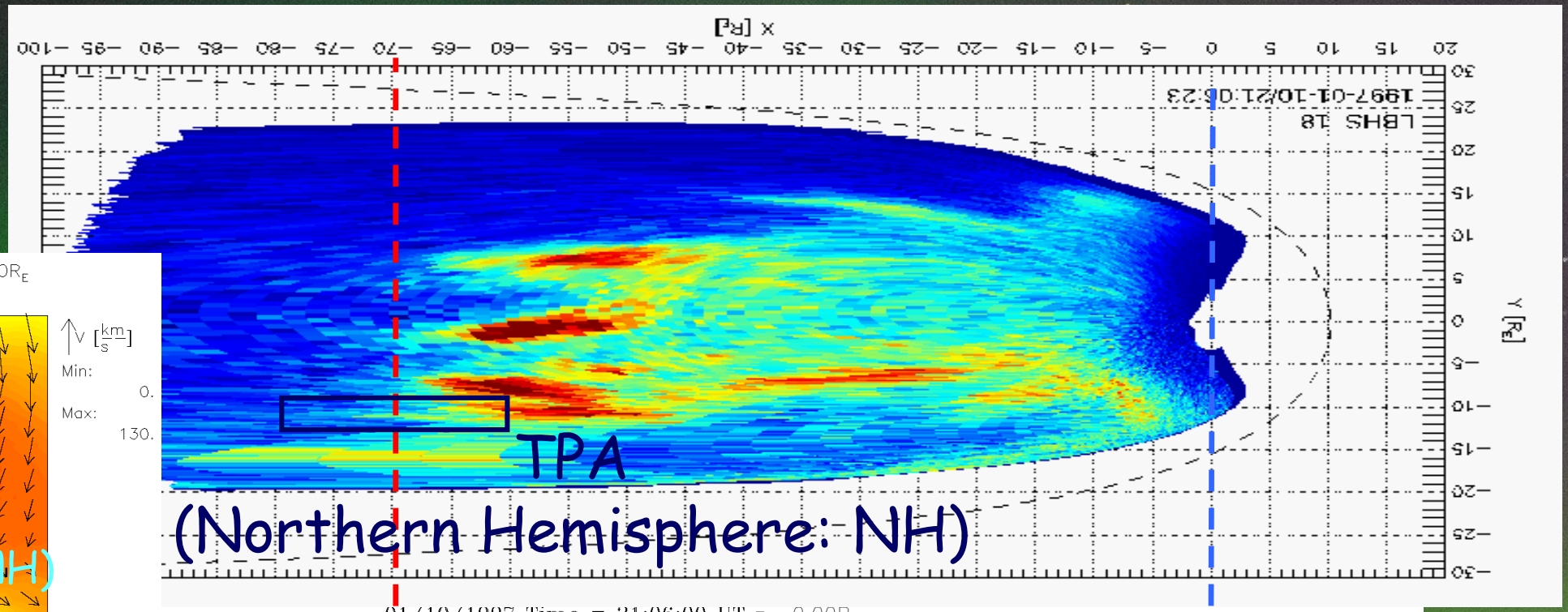
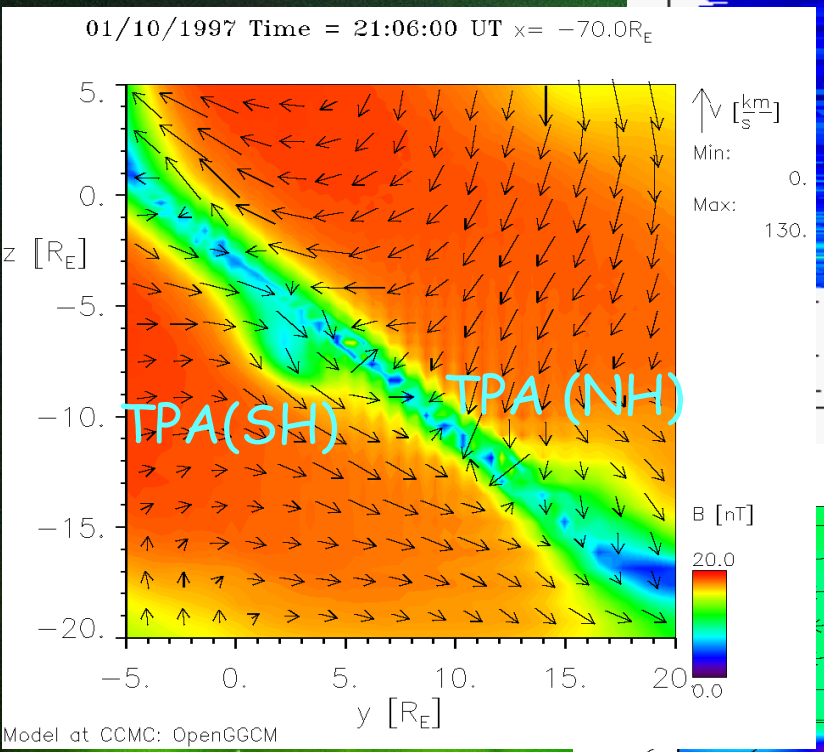
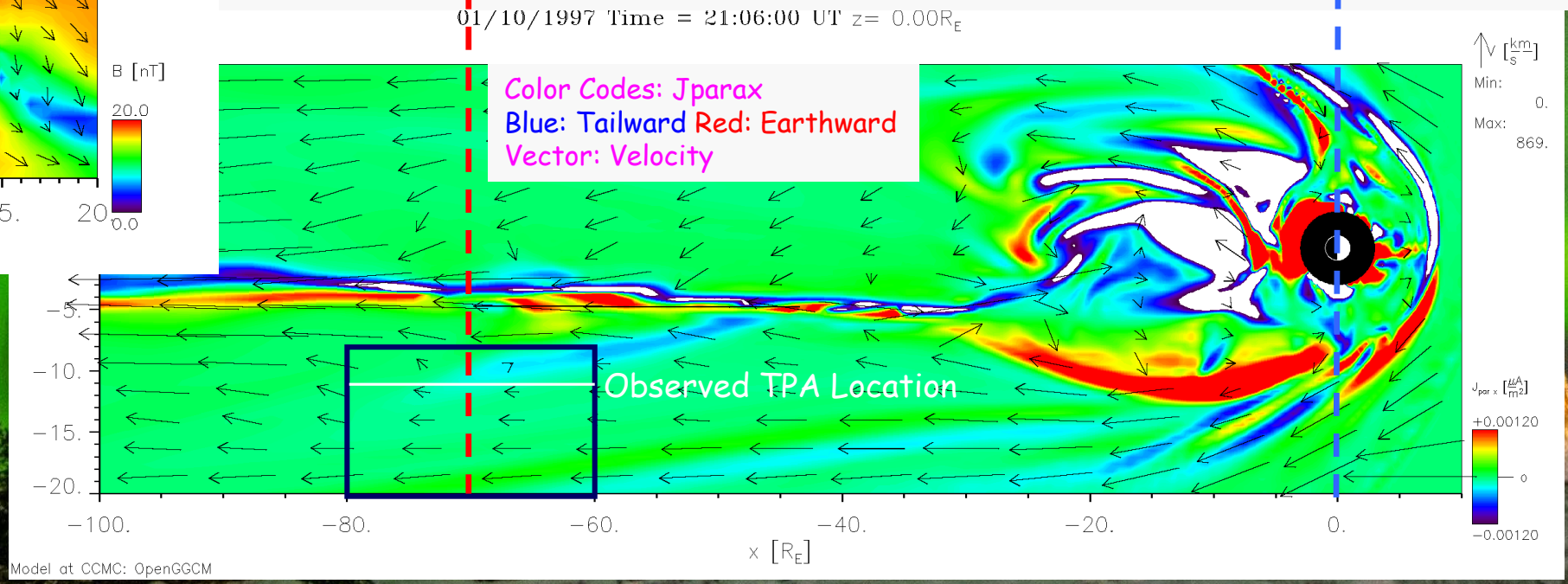
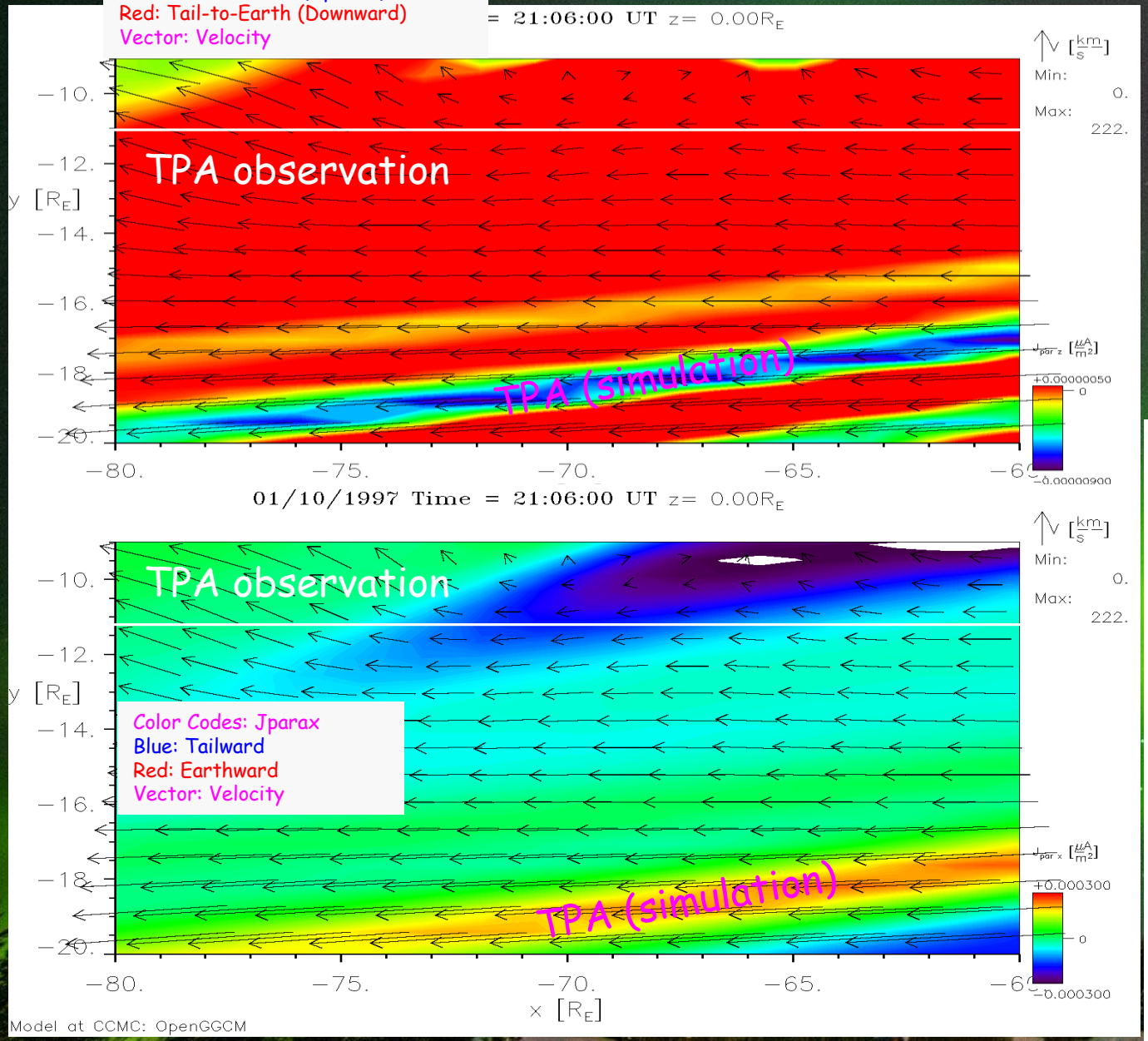




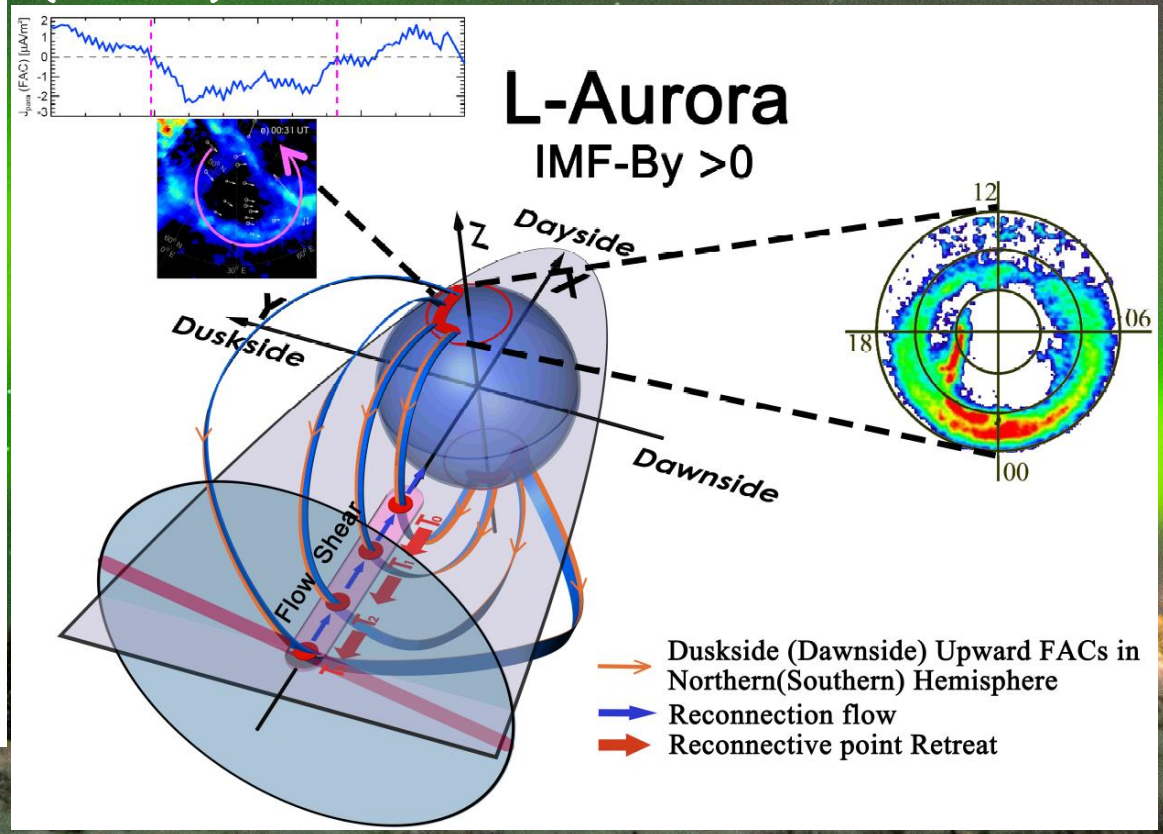


Field-aligned Current Structure of TPA (Simulation)

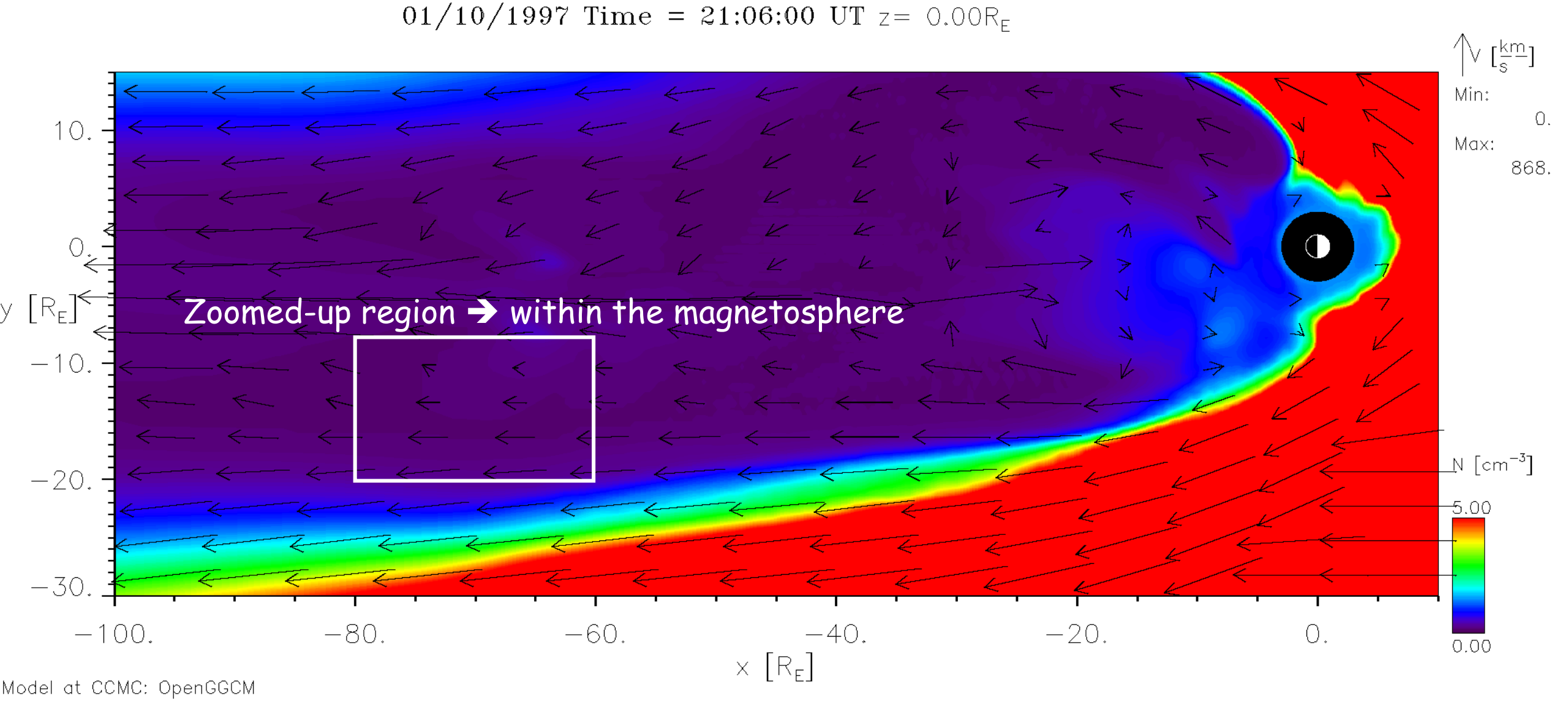


TPA was including the component of **field-aligned currents from ionosphere to tail (upward FACs).**

→ 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 ?



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 occurrences

   The 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.