GEM Tutorial: Expansion Phase Onset

Eric Donovan

(1) Back to Akasofu
(2) Some basics everyone agrees on
(3) Where the problem arises (in-out vs out-in)
(4) An example multi-onset event
(5) Challenges
(6) Conclusions

See also Kepko student sponsored tutorial, substorm sessions

Acknowledgements: Emma Spanswick, Greg Baker, Trond Trondsen, Brian Jackel, NASA, CSA, NOAA, SEL, CSSDP, The THEMIS instrument teams.

THE DEVELOPMENT OF THE AURORAL SUBSTORM

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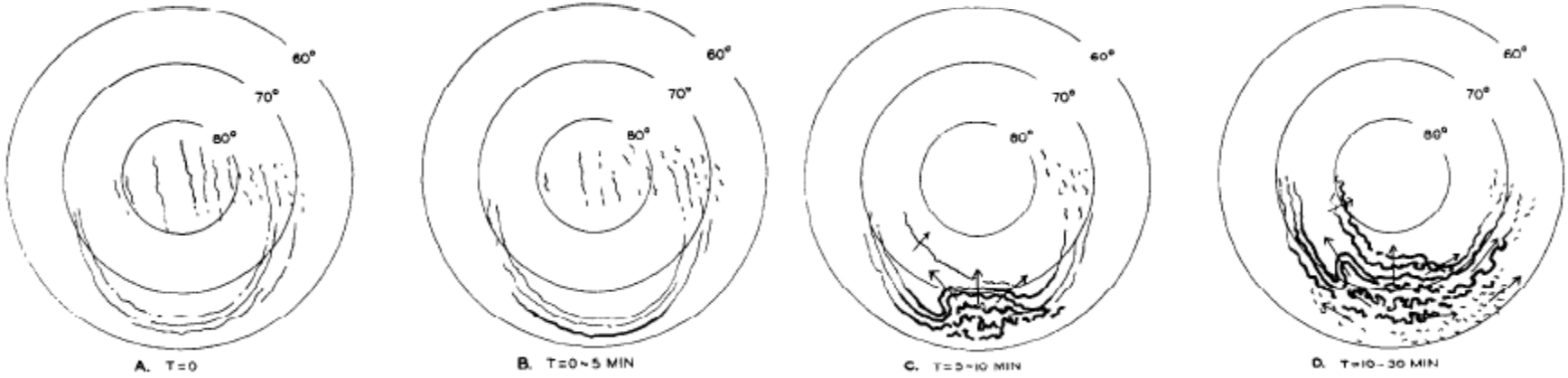
Geophysical Institute, University of Alaska, College, Alaska

(*Received* 13 *January* 1964)

Abstract—A working model of simultaneous auroral activity over the entire polar region is presented in terms of the auroral substorm. The substorm has two characteristic phases, an expansive phase and a recovery phase. Each phase is divided into three stages, and characteristic auroral displays over the entire polar region during each stage are described in detail. Further, all the major features seen at a single station are combined into a consistent picture of large-scale auroral activity.



Irrefutable: Expansion phase onset is on or near a pre-existing arc.

"… at the northern boundary of the diffuse auroras …"

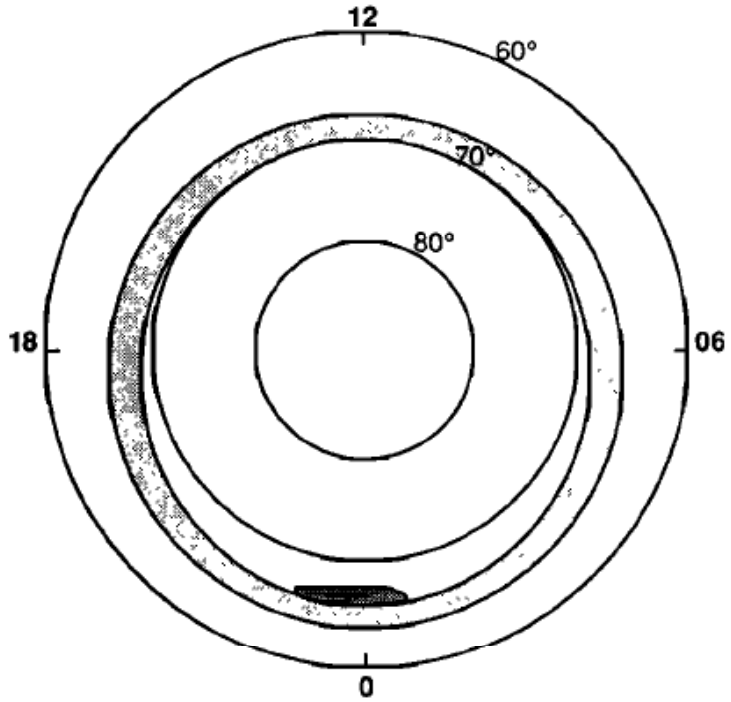
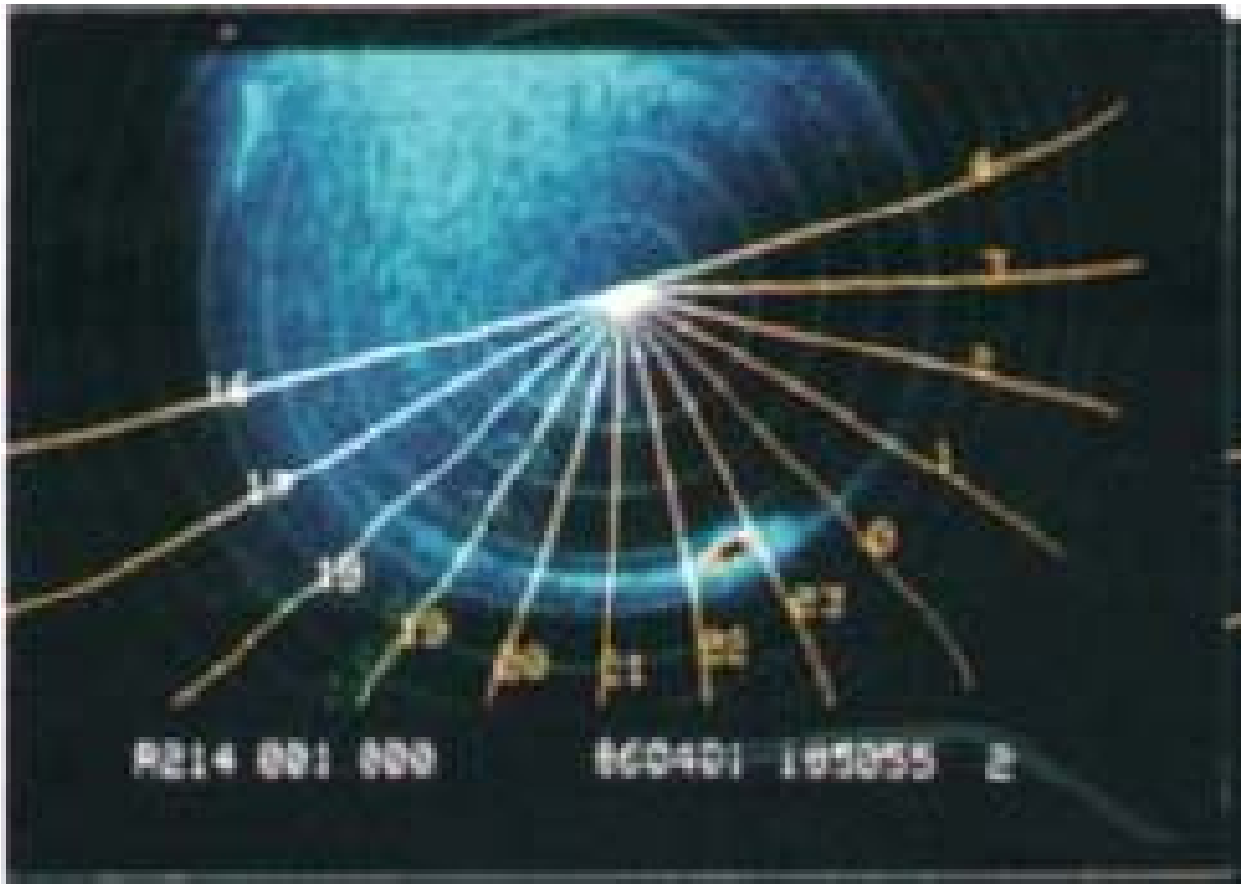


Fig. 1. Schematics adapted from *Akasofu* [1977]. (*a*) The auroral arcs as they appear at breakup, at the northern boundary of the diffuse auroras, at a magnetic latitude typically between 65° and 70°. The shaded areas indicate the regions where diffuse auroras are observed. (*b*) After breakup, the discrete auroral forms expand to the west, to the east, and to the north. At the end of the expansion phase, the discrete arcs cover a region which typically extends from 65°–70° to 75°–80° magnetic latitude.



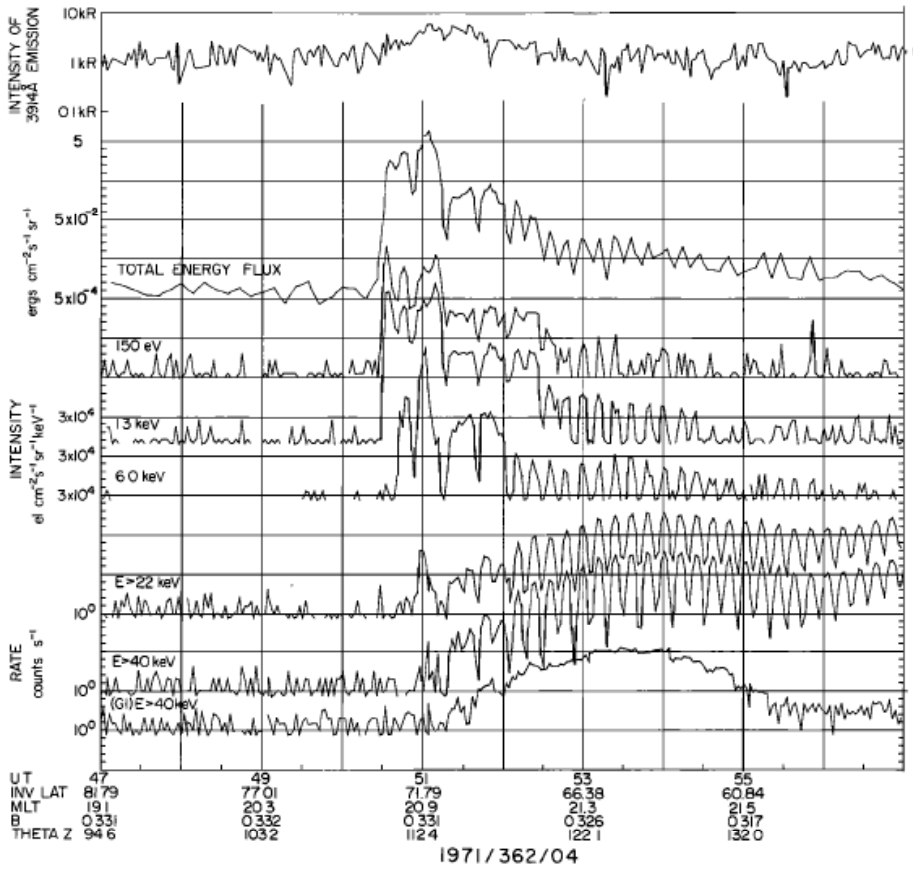


Fig. 2. The auroral emission profile and particle flux profiles along the satellite path for the Isis 2 pass between 0447 and 0457 UT on December 28, 1971. The arc (or arc system) brightening location was near the transition between CPL and BPL.

1978

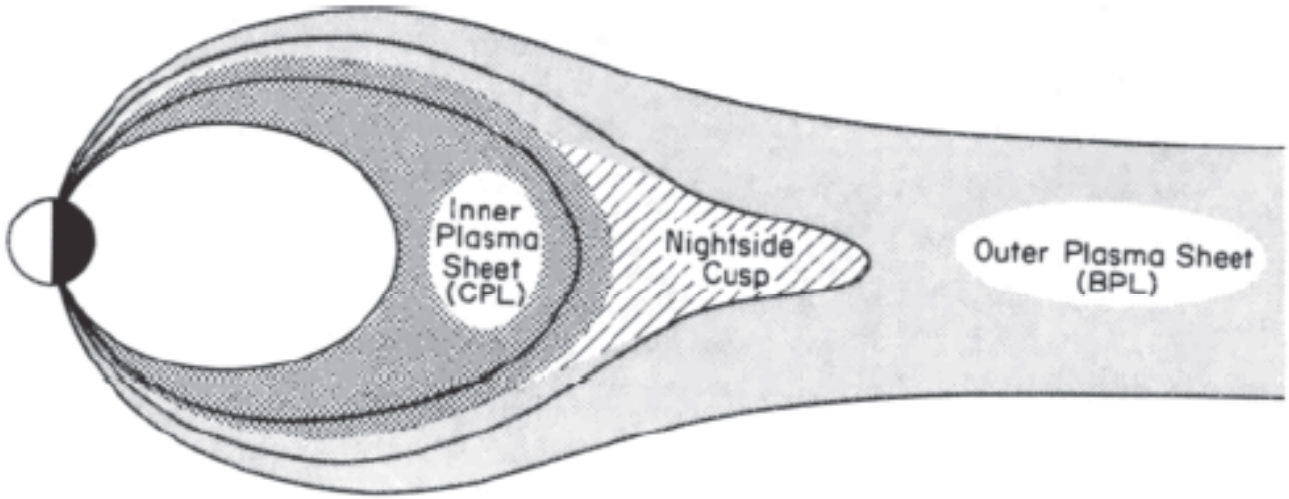


Fig. 5. A schematic diagram to illustrate the suggestion that the nightside cusp is the probable location of substorm triggering in the tail and is a transition region between the inner plasma sheet (CPL) and the outer plasma sheet (BPL).

Irrefutable: [There is a class of substorm for which] auroral onset is on field-lines threading the "night-side cusp" or region of transition between tail-like & dipolar field lines.

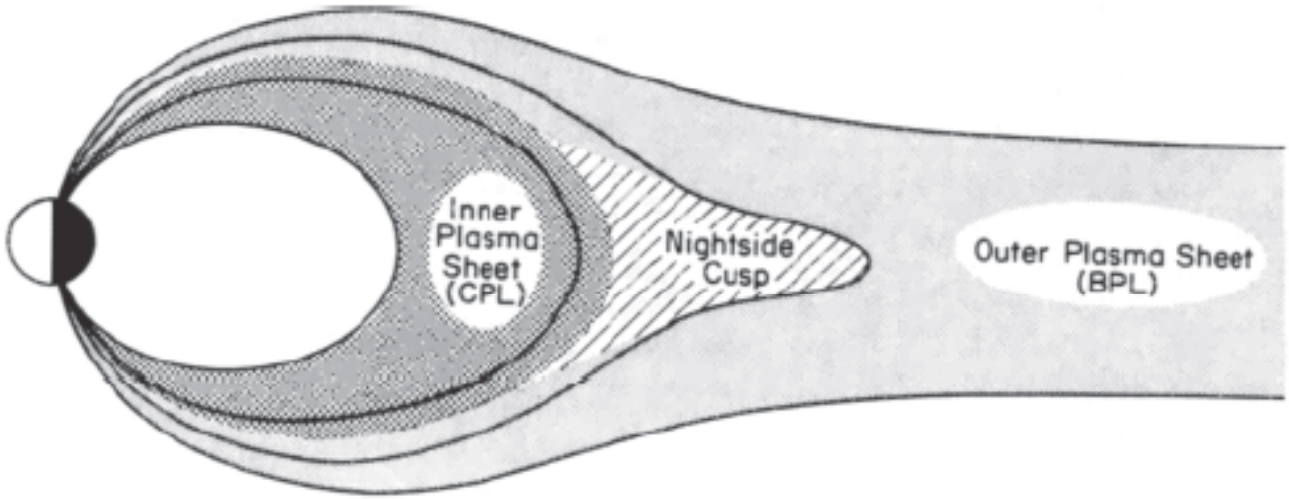


Fig. 5. A schematic diagram to illustrate the suggestion that the nightside cusp is the probable location of substorm triggering in the tail and is a transition region between the inner plasma sheet (CPL) and the outer plasma sheet (BPL).

Difficulty: We understand the substorm expansion phase onset represents a magnetotail instability. The auroral onset might mark its beginning, or might mark the start of something that is a result of expansion phase onset.

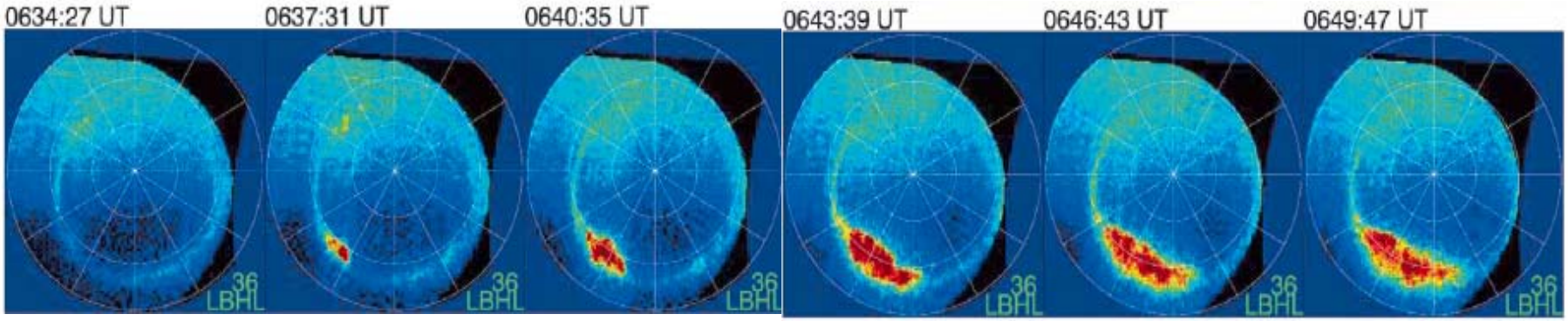
This has long been established and elaborated on in numerous subsequent published studies, four of which are listed here…

Samson, J. C., L. R. Lyons, P. T. Newell, F. Creutzberg, and B. Xu, Proton aurora and substorm intensifications, Geophys. Res. Lett., 19, 2167, 1992.

Voronkov I. O., E. F. Donovan, and J. C. Samson, Observations of the phases of the substorm, J. Geophys. Res., 108 (A2), 1073, doi:10.1029/2002JA009314, 2003.

Dubyagin, S. V., V. A. Sergeev, C. W. Carlson, S. R. Marple, T. I. Pulkkinen, and A. G. Yahnin, Evidence of near-Earth breakup location, *Geophys. Res. Lett.*, 30(6), 1282, doi:10.1029/2002GL016569, 2003.

Donovan, E., et al., Simultaneous THEMIS in situ and auroral observations of a small substorm, Geophys. Res. Lett., doi:10.1029/2008GL033794, in press, 2008.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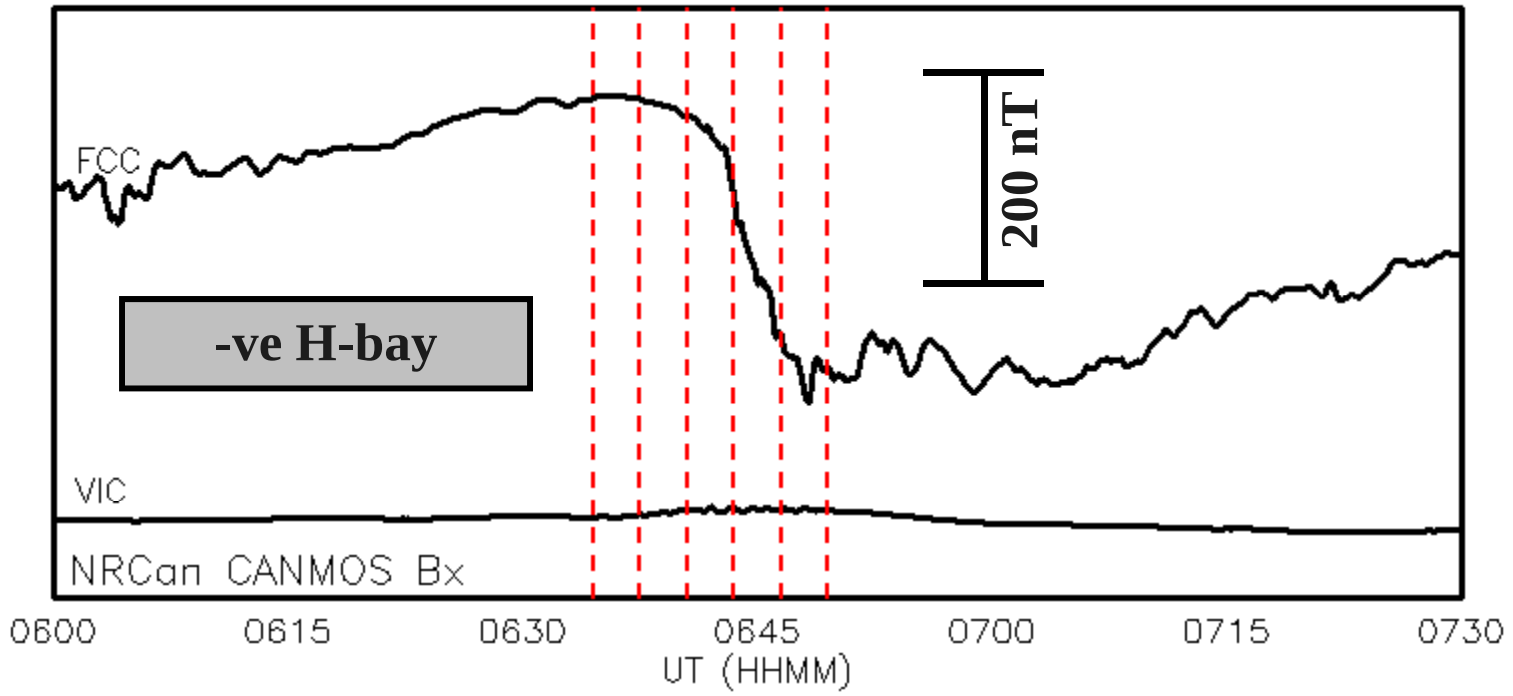
0637:31 UT
0640:35 UT
0643:39 UT
0646:43 UT
0649:47 UT
36
LBHL


FCC
200 nT
-ve H-bay
VIC
NRCan CANMOS Bx
0600
0615
0630
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0700
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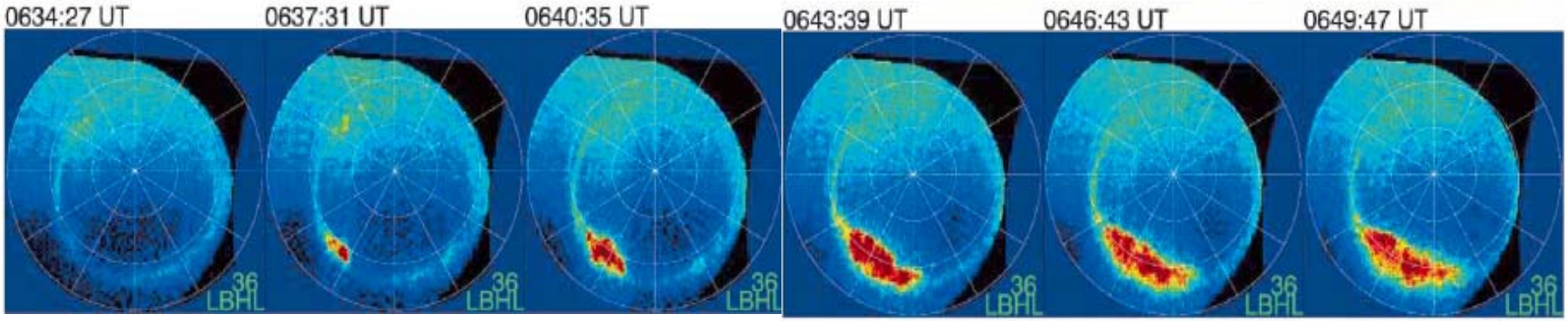
UT (HHMM)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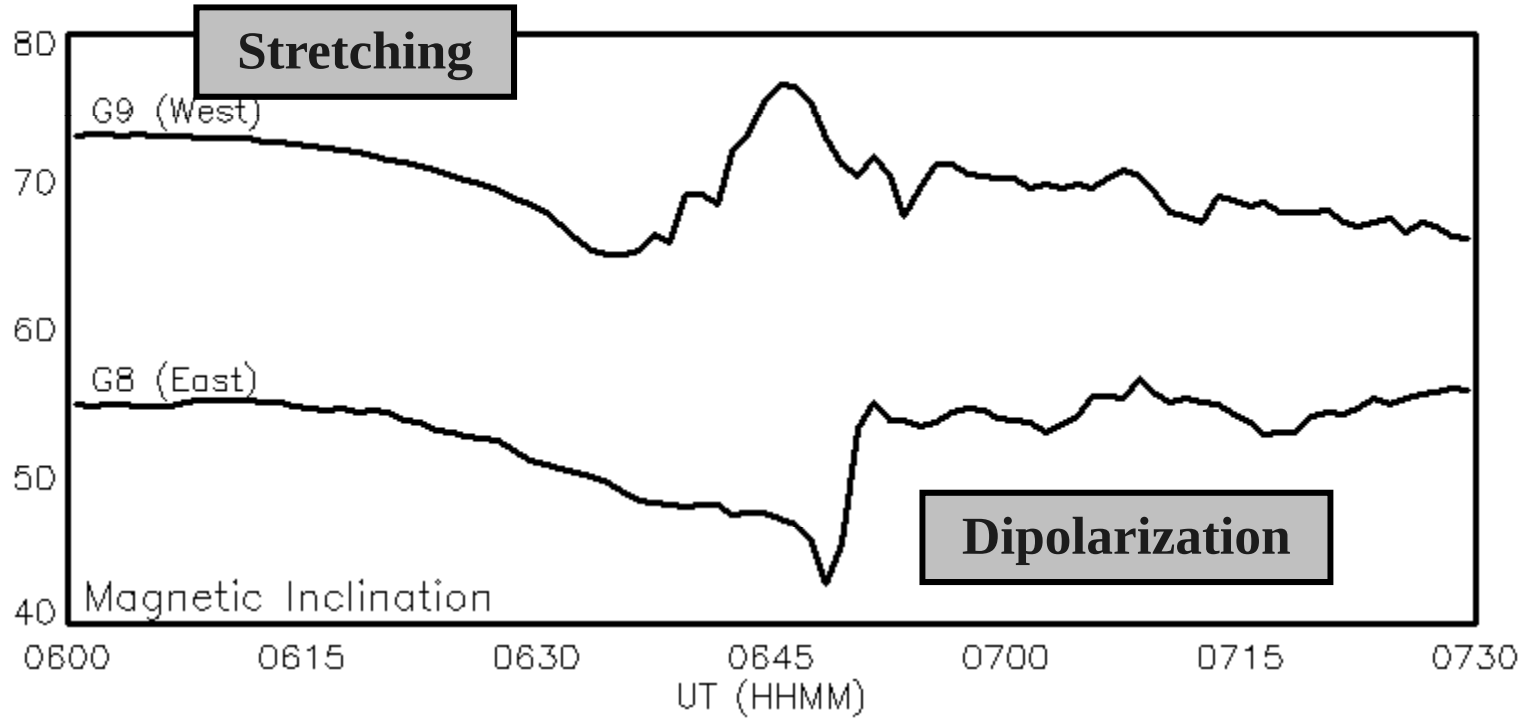
LBHL


Stretching
G9 (West)
G8 (East)
Dipolarization
Magnetic Inclination
80
70
60
50
40
0600
0615
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0700
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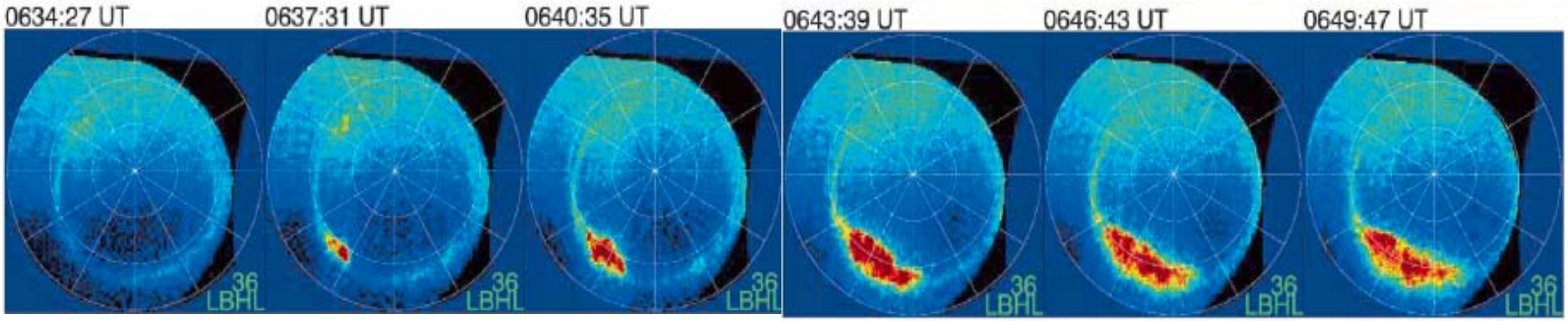
0730
UT (HHMM)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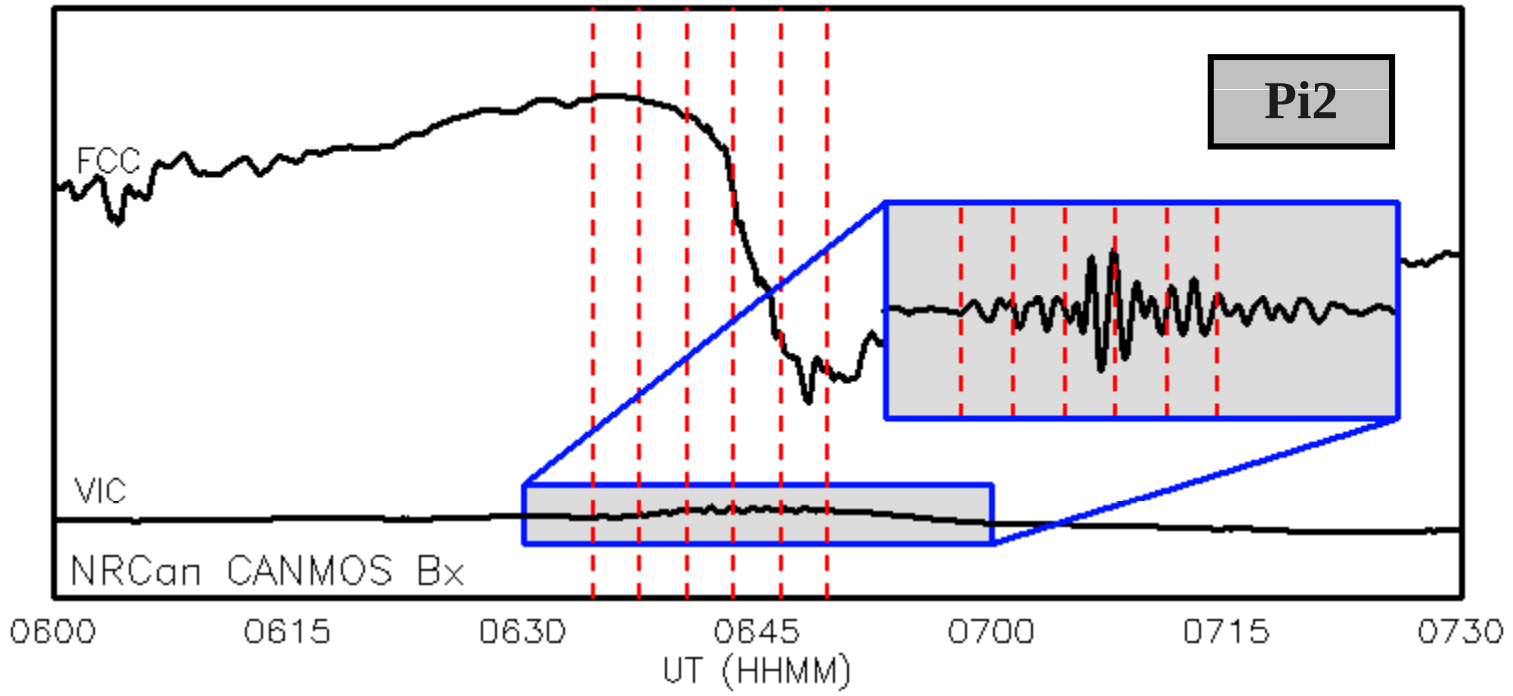
36
LBHL


Pi2
FCC
VIC
NRCan CANMOS Bx
0600
0615
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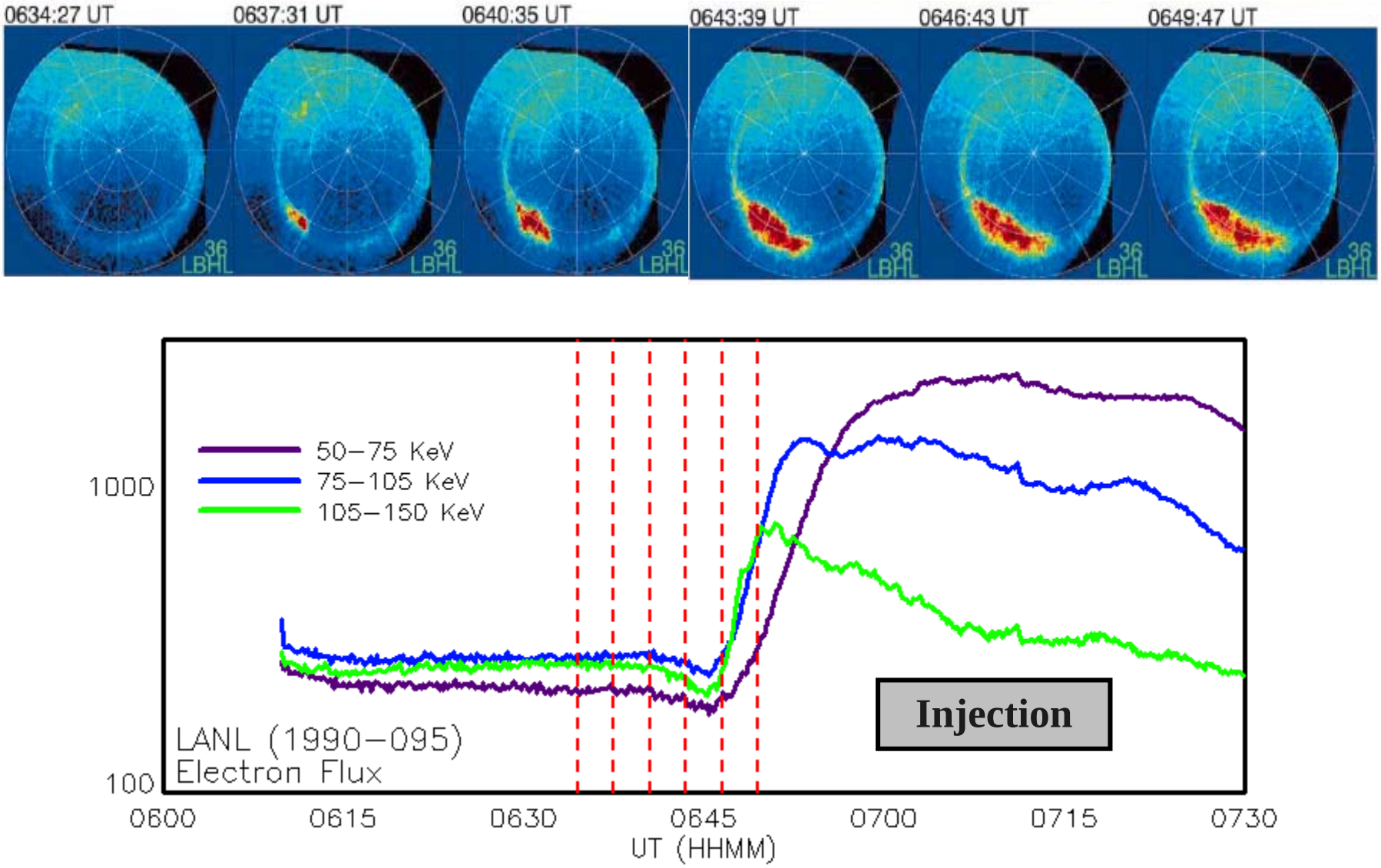
UT (HHMM)


0634:27 UT
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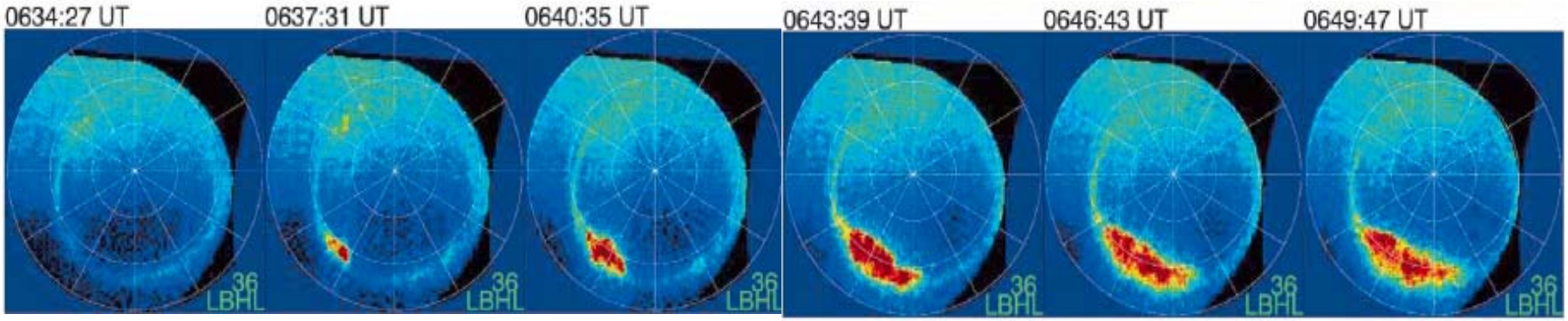
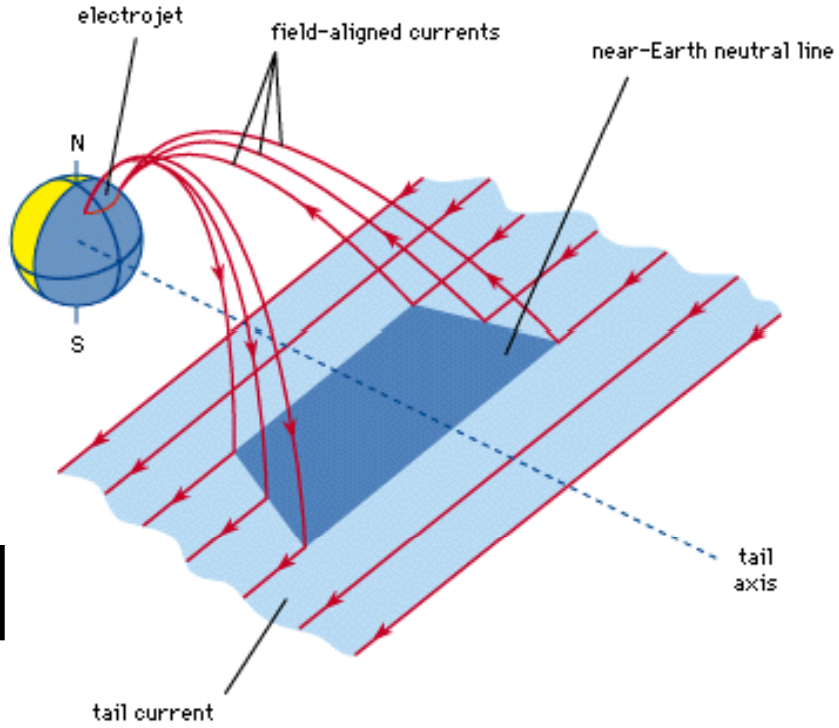
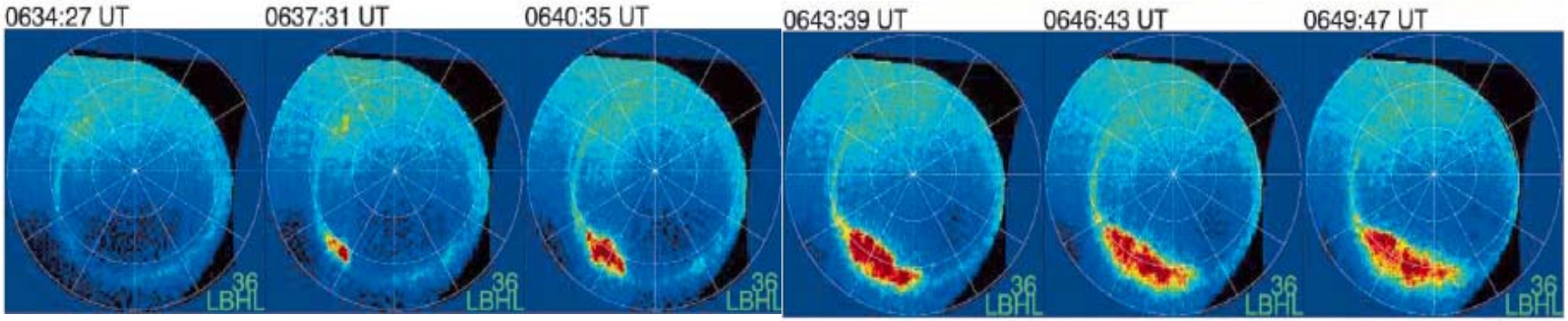
LBHL
50–75 KeV
75–105 KeV
105–150 KeV
1000
100
LANL (1990–095)
Electron Flux
Injection
0600
0615
0630
0645
0700
0715
0730
UT (HHMM)





Current Wedge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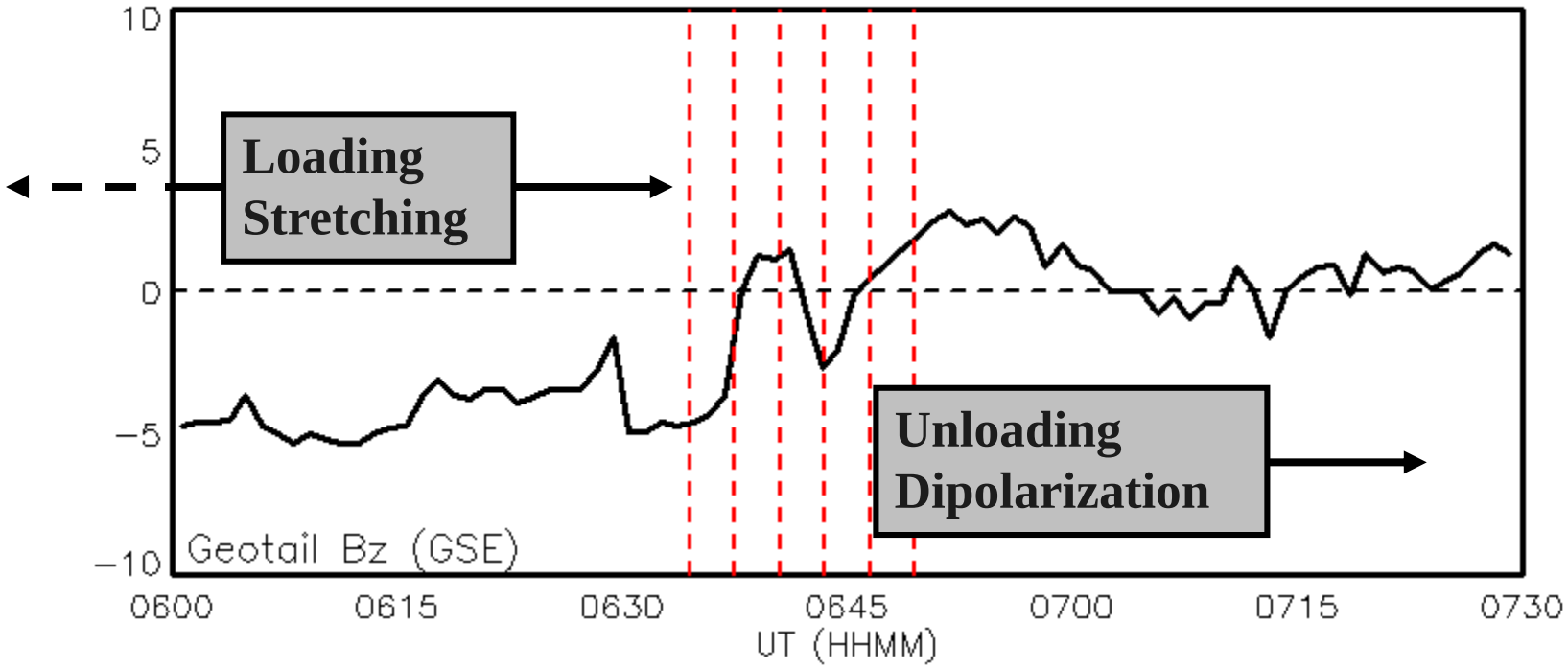
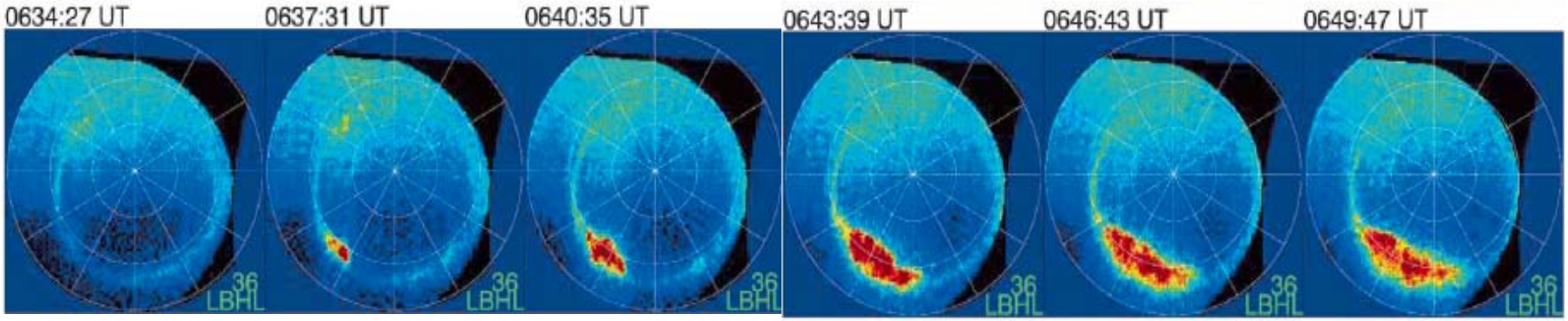
LBHL


10
5
0
−5
−10
Loading
Stretching
Unloading
Dipolarization
Geotail Bz (GSE)
0600
0615
0630
0645
0700
0715
0730
UT (HHMM)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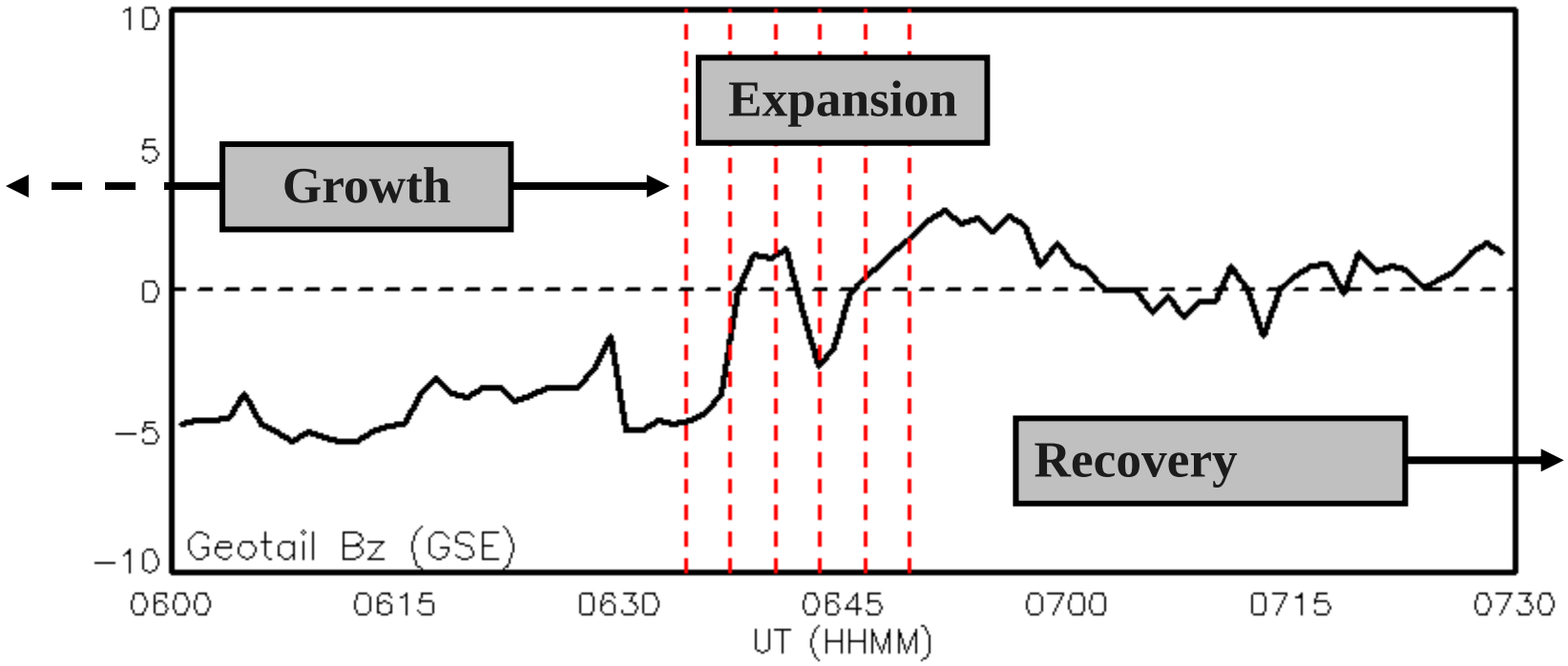
LBHL


10
5
0
−5
−10
Expansion
Growth
Recovery
Geotail Bz (GSE)
0600
0615
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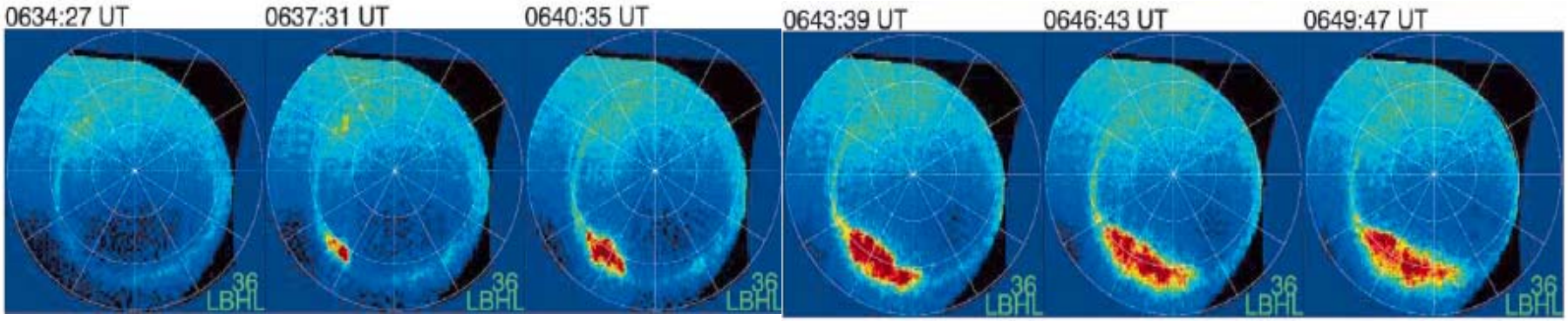
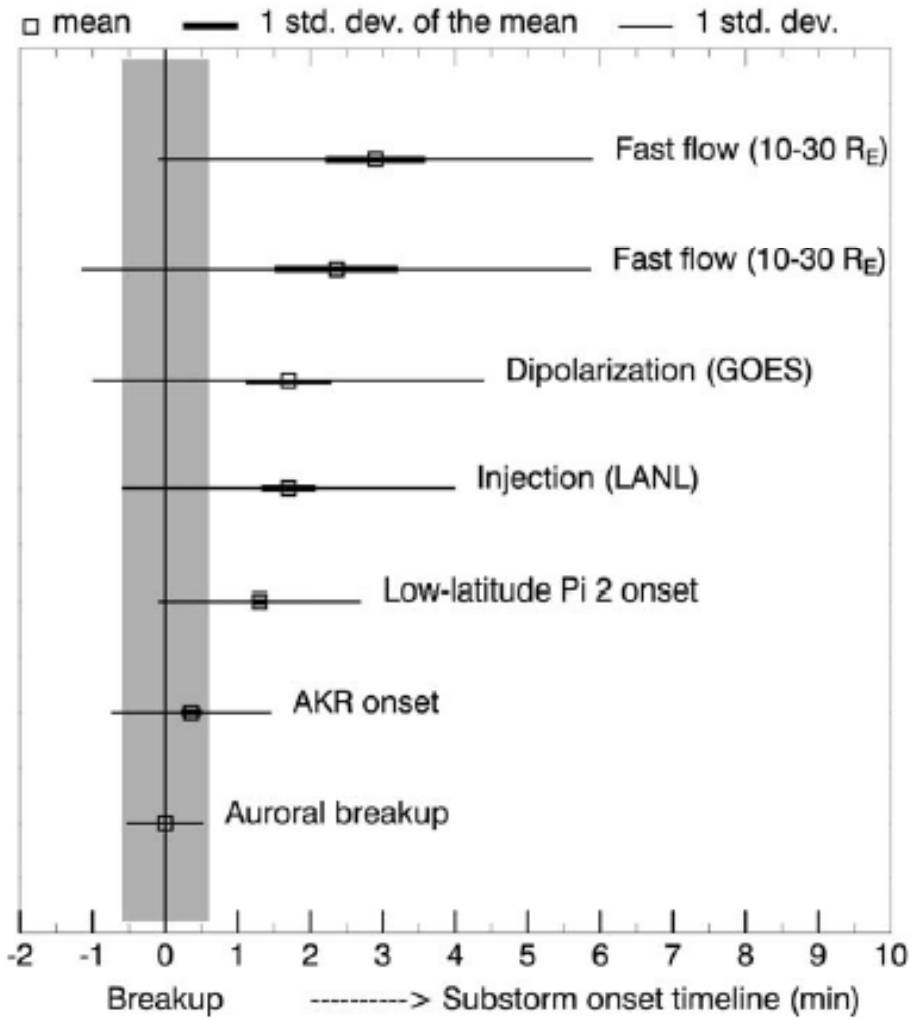
0645
0700
0715
0730
UT (HHMM)

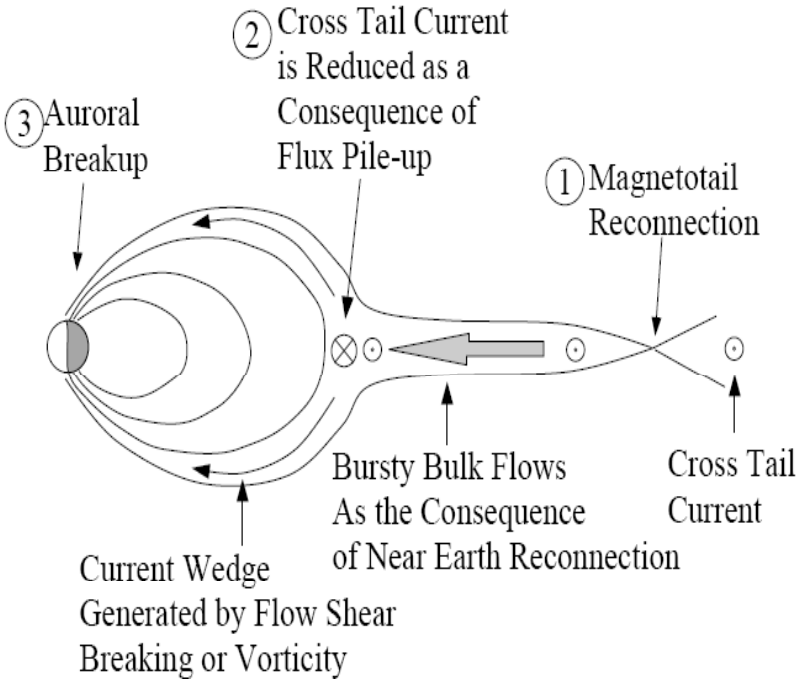


Ionospheric & Magnetospheric things that happen around onset…

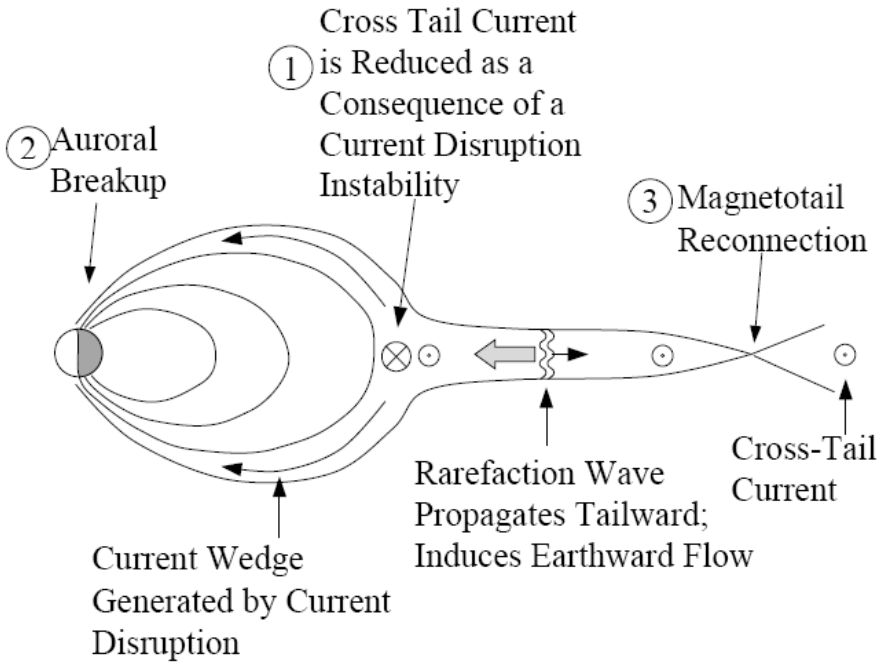
Auroral Brightening	-ve H-bay	Pi2
AKR	SAPS	Absorption Spike
Absorption Bay	VHF Burst	Injection
Pi1B	Auroral Breakup	BBF
BBF Braking	Convection Pulses	Dipolarization
Current Disruption	Current Diversion	Current Wedge
NENL Formation	Lobe Flux Reconnection	


mean
1 std. dev. of the mean
1 std. dev.
Fast flow (10-30 R_E)
Fast flow (10-30 R_E)
Dipolarization (GOES)
Injection (LANL)
Low-latitude Pi 2 onset
AKR onset
Auroral breakup
-2 -1 0 1 2 3 4 5 6 7 8 9 10
Breakup
----------> Substorm onset timeline (min)

What causes substorm expansion phase onset?

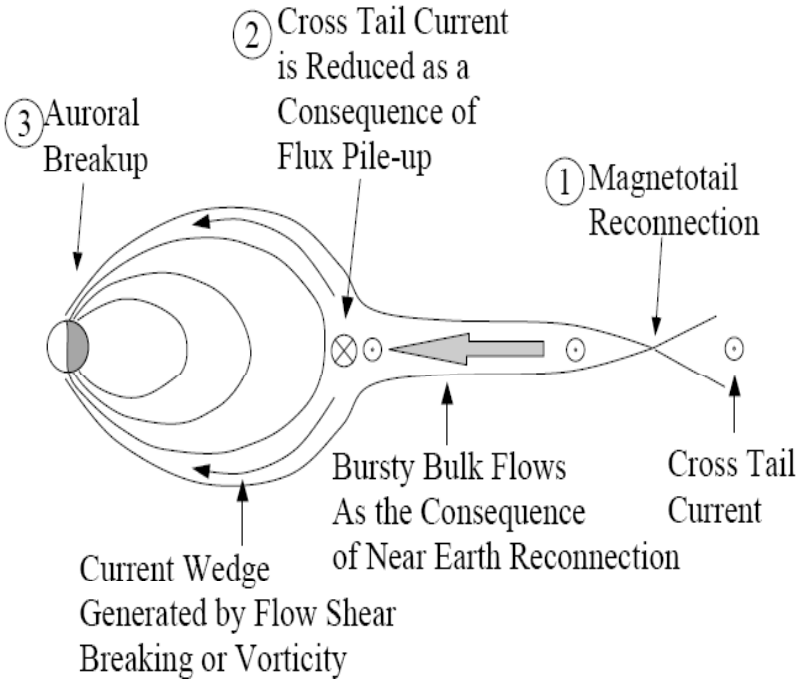


Near-Earth Neutral Line

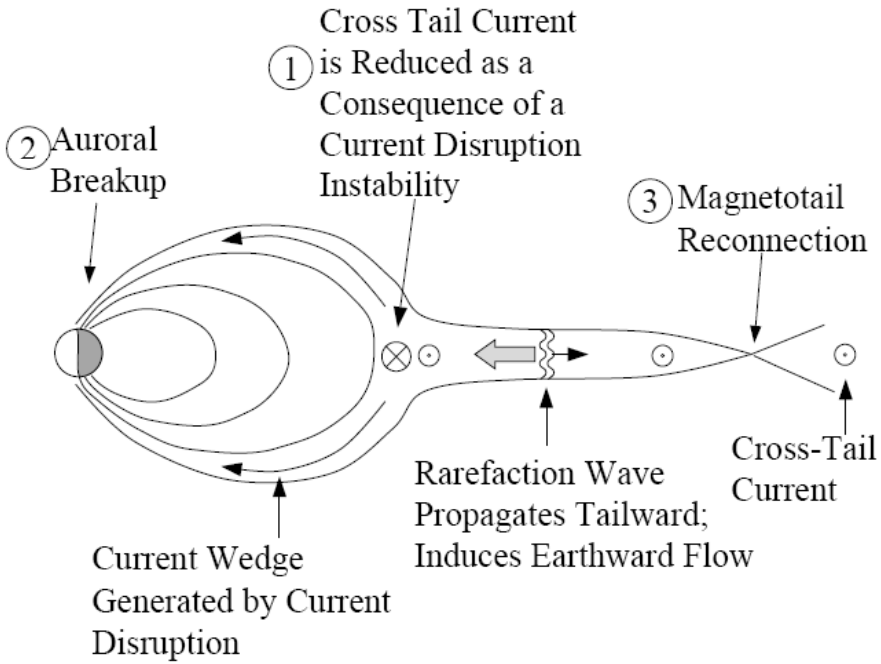


Current Disruption

What causes substorm expansion phase onset?

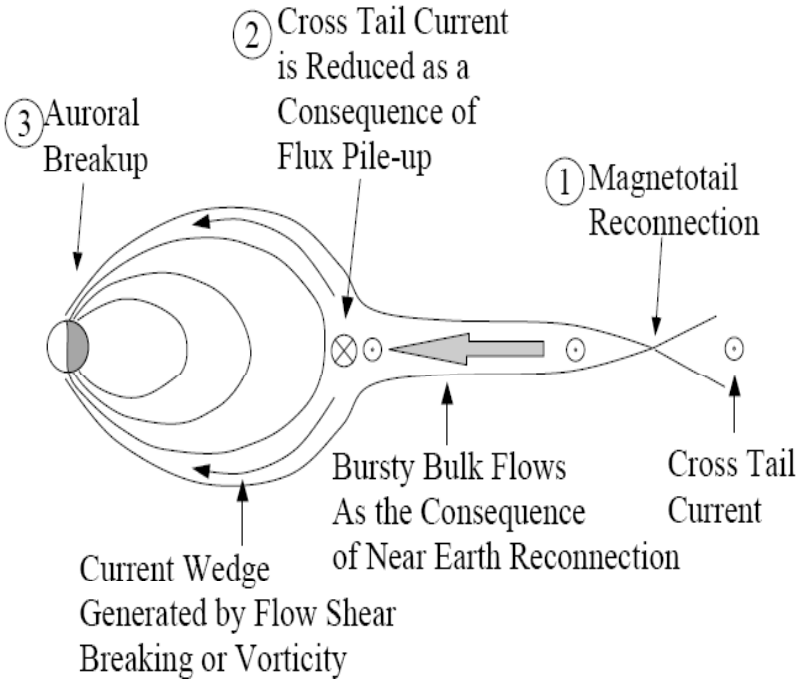


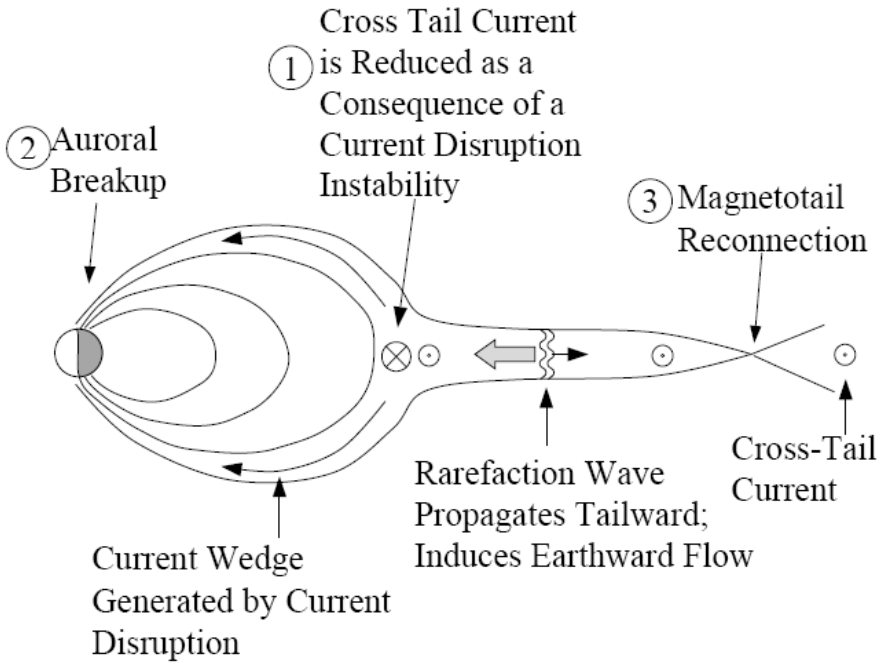
"Out-In"



"In-Out"

What causes substorm expansion phase onset?



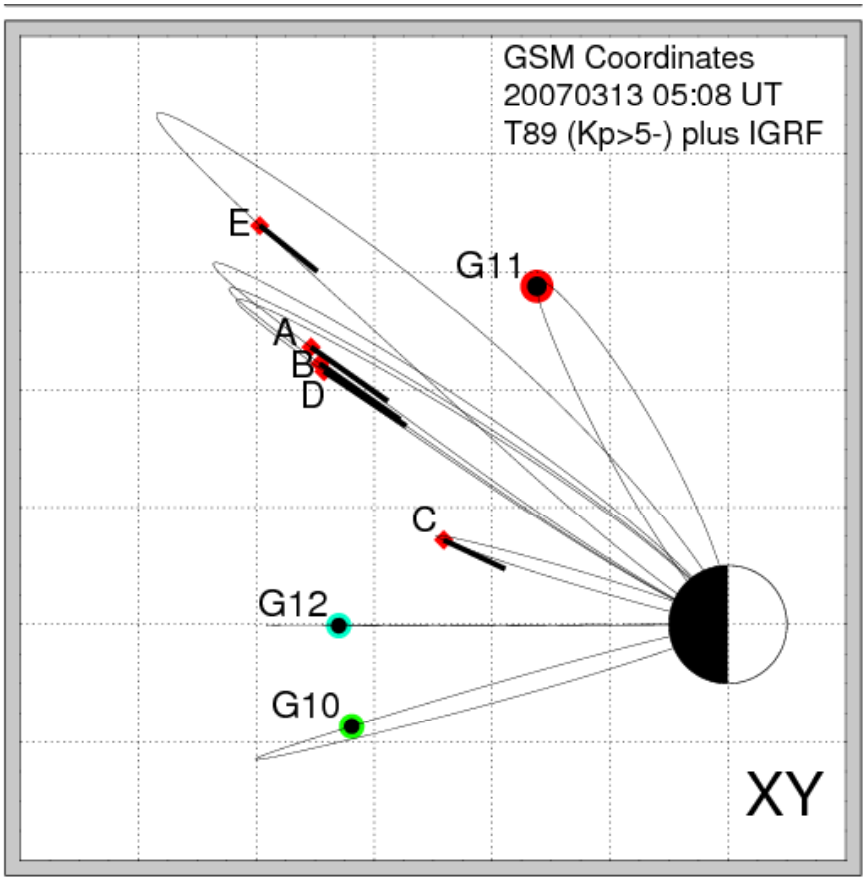


"Out-In"

In the TCS away from the dipolar region… NENL

"In-Out"

In the transition between the TCS and the dipolar region… CD (CLI) or Ballooning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20070313 05:08 UT
T89 (Kp>5-) plus IGRF
E
G11
A
B
D
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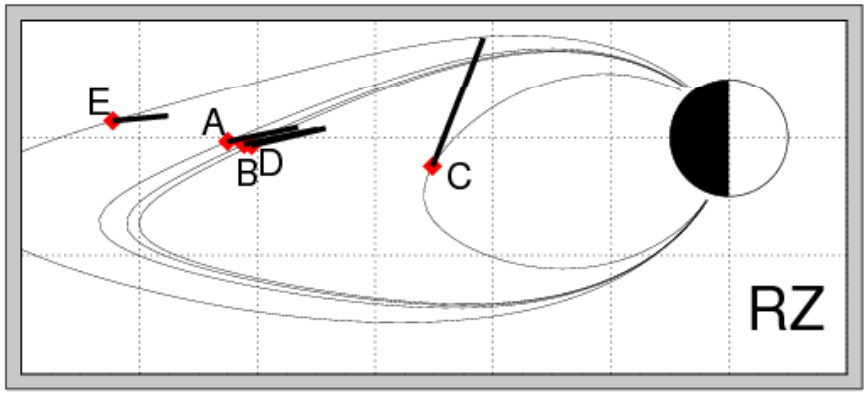
G12
G10
XY


E
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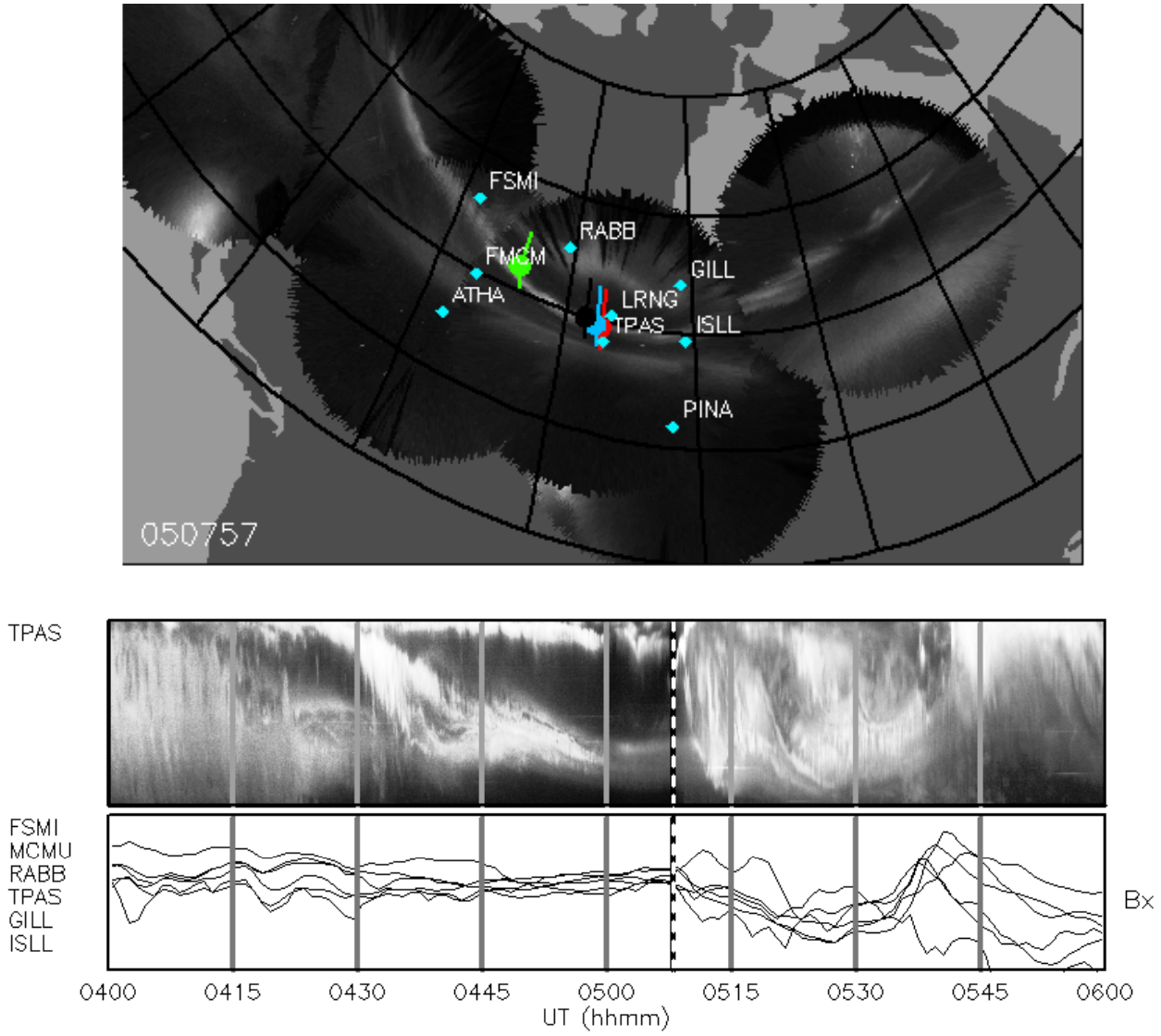
FSMI
RABB
FMCM
GILL
ATHA
LRNG
TPAS
ISLL
PINA
050757
TPAS
FSMI
MCMU
RABB
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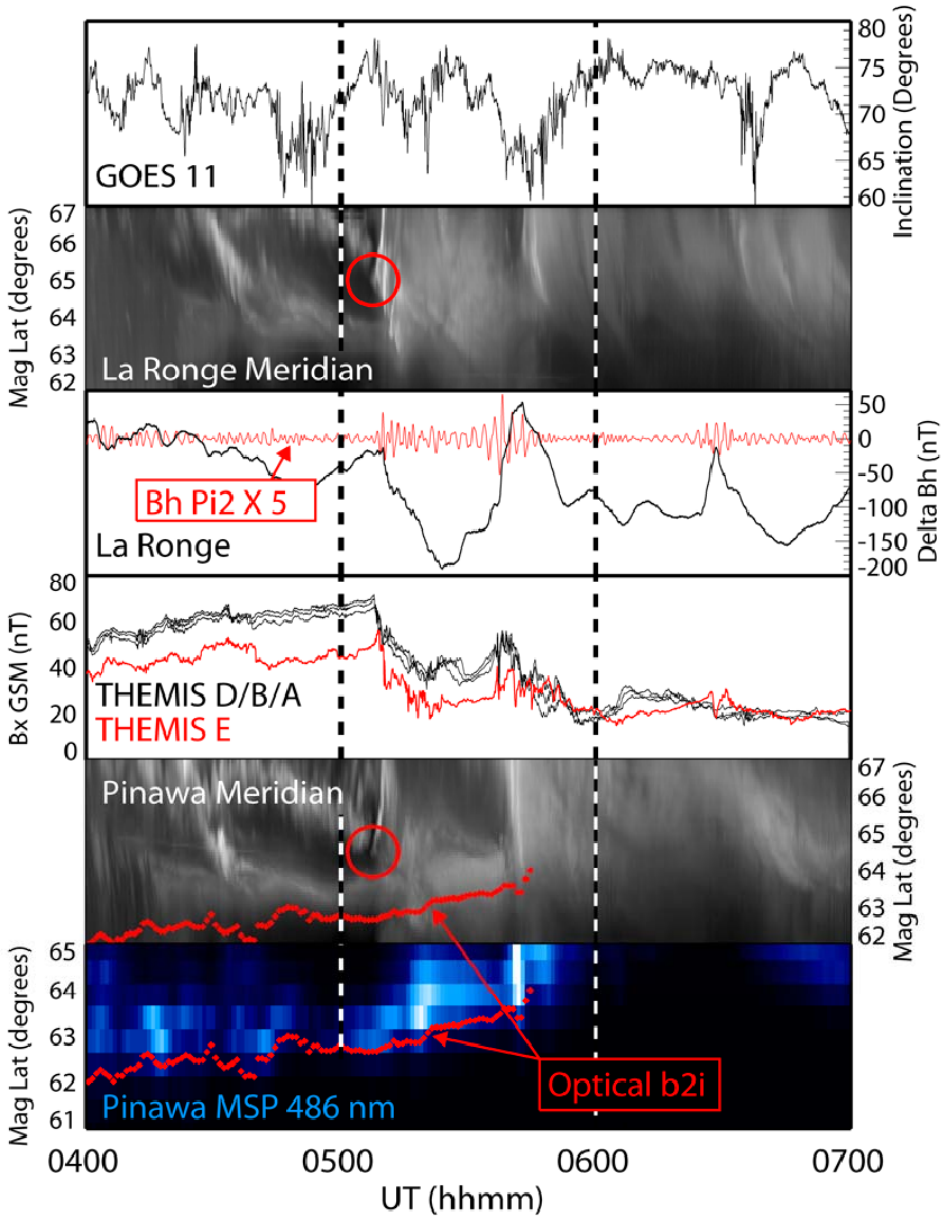
0545
0600
UT (hhmm)


GOES 11
Inclination (Degrees)
80
75
70
65
60
Mag Lat (degrees)
67
66
65
64
63
62
La Ronge Meridian
Bh Pi2 X 5
La Ronge
50
0
-50
-100
-150
-200
Delta Bh (nT)
Bx GSM (nT)
80
60
40
20
0
THEMIS D/B/A
THEMIS E
Pinawa Meridian
Mag Lat (degrees)
65
64
63
62
61
Pinawa MSP 486 nm
Optical b2i
0400
0500
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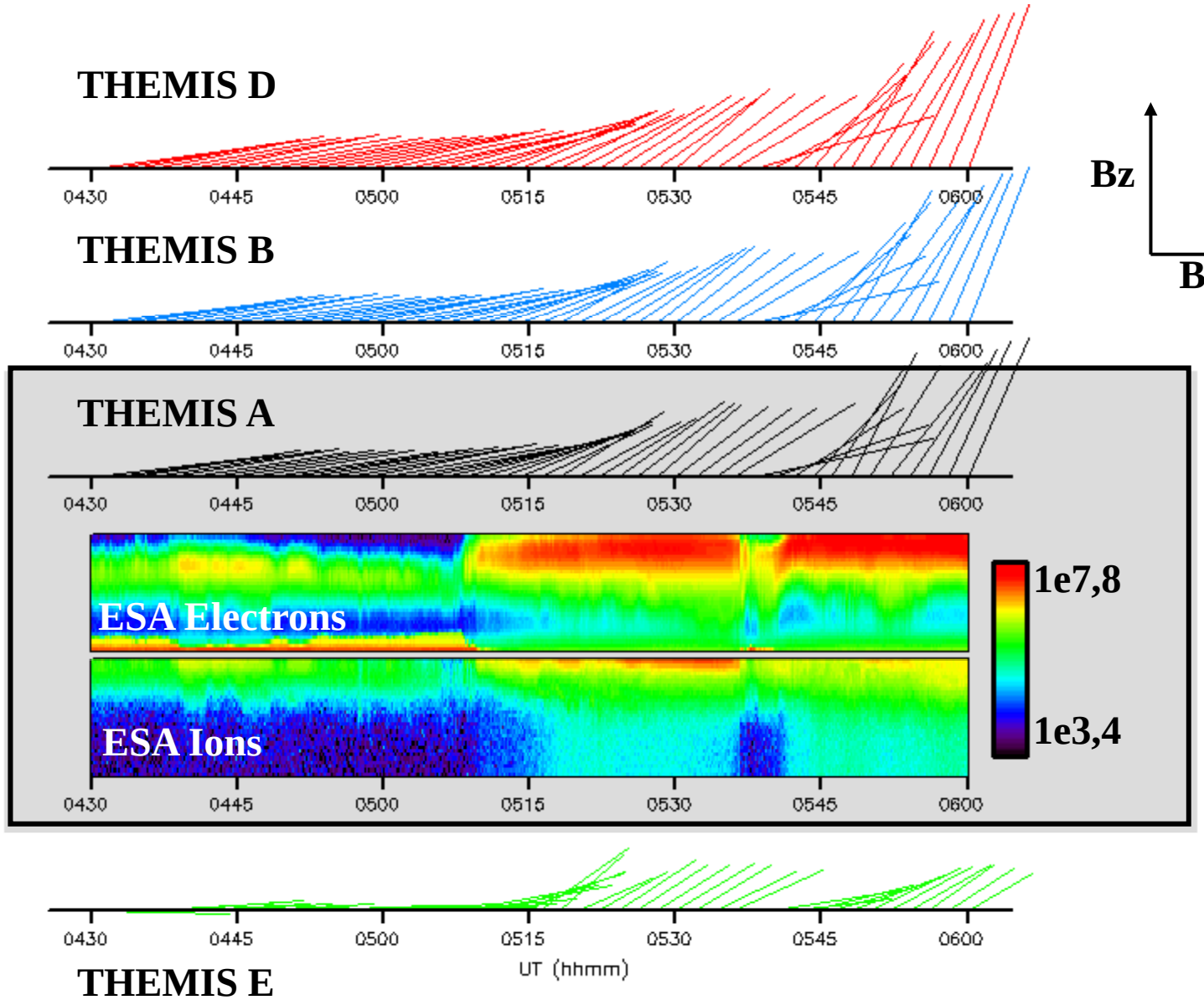
UT (hhmm)


THEMIS D
0430
0445
0500
0515
0530
0545
0600
THEMIS B
0430
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0530
0545
0600
Bz
Bx
THEMIS A
0430
0445
0500
0515
0530
0545
0600
ESA Electrons
ESA Ions
1e7,8
1e3,4
0430
0445
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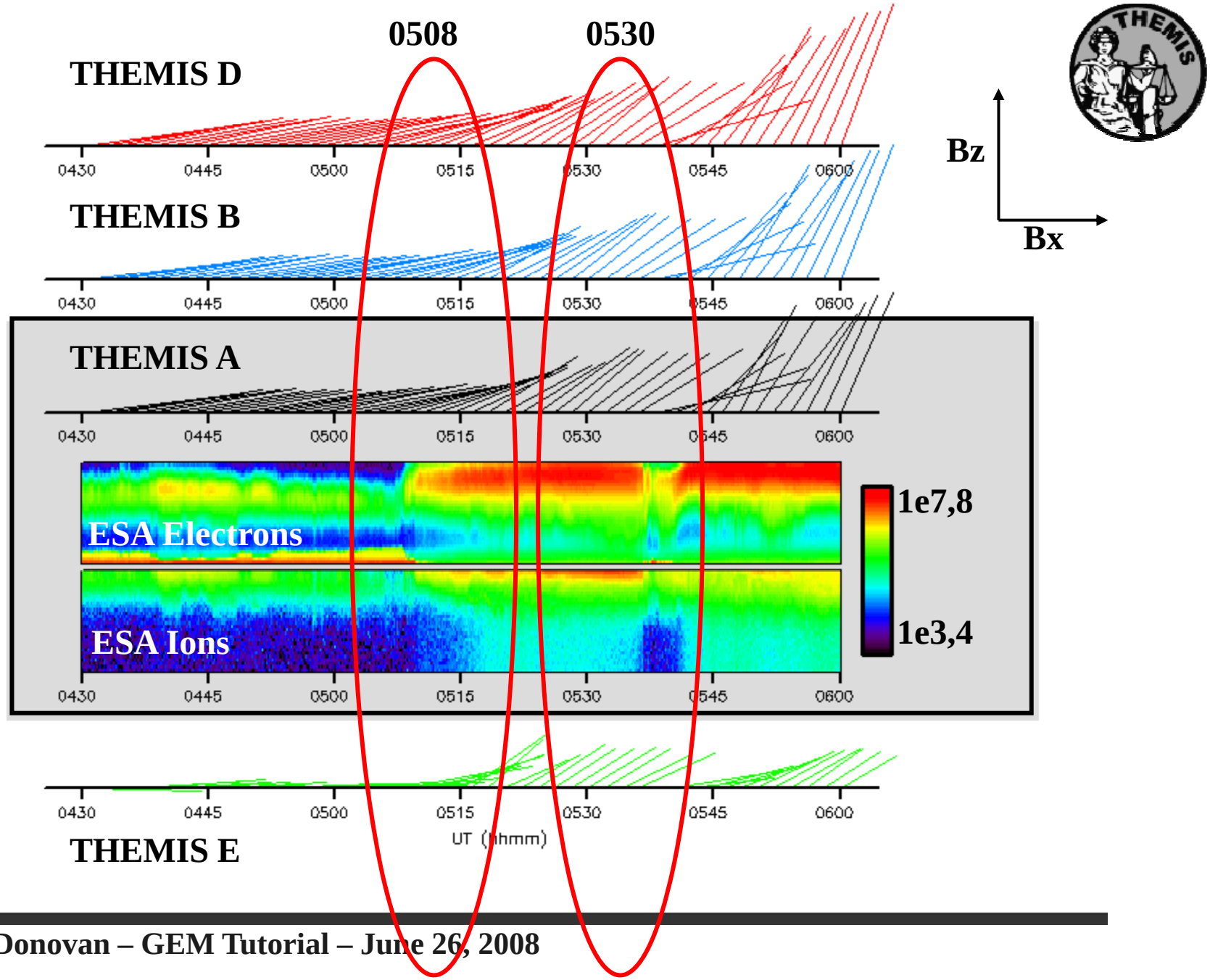
UT (hhmm)
THEMIS E


0508
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THEMIS D
THEMIS B
THEMIS A
THEMIS E
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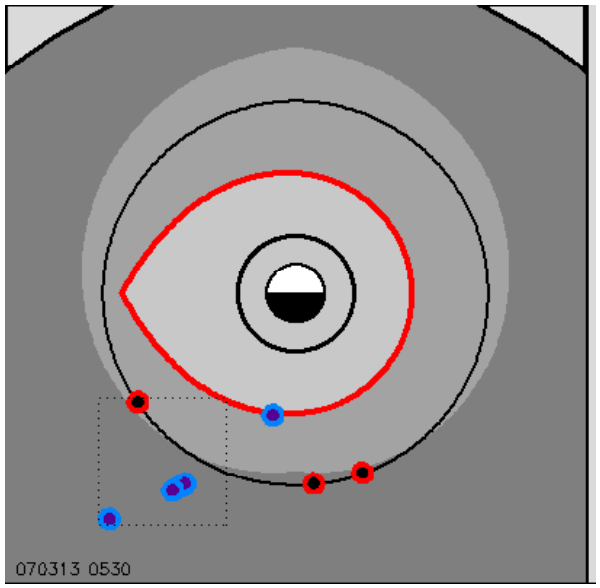
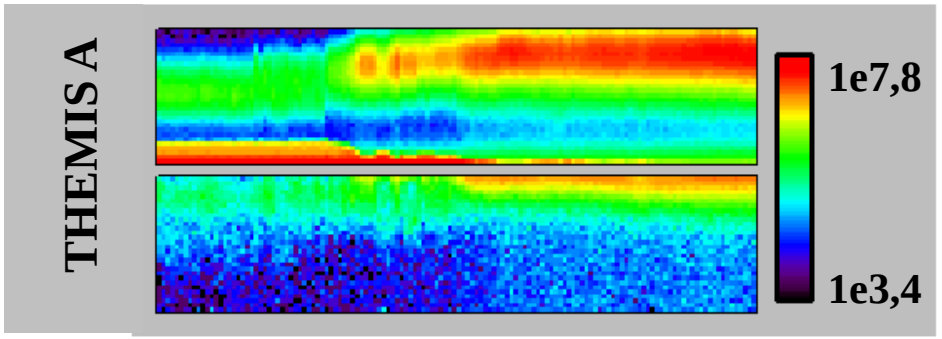
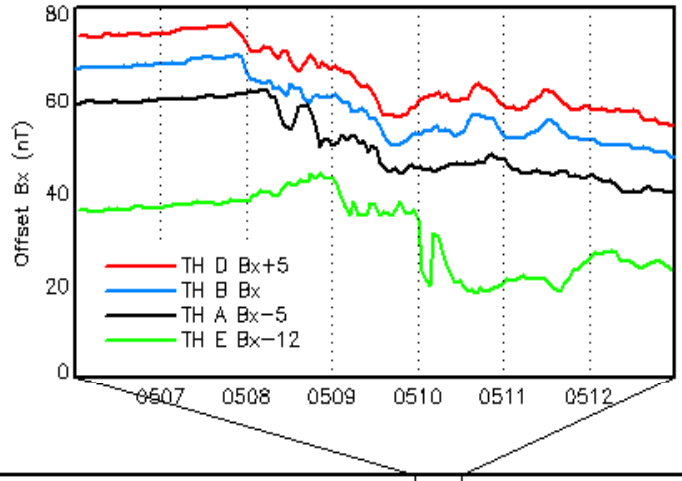
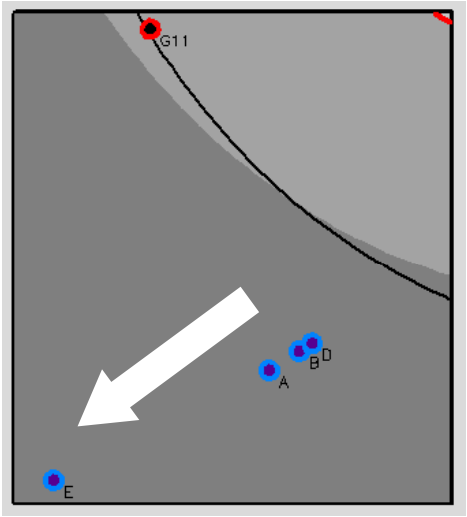
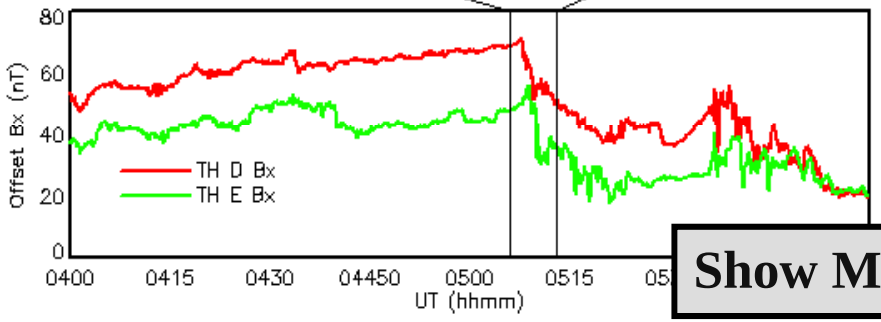
Bz
Bx
ESA Electrons
ESA Ions
1e7,8
1e3,4
UT (hhmm)


070313 0530

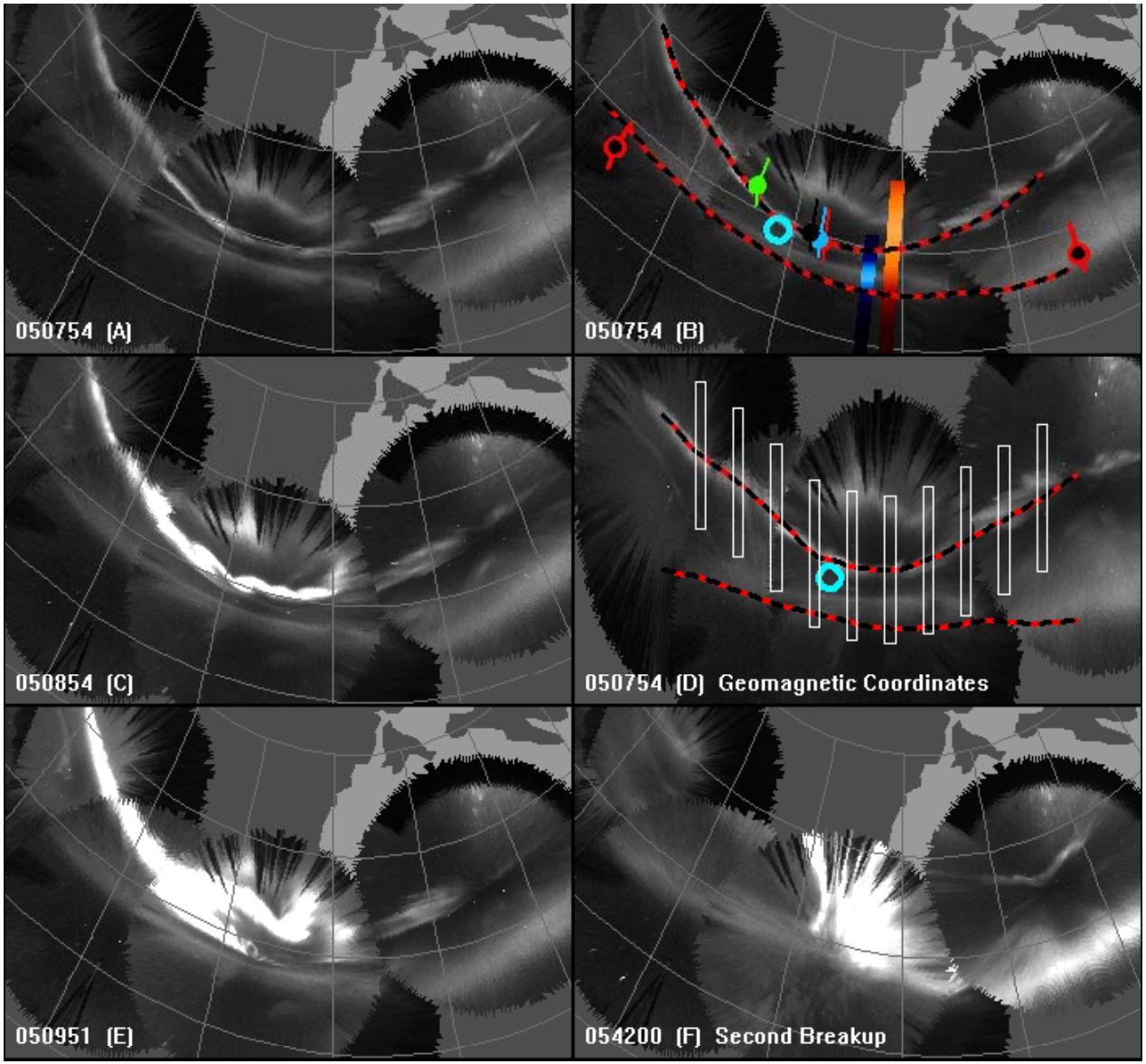

THEMIS A
1e7,8
1e3,4

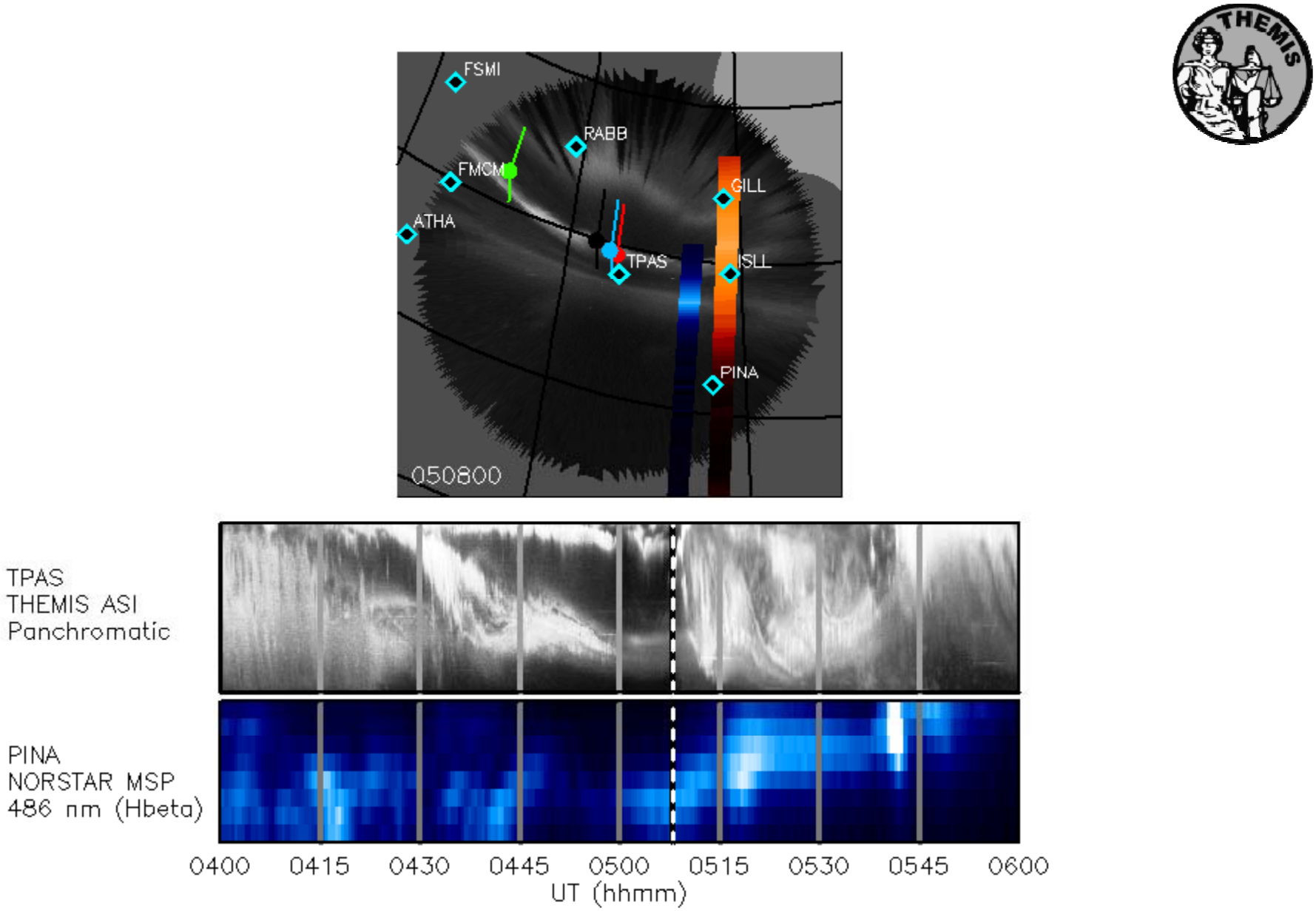

Offset Bx (nT)
TH D Bx+5
TH B Bx
TH A Bx−5
TH E Bx−12
0507
0508
0509
0510
0511
0512

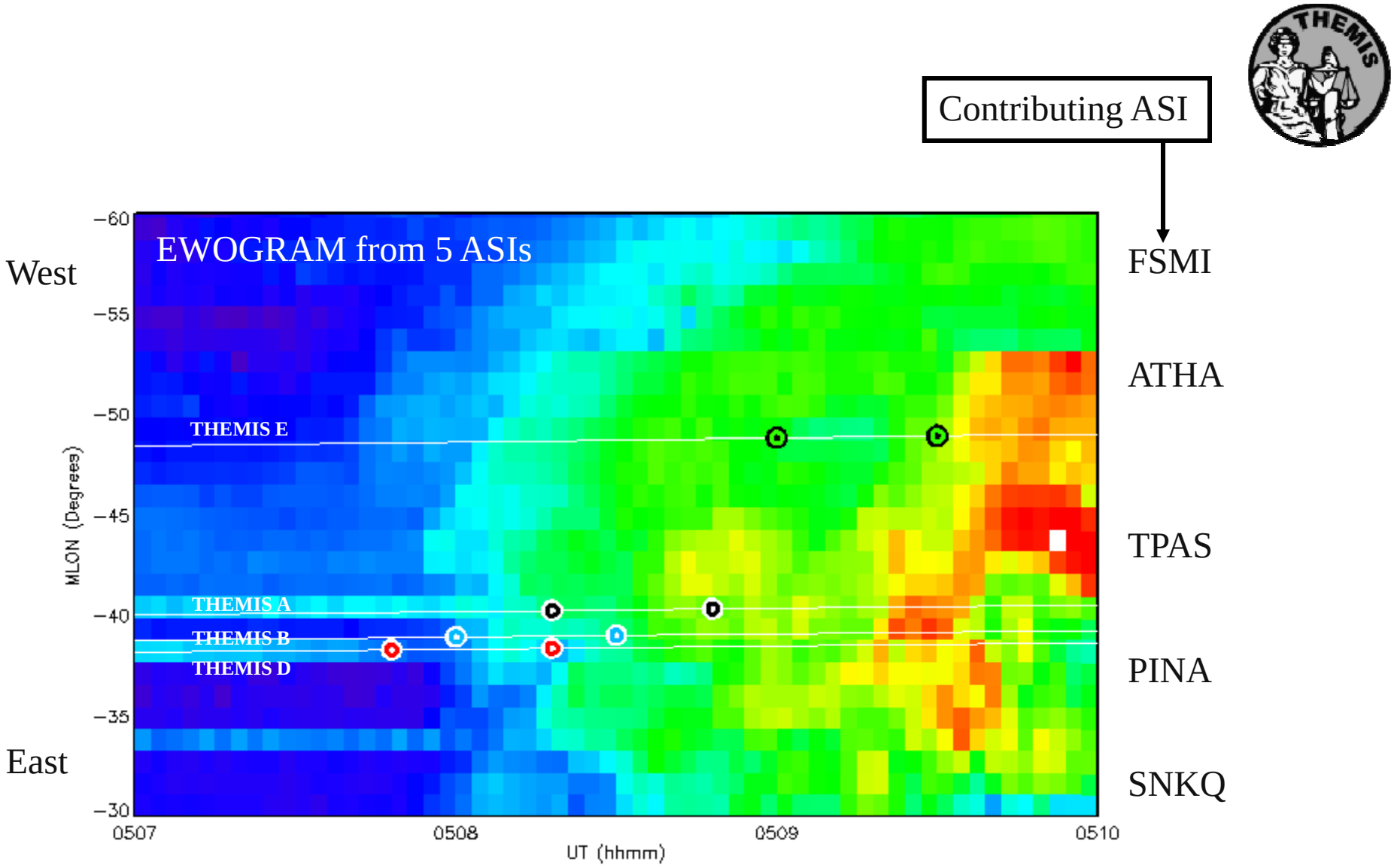

G11
A
B
D
E

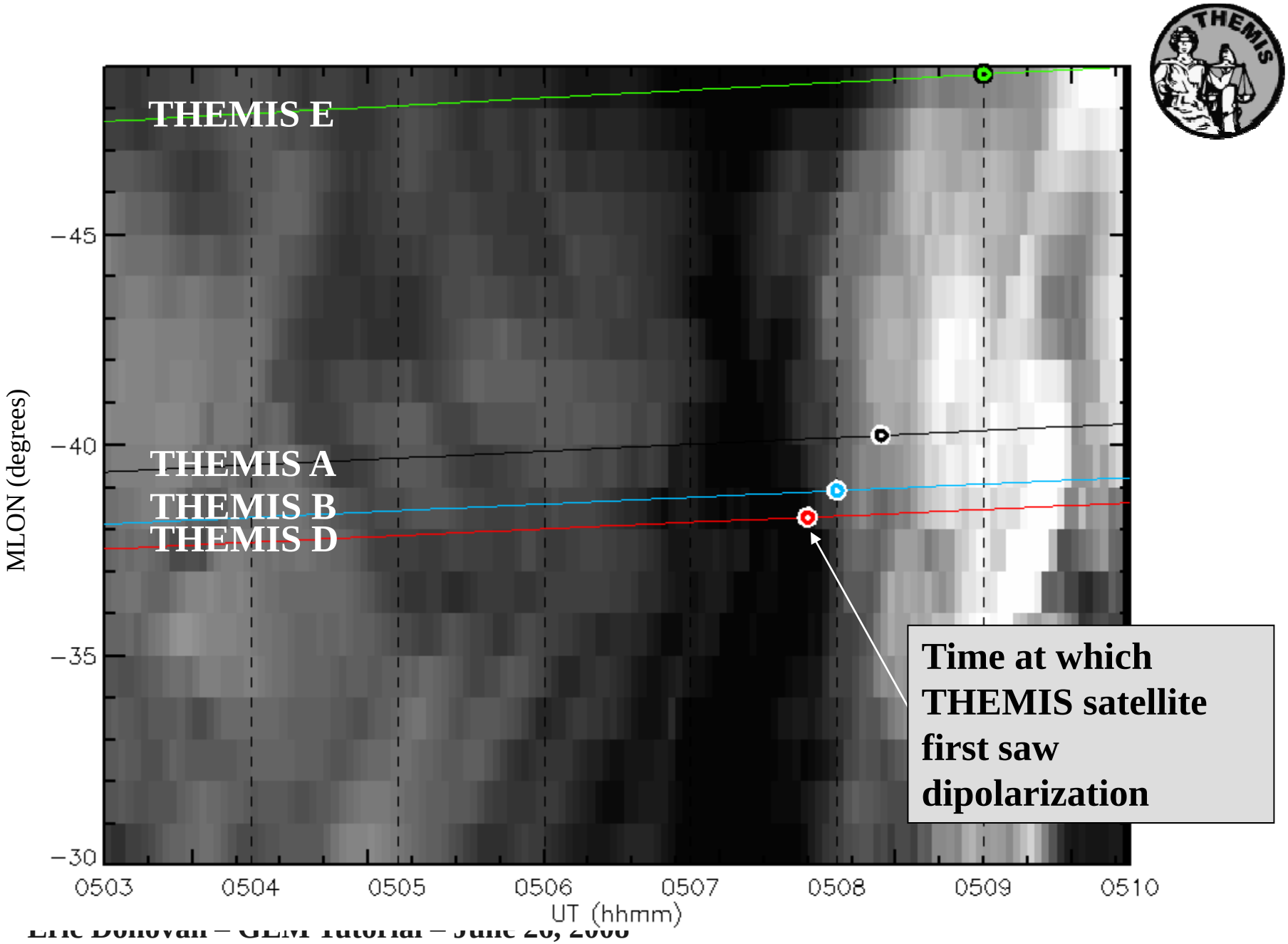

Offset Bx (nT)
TH D Bx
TH E Bx
0400
0415
0430
04450
0500
0515
UT (hhmm)

Show Movie

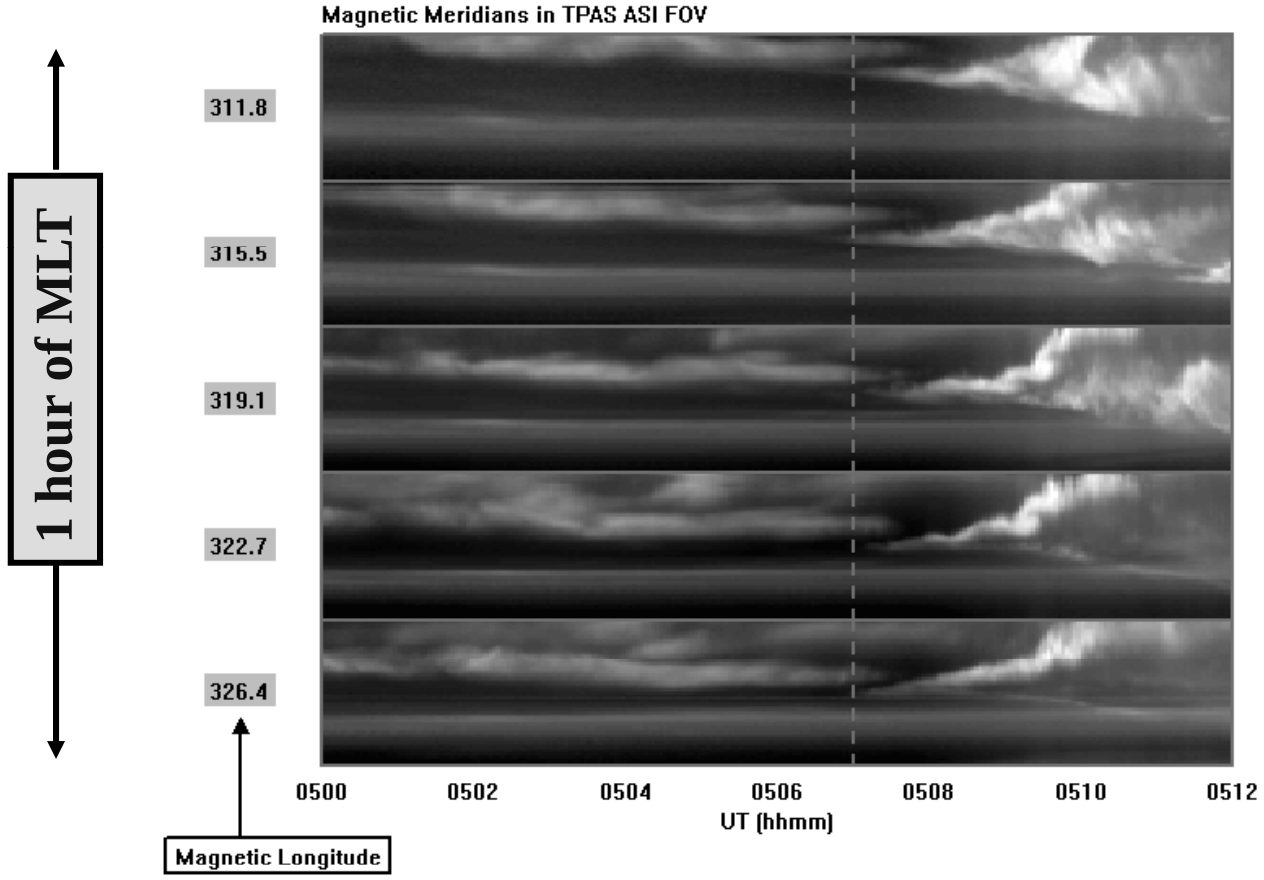

050754 (A)
050754 (B)
050854 (C)
050754 (D) Geomagnetic Coordinates
050951 (E)
054200 (F) Second Breakup

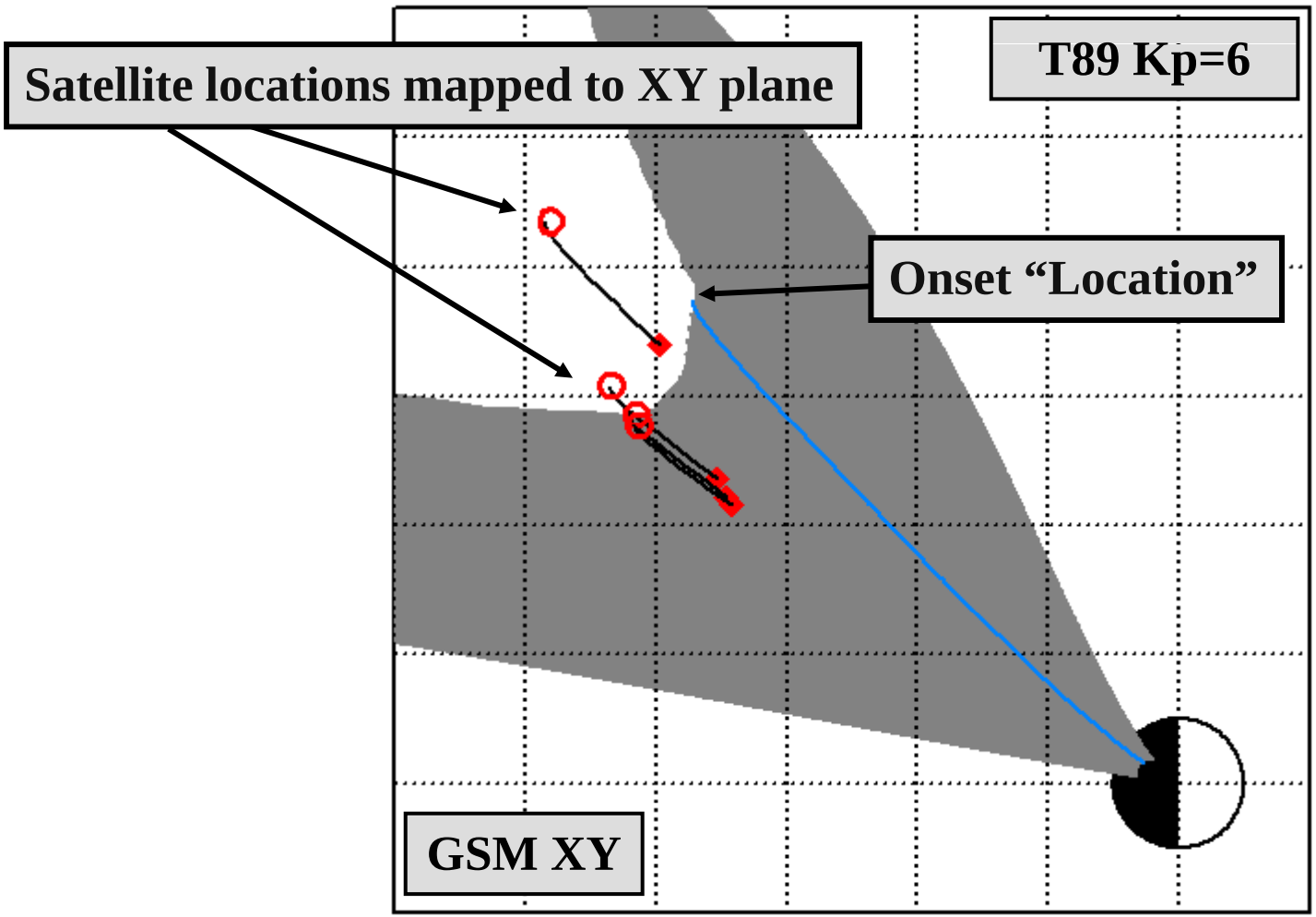

FSMI
RABB
FMCM
ATHA
GILL
TPAS
ISLL
PINA
050800
TPAS
THEMIS ASI
Panchromatic
PINA
NORSTAR MSP
486 nm (Hbeta)
0400
0415
0430
0445
0500
0515
0530
0545
0600
UT (hhmm)


Contributing ASI
EWOGRAM from 5 ASIs
West
East
FSMI
ATHA
TPAS
PINA
SNKQ
THEMIS E
THEMIS A
THEMIS B
THEMIS D
MLON (Degrees)
−60
−55
−50
−45
−40
−35
−30
0507
0508
0509
0510
UT (hhmm)

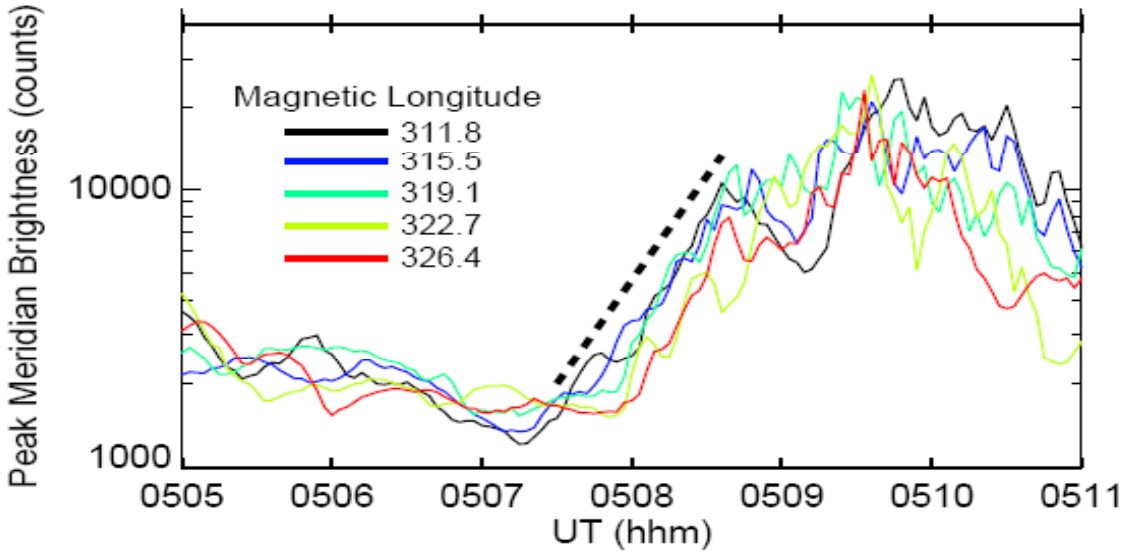

THEMIS E
THEMIS A
THEMIS B
THEMIS D
−45
−40
−35
−30
MLON (degrees)
0503
0504
0505
0506
0507
0508
0509
0510
UT (hhmm)
Time at which THEMIS satellite first saw dipolarization

Auroral brightness on 5 magnetic meridians during the onset. Note that the arc that brightens is in fact (in this case) a new feature that emerges just equatorward of the growth phase arc as discussed in *Lyons et al.* [2002]. Further, this is not simply a "cycle" in an FLR (based on the behavior of the arc for the 15 minutes prior to the onset – from 0450 until breakup the arc is NOT oscillating). I am *convinced* that the signature of the dipolarization/PS expansion at TH D/B/A/E marks the times when the poleward moving disturbance in the aurora passes those satellites.




Satellite locations mapped to XY plane
T89 Kp=6
Onset “Location”
GSM XY

Graph is derived from the keogram data shown in the previous slide. Peak brightness shows fading followed by linear growth (e-folding time is 30 seconds). There is linear growth for three cycles followed by saturation. So there are some interesting features here that answer some questions (at least for this event) but that also raise some questions. The arc that brightens (see panel of mosaics above) is a “regular shape” – I’m not sure how to describe what I’m getting at but this *proves* that the magnetospheric feature that the arc signifies is a boundary/gradient that is either in or against low-Beta plasma (such a shape could not maintain its integrity in a turbulent high beta plasma). The fact that the saturation occurs after three e-folding times is completely consistent with the predictions of ballooning in the transition region between high and low beta and tail-like and dipolar. Igor’s material, though, is for shear-flow ballooning, and I see no evidence of an FLR here. Perhaps ---- perhaps ---- the arc could signify something like the min-B scenario of Galperin, coupled with ballooning. That would explain the fading, the growth time, the saturation and the properties of the arc near the time of breakup.



Inevitable: Numerous studies in the near future are going to establish irrefutable examples of “in-out” and “out-in” expansion phase substorms.

Supposition: The first onset in a multi-onset sequence will be “in-out” and the large “final” onset will be “out-in”.

Difficulty: There is an argument against the “in-out” scenario that is very difficult to refute (and equally difficult to substantiate)… fast flows from the NENL cause the breakup (precede the auroral brightening) but are narrow and missed by the satellites.

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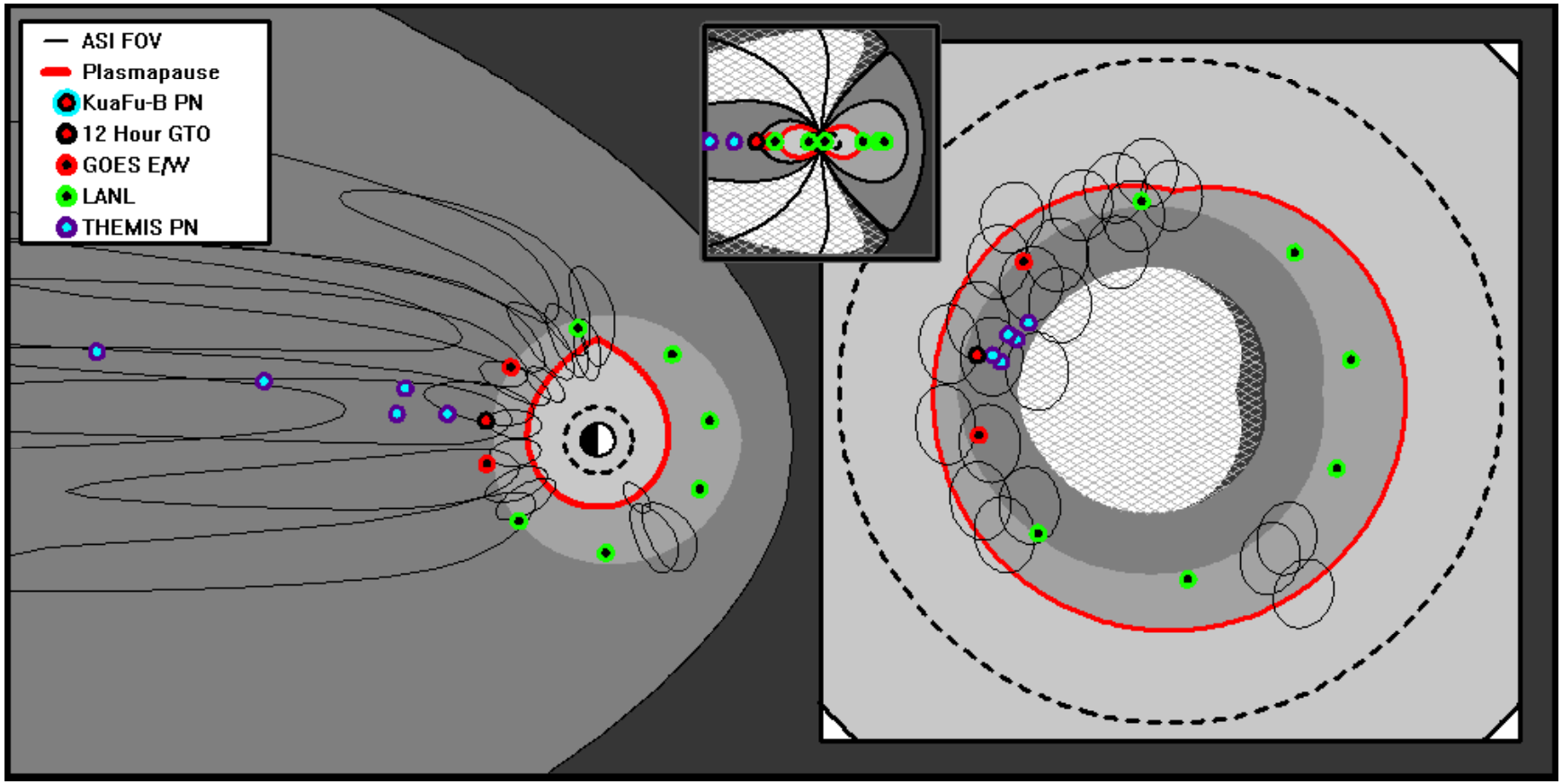
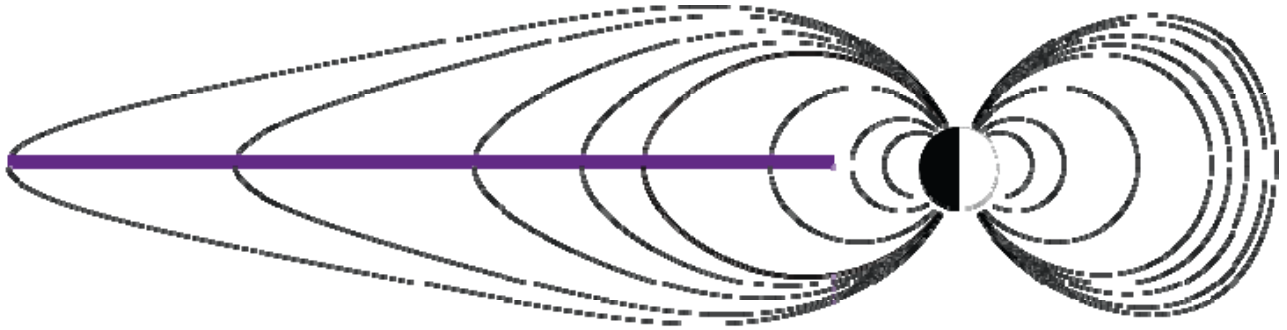
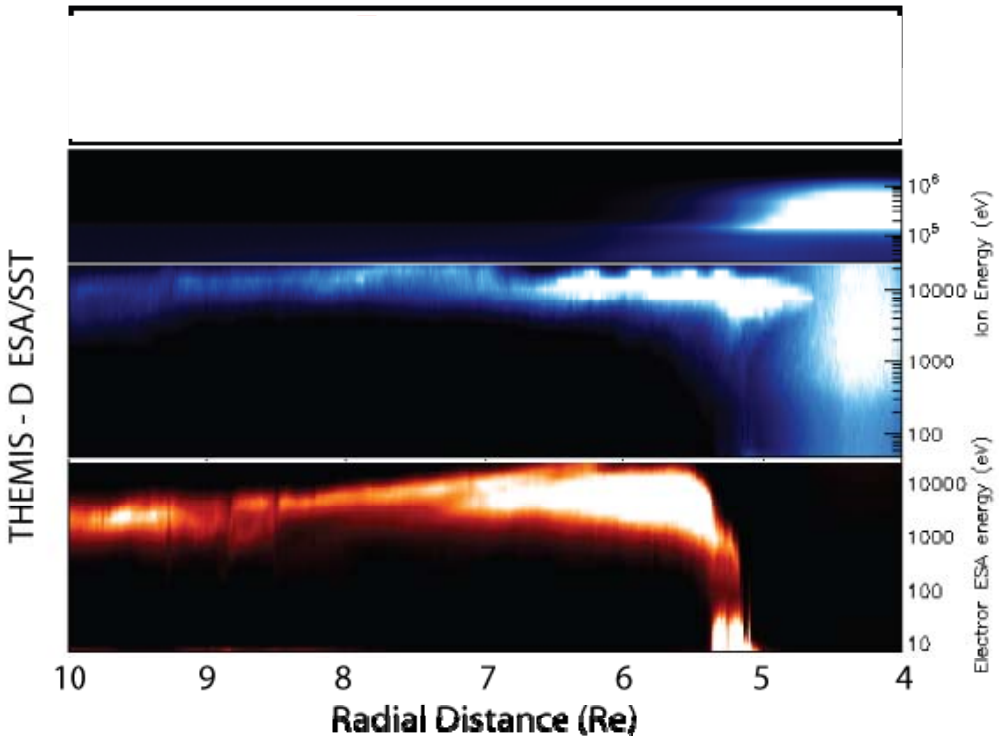
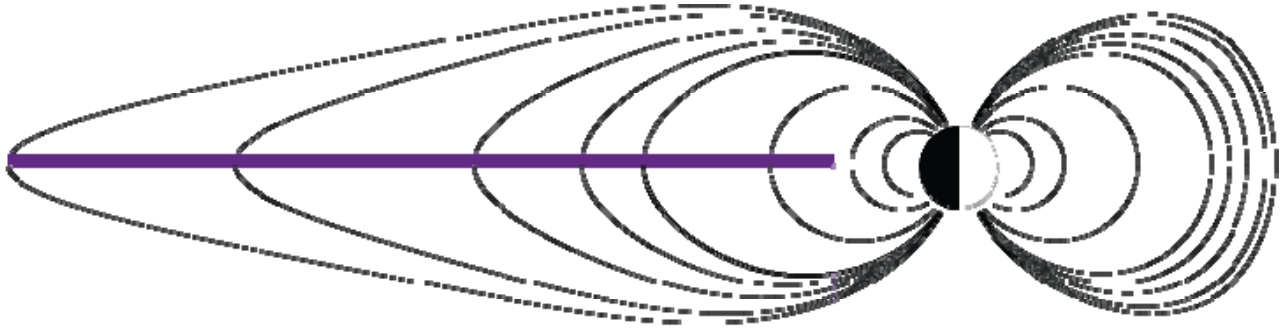
Challenge: What are the ionospheric signatures of NENL formation? What are the ionospheric signatures of the fast flow? Is it enough that the arcs poleward of the onset are often undisturbed until after the breakup?

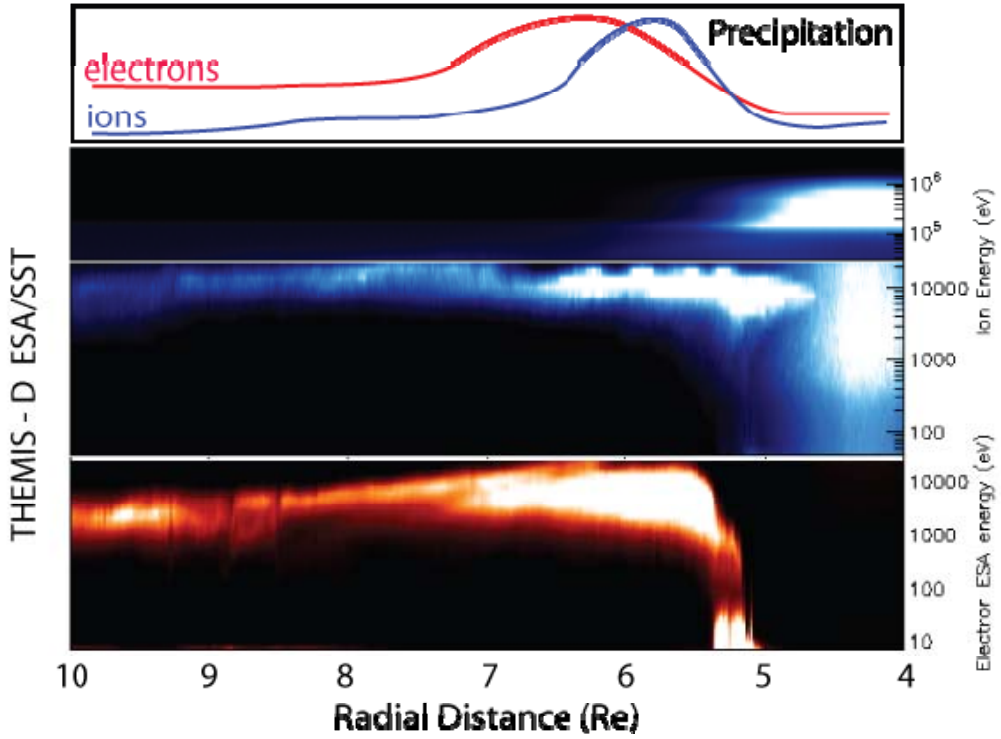
Challenge: Mapping between the ionosphere and magnetosphere via physics-based models, empirical models, and observations.

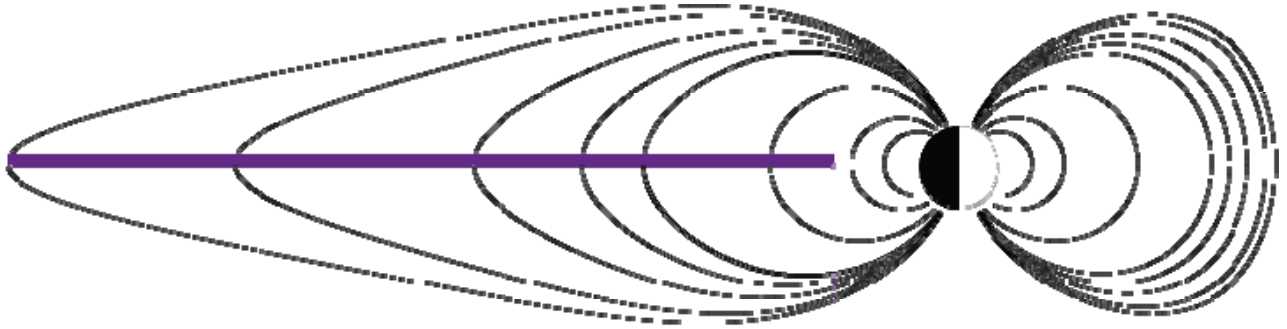


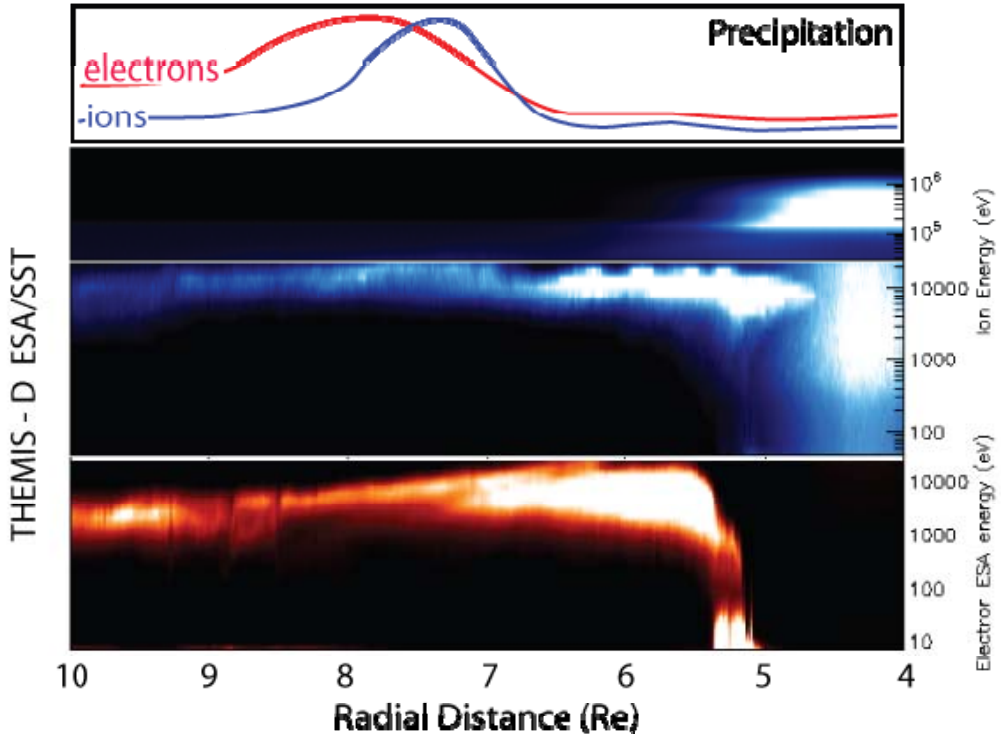



THEMIS - D ESA/SST
10^6
10^5
10000
1000
100
Ion Energy (eV)
10000
1000
100
10
Electron ESA energy (eV)
10
9
8
7
6
5
4
Radial Distance (Re)

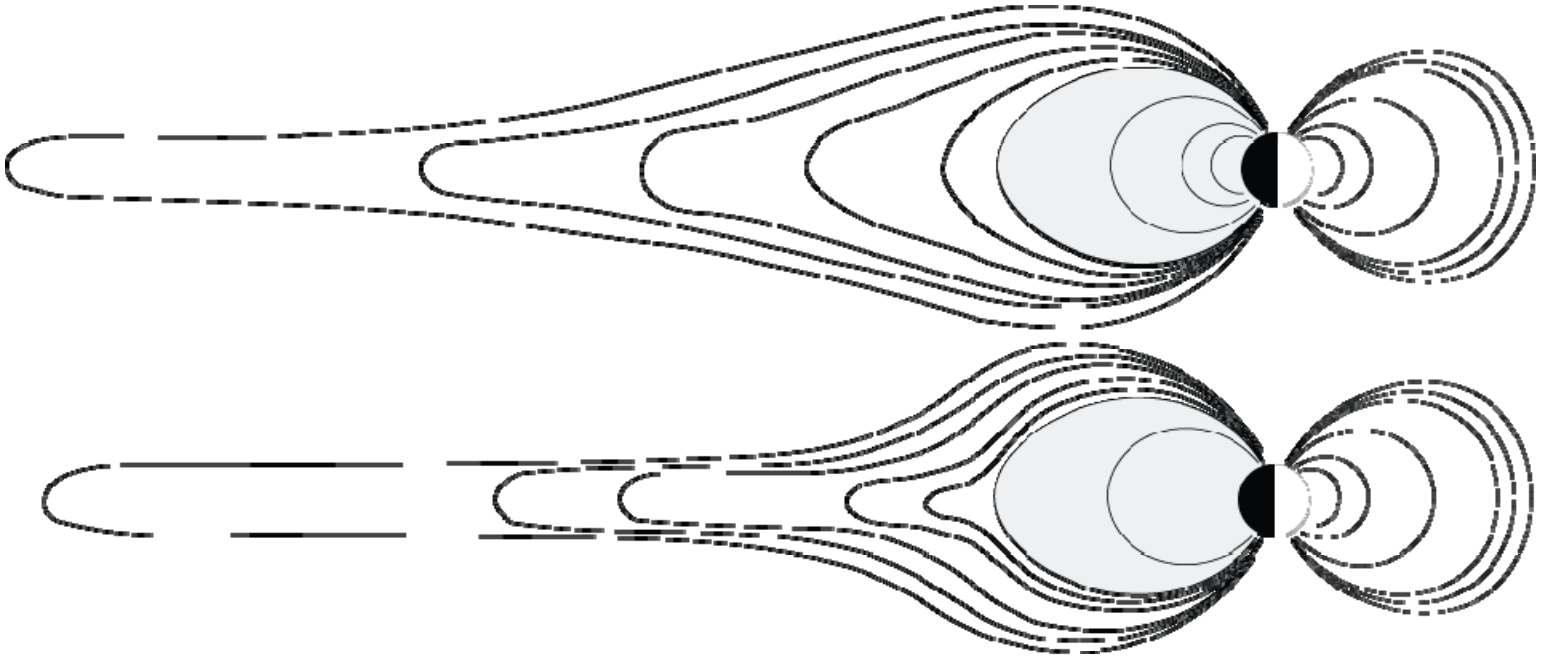



Precipitation
electrons
ions
THEMIS - D ESA/SST
10^6
10^5
10000
1000
100
Ion Energy (eV)
10000
1000
100
10
Electron ESA energy (eV)
10
9
8
7
6
5
4
Radial Distance (Re)

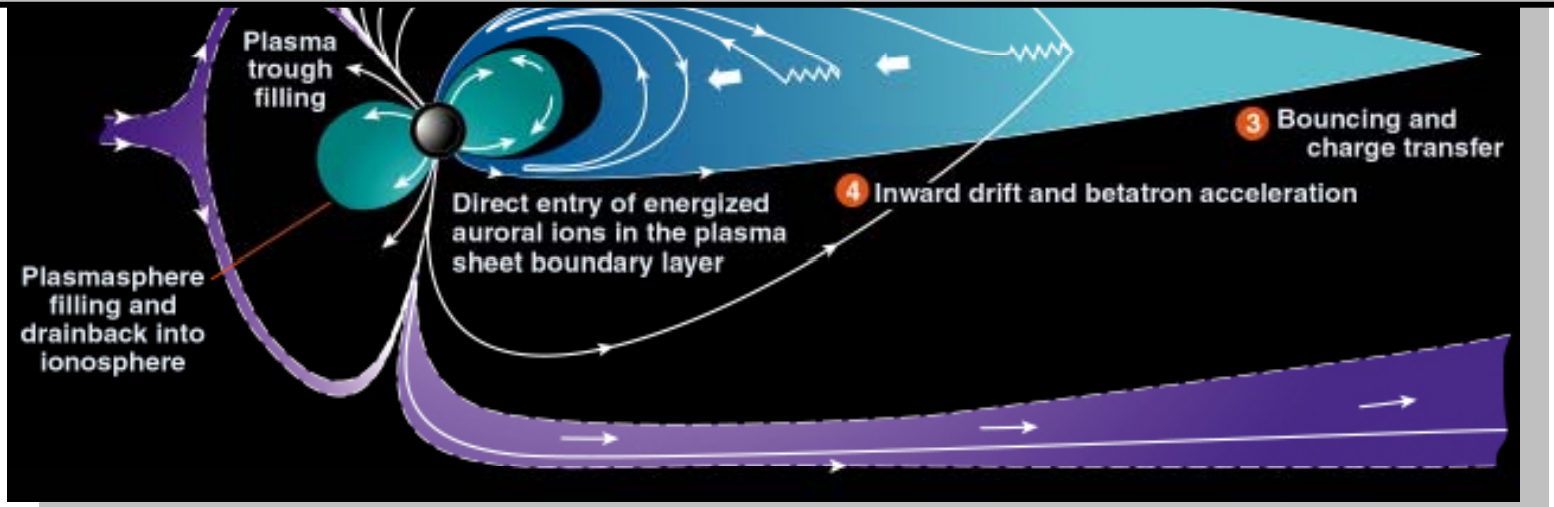



Precipitation
electrons
ions
THEMIS - D ESA/SST
10^6
10^5
10000
1000
100
Ion Energy (eV)
10000
1000
100
10
Electron ESA energy (eV)
10
9
8
7
6
5
4
Radial Distance (Re)

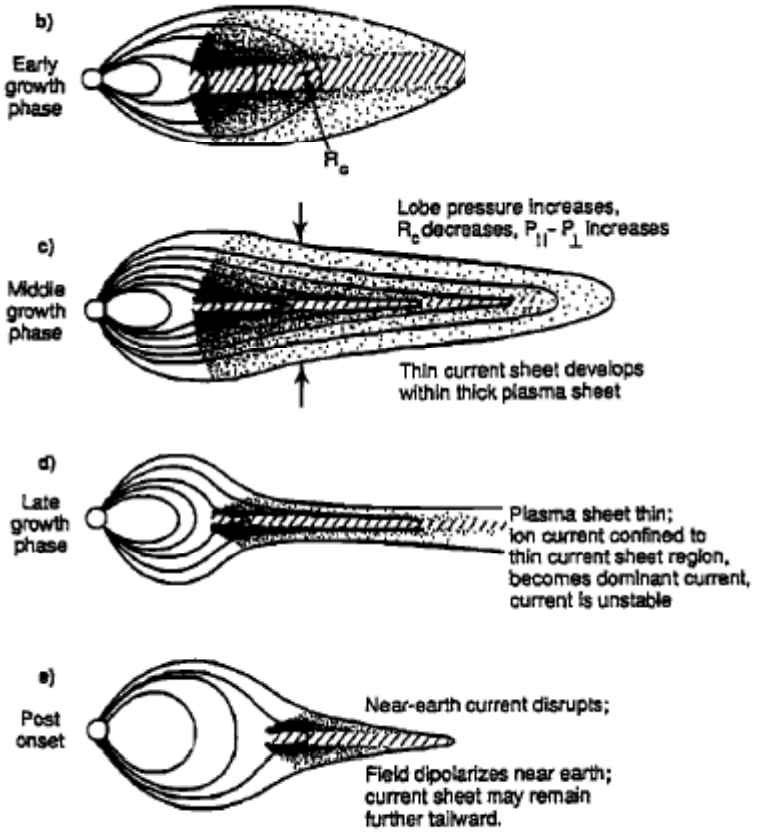
Challenge: The onset arc is in the proton aurora which is the ionospheric footprint of the transition between dipolar and tail-like field lines. How abrupt is that transition? Where is that transition?

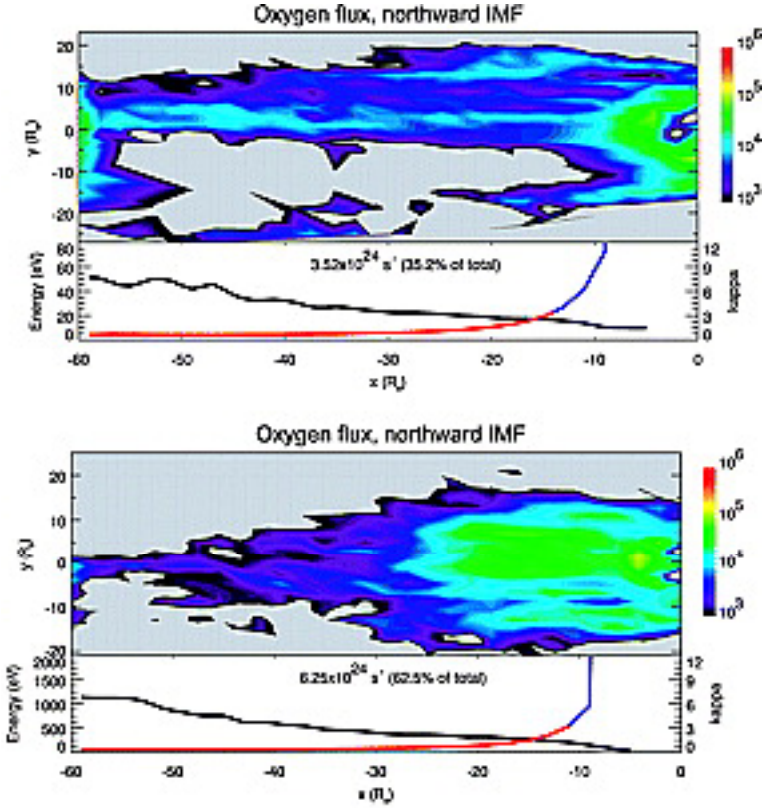


Challenge: There are things we have a very poor understanding of, but that may be of central importance to our ultimate understanding of the expansion phase onset. What, for example, is the role of ions of ionospheric origin in the expansion phase onset?



Chappel, C., T. Moore, and J. Waite, The ionosphere as a fully adequate source of plasma for the earth's magnetosphere, J. Geophys. Res., 92, 5896–5910, 1987.

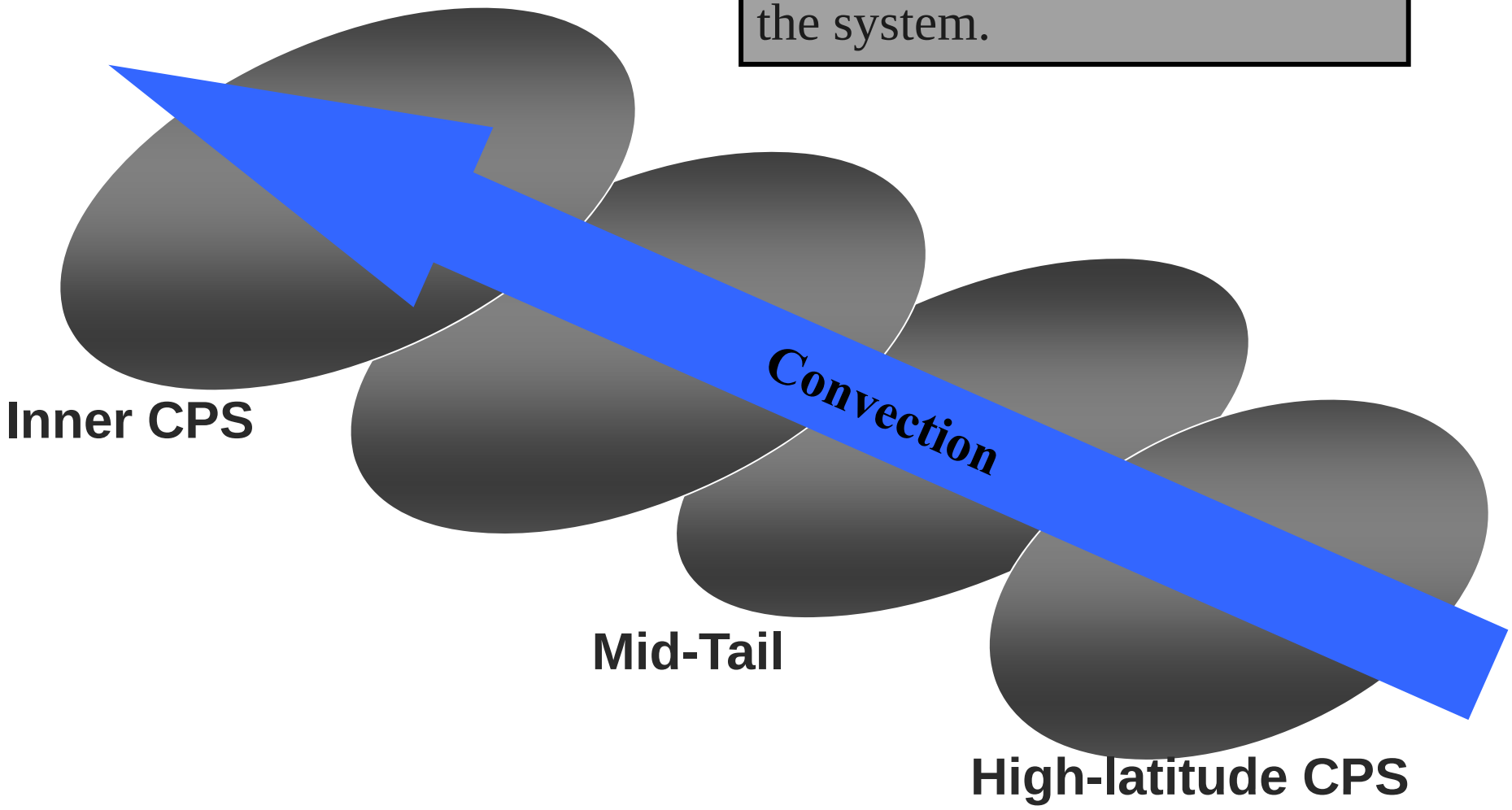




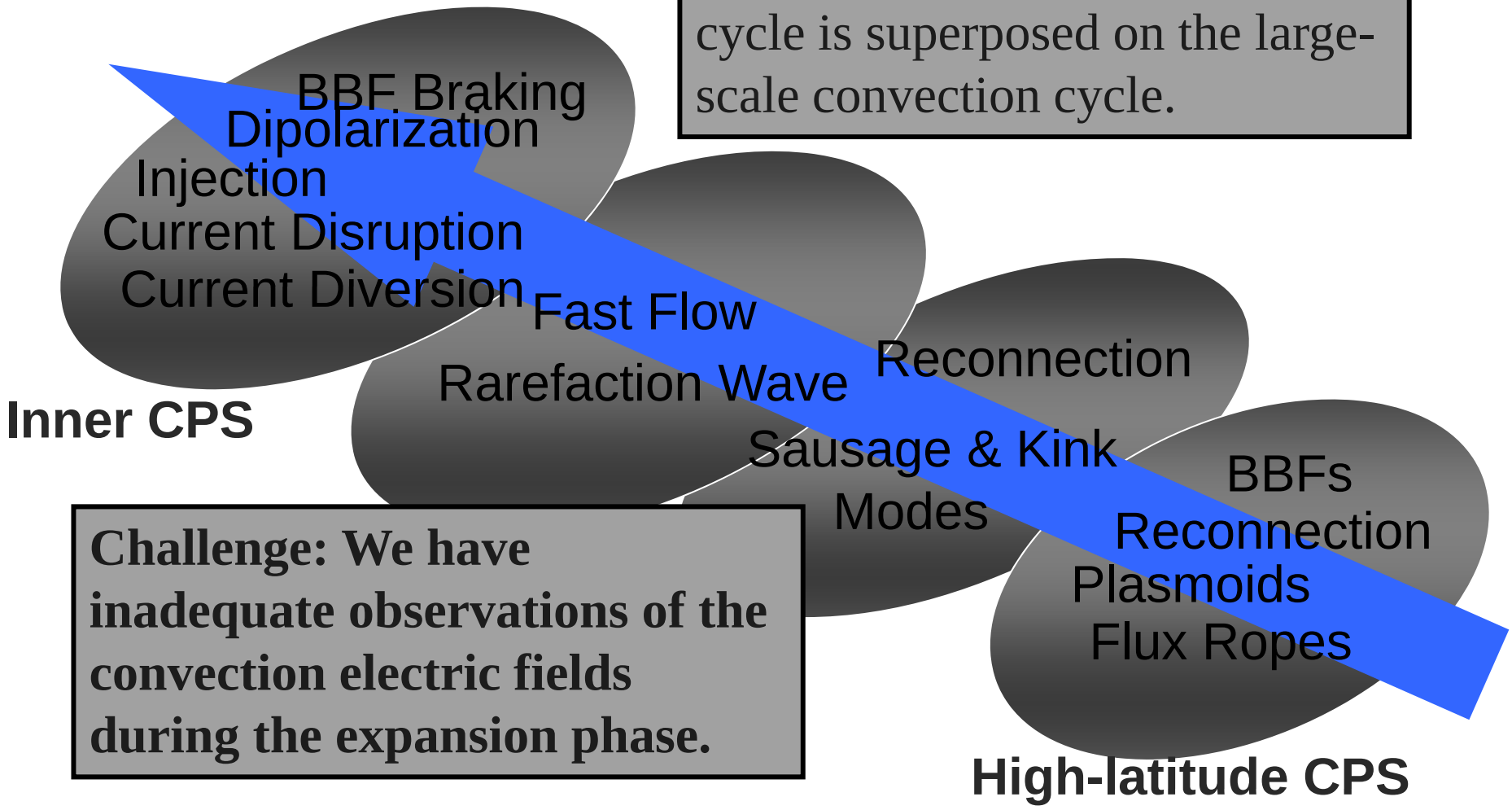
Mitchell, D., D. Williams, C. Huang, L. Frank, and C. Russell, Current carriers in the near-Earth current sheet during growth phase, GRL, 17(5), 583–586, 1990.

Cully, C., E. Donovan, A. Yau, and H. Opgenoorth, Supply of thermal ionospheric ions to the central plasma sheet, JGR, 108(A2), 1092, 2003.

Convection moves mass to, through, and ultimately out of the system.



The substorm loading/unloading (growth, expansion, recovery) cycle is superposed on the large-scale convection cycle.



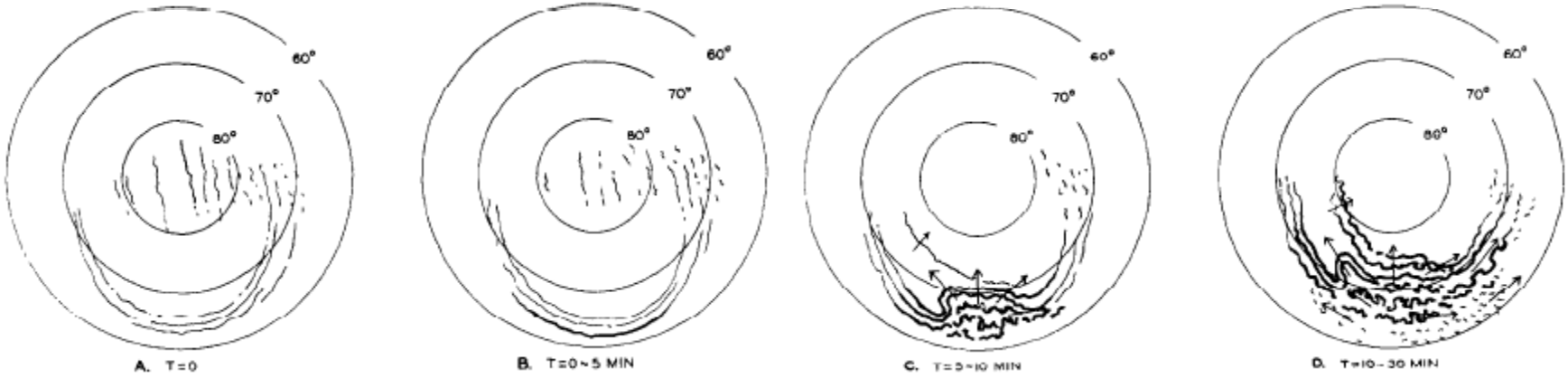
Challenge: We have inadequate observations of the convection electric fields during the expansion phase.

THE DEVELOPMENT OF THE AURORAL SUBSTORM

S.-I. AKASOFU
Geophysical Institute, University of Alaska, College, Alaska

(*Received* 13 *January* 1964)

Abstract—A working model of simultaneous auroral activity over the entire polar region is presented in terms of the auroral substorm. The substorm has two characteristic phases, an expansive phase and a recovery phase. Each phase is divided into three stages, and characteristic auroral displays over the entire polar region during each stage are described in detail. Further, all the major features seen at a single station are combined into a consistent picture of large-scale auroral activity.



Irrefutable: Expansion phase onset is on or near a pre-existing arc.

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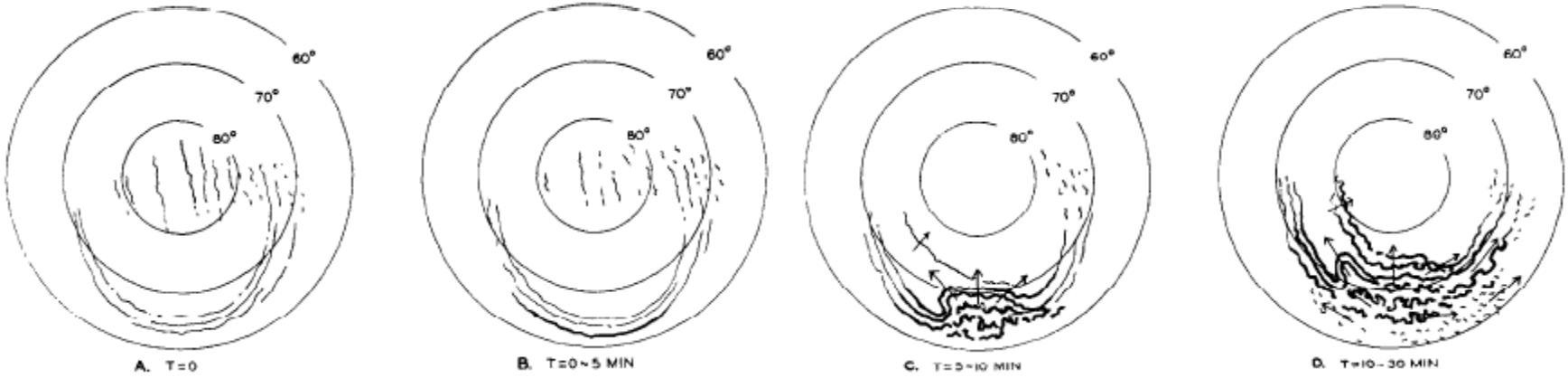

Challenge: What is an auroral arc?

Conclusions

The substorm problem is difficult

- there are a lot of necessary details
- we all bring biases to interpretation of inadequate data
- substorm may encompass more than one phenomena

New GB & in situ (THEMIS) observations are paying off…

- verification of both substorm scenarios
- tests of models of the onset physics

Clearly, exciting challenges remain…

- convection
- ion outflow
- auroral electrodynamics (what is an arc?)
- mapping
- ionospheric signatures of magnetospheric dynamics