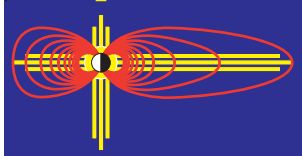
What We Know & What We Don't Know About Substorm Injections

Geoff Reeves

GEOSPACE ENVIRONMENT MODELLING WORKSHOP
SNOWMASS COLORADO

JUNE 16, 1997

What I think I Know & some of What I Don't Know About Substorm Injections



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* What Is a “Substorm Injection”?

* Where Do They Occur?

* What Causes Them?

* How Do They Fit in the Big Picture of Substorms?

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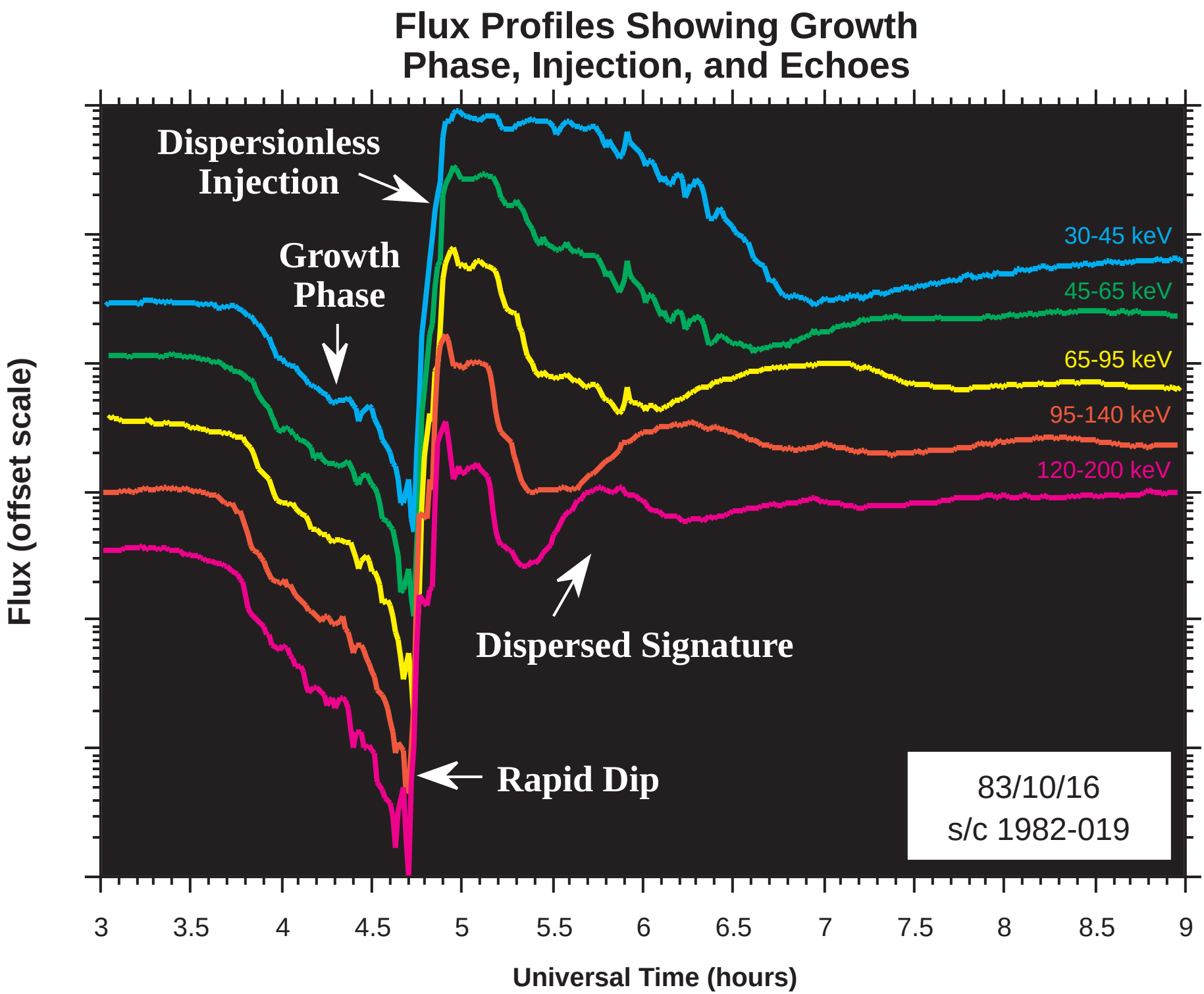
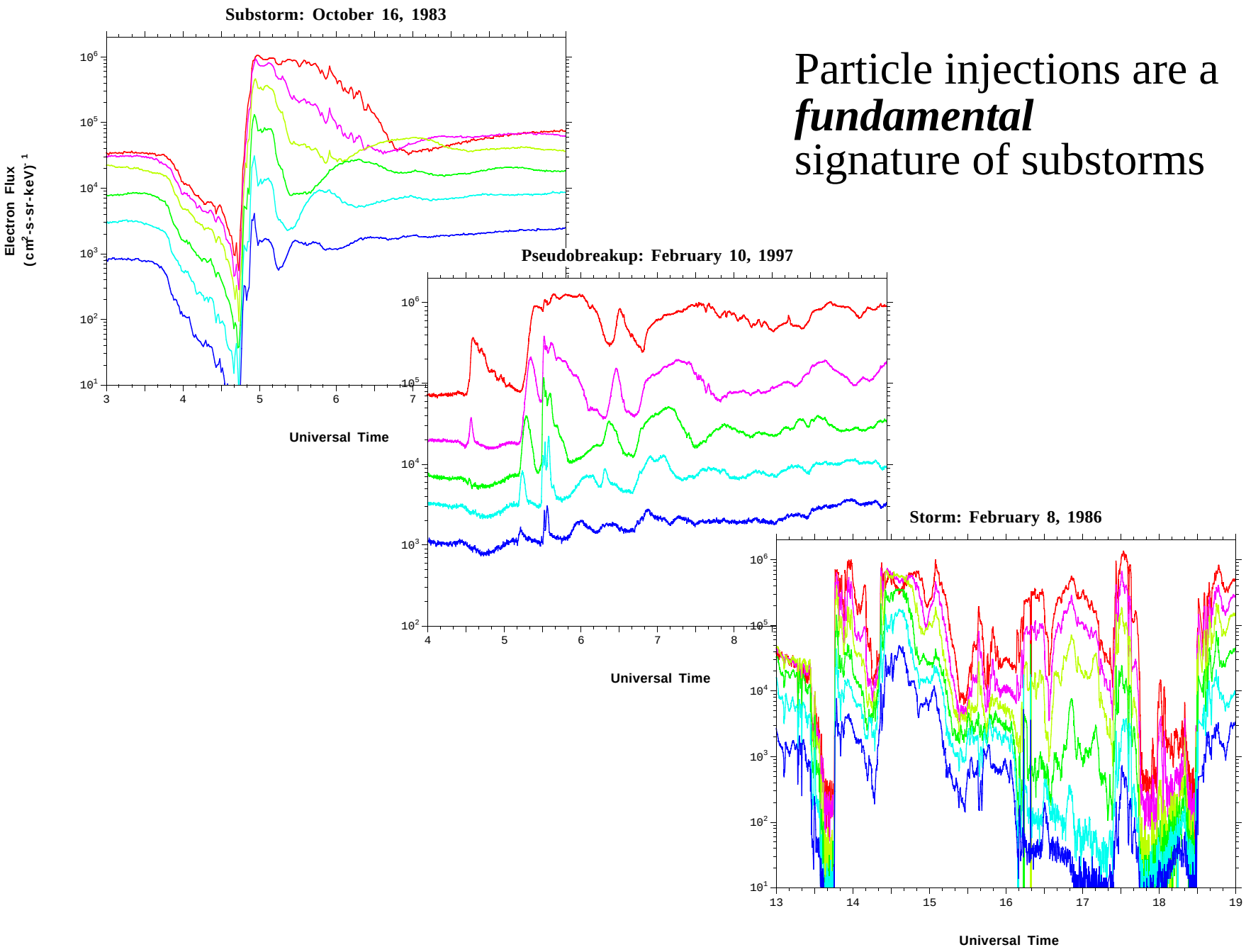
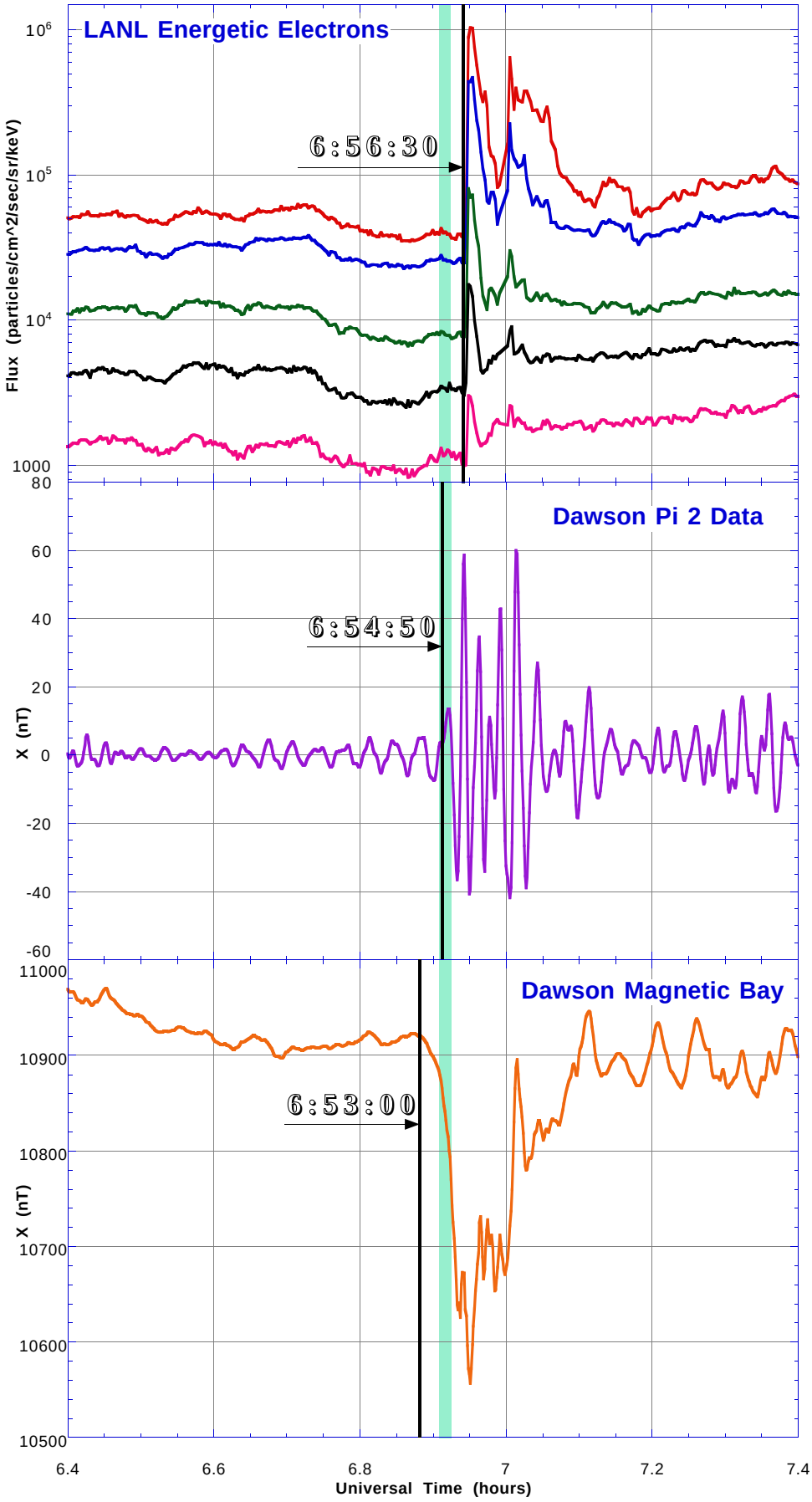

Flux Profiles Showing Growth Phase, Injection, and Echoes
Dispersionless Injection
Growth Phase
Dispersed Signature
Rapid Dip
30-45 keV
45-65 keV
65-95 keV
95-140 keV
120-200 keV
83/10/16
s/c 1982-019
Flux (offset scale)
Universal Time (hours)
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9

Particle injections are a ***fundamental*** signature of substorms



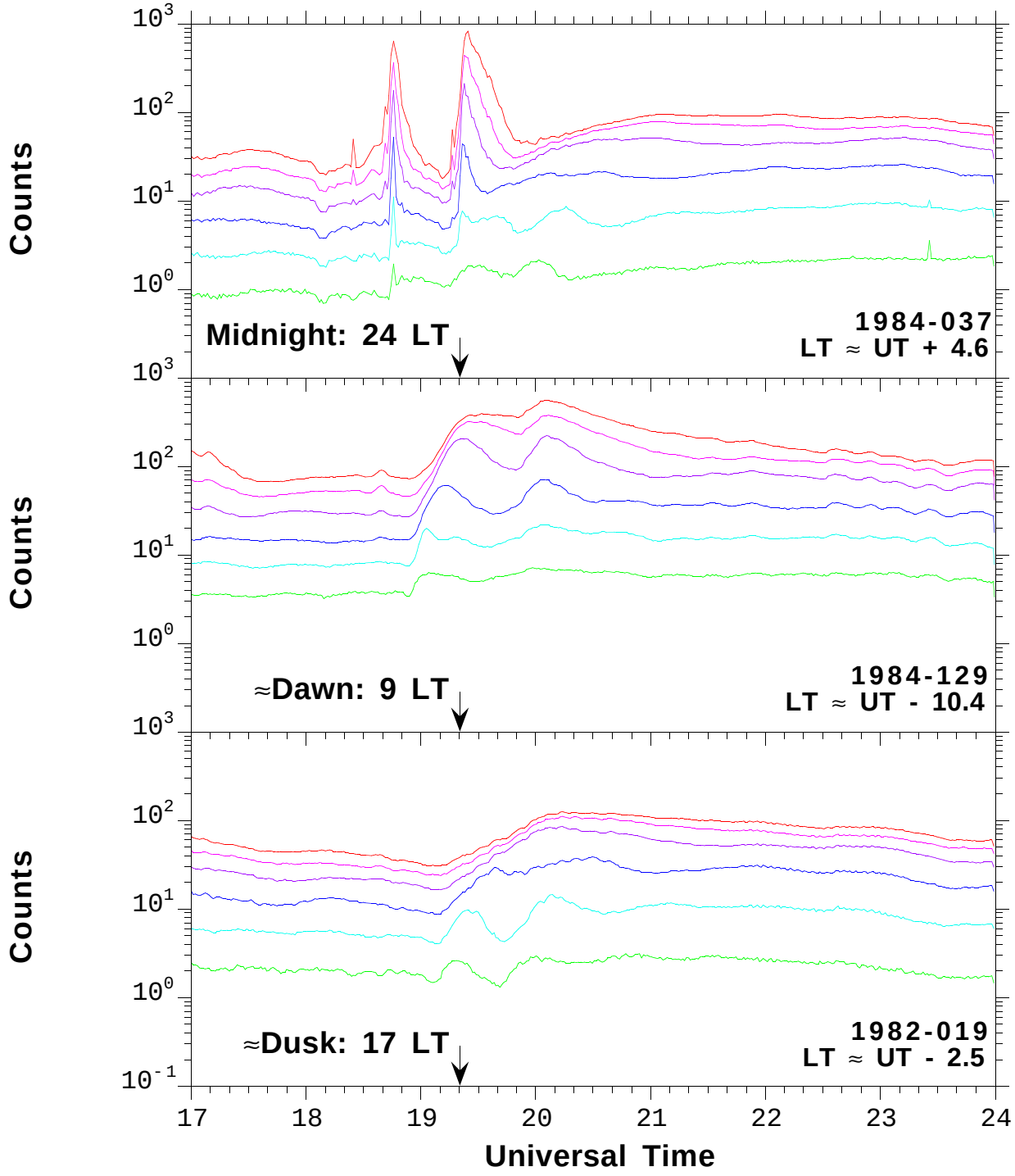
Geoff Reeves, ICS-4, Hamanako Japan, 1998.

Comparison of Relative Substorm Onset Timing
January 30, 1995



Drift of Injected Electrons: March 31, 1986

Because of their drift energy-dispersed injections
can be observed at a wide range of local times,
not just in the injection region



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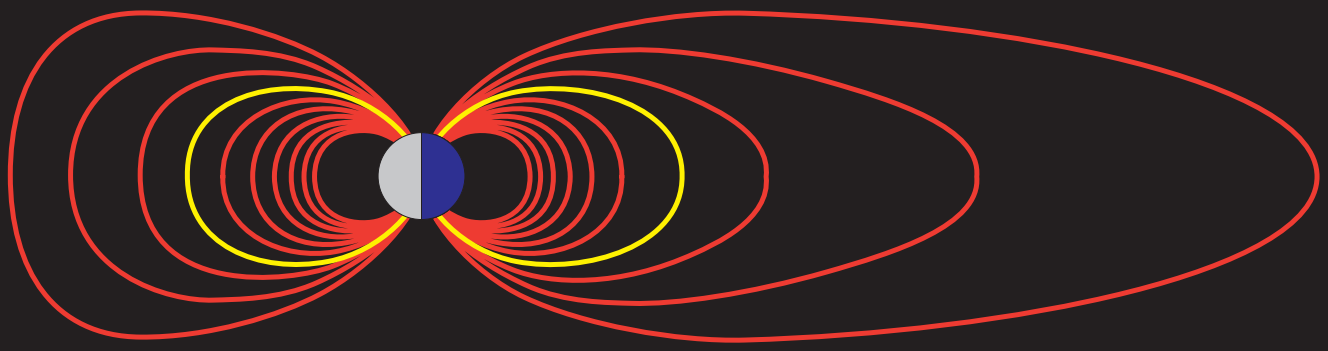
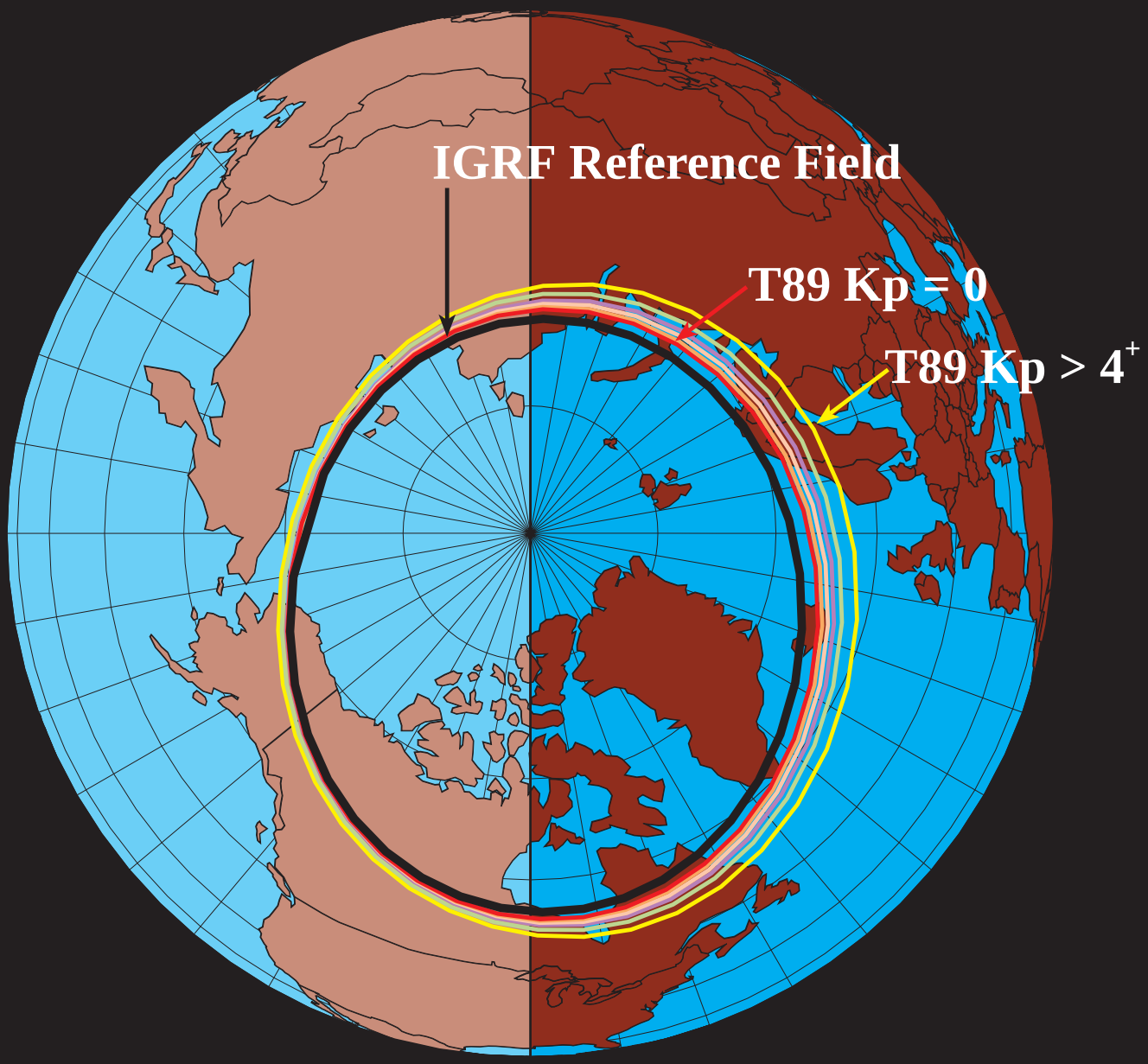
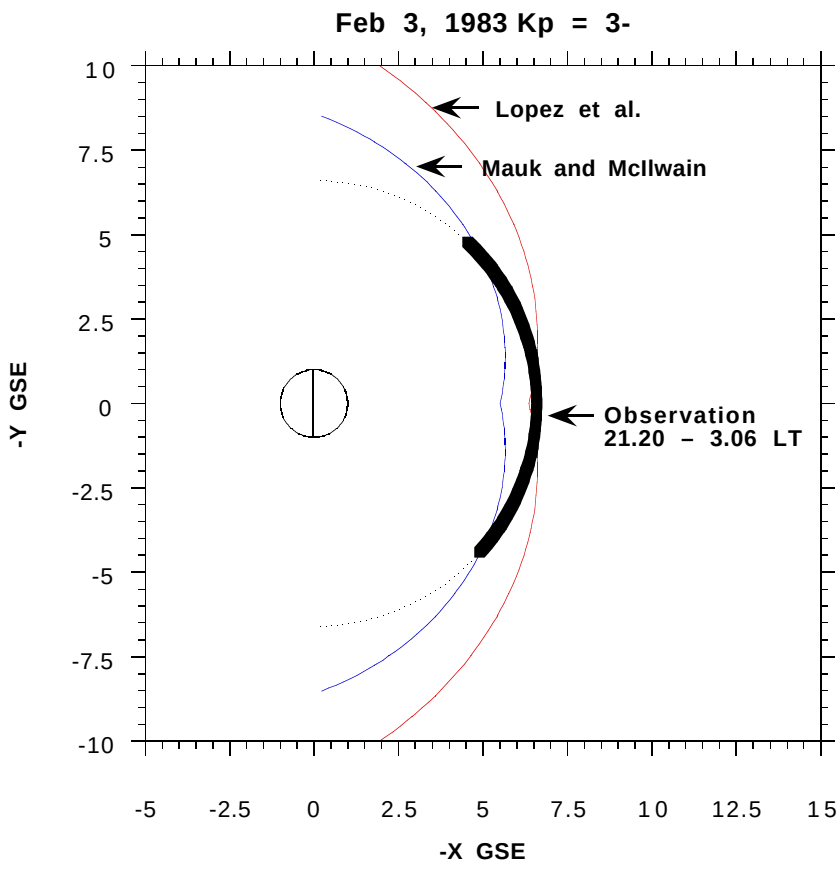
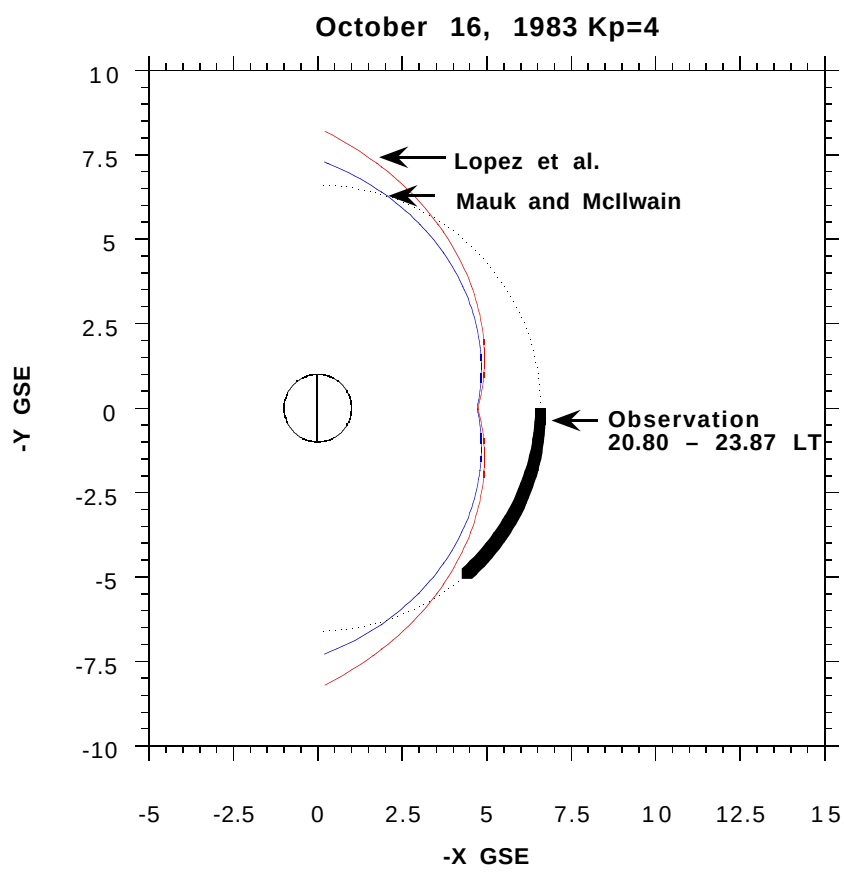
Tsyganenko 1989 Model





Comparison of Injection Boundaries





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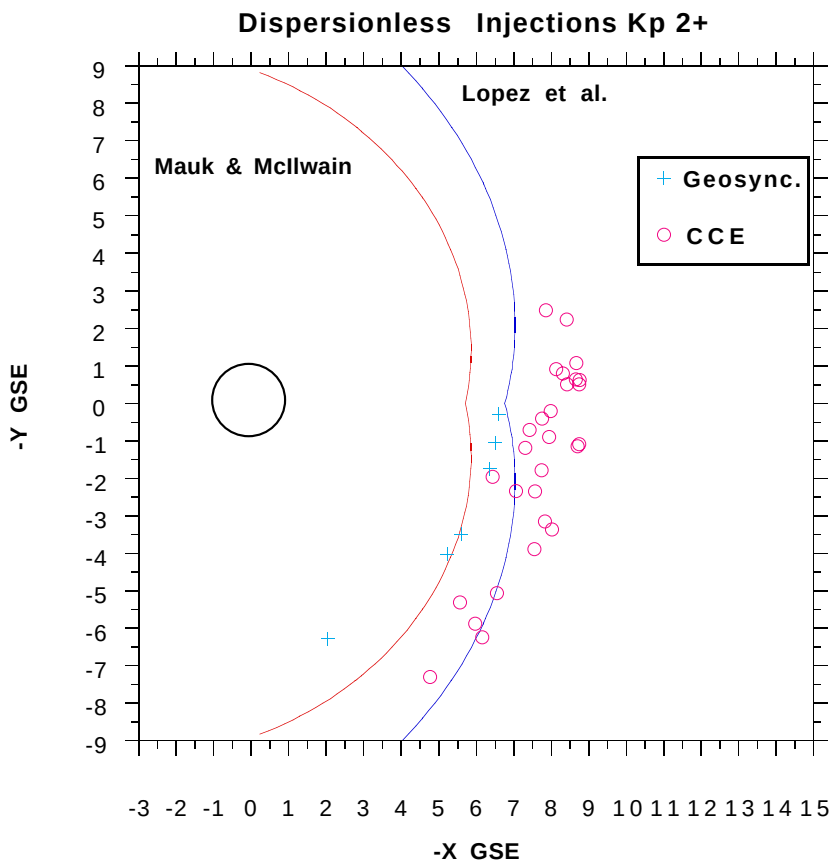
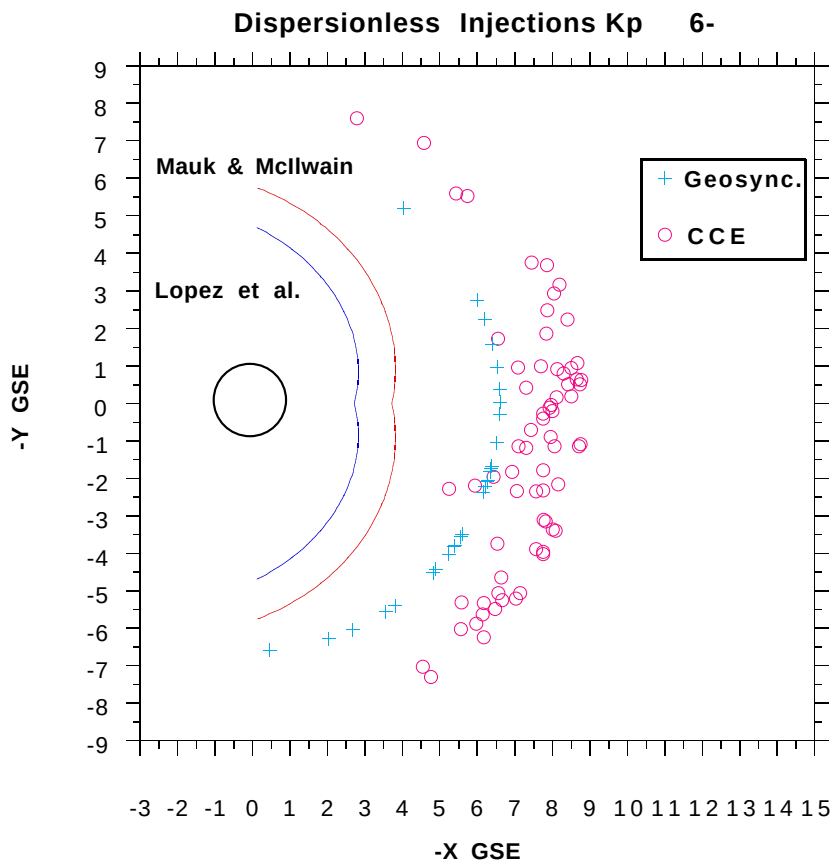
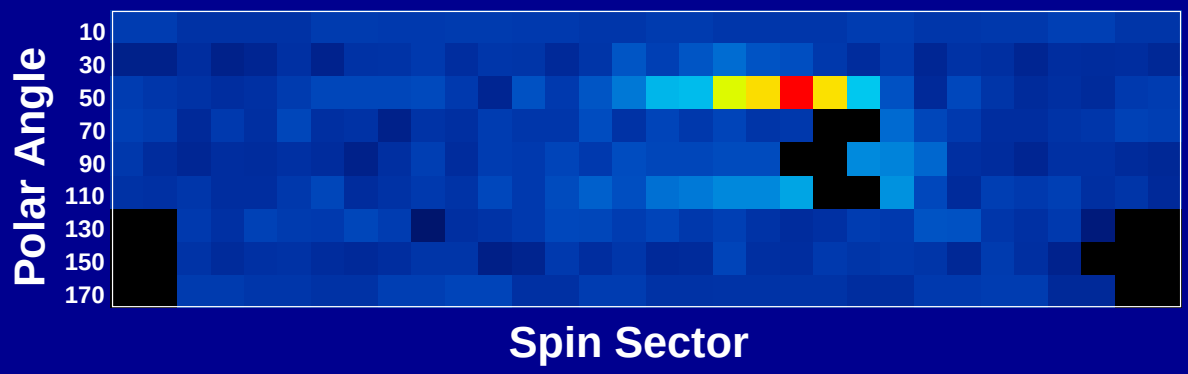


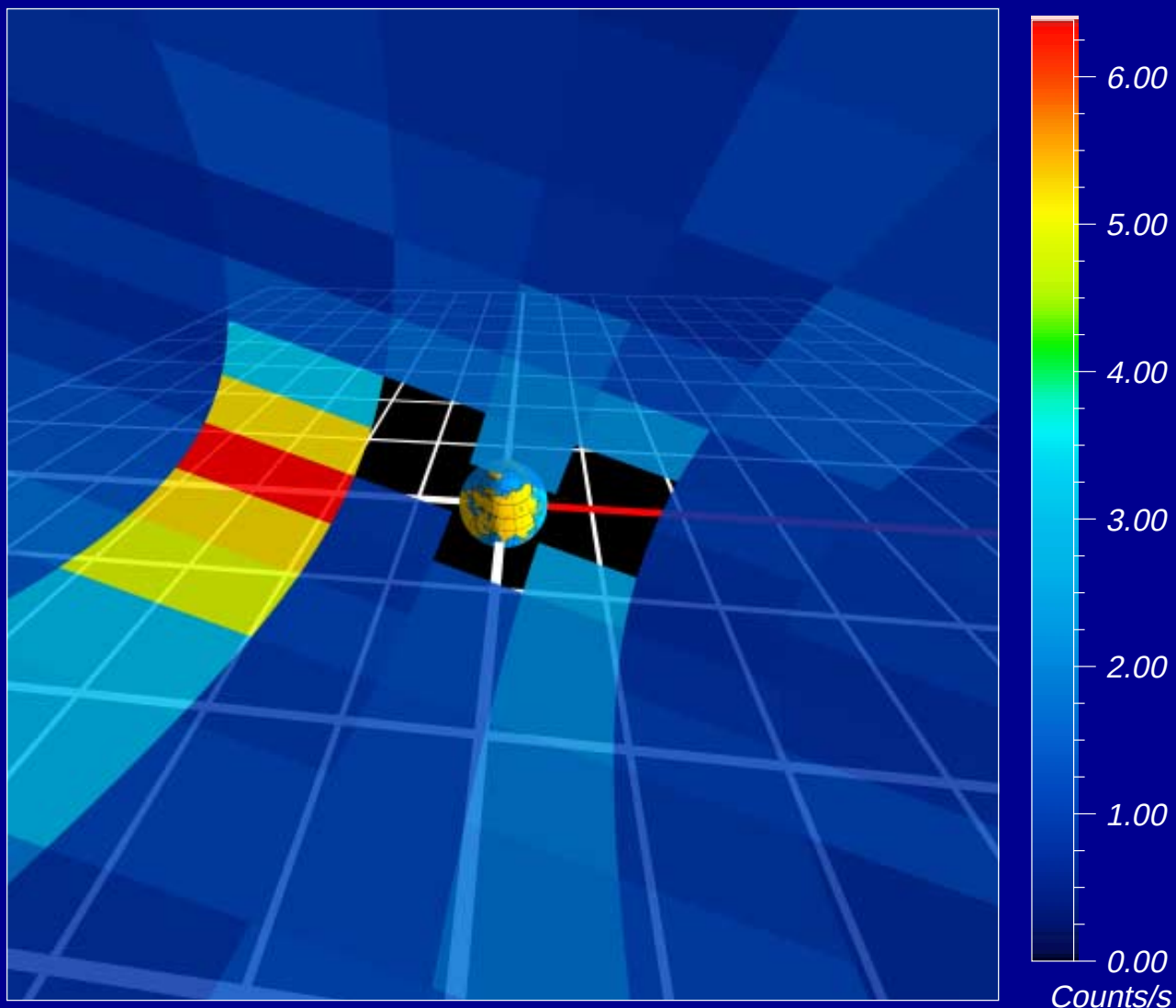


POLAR CEPPAD/IPS

ENA/Substorm Associations

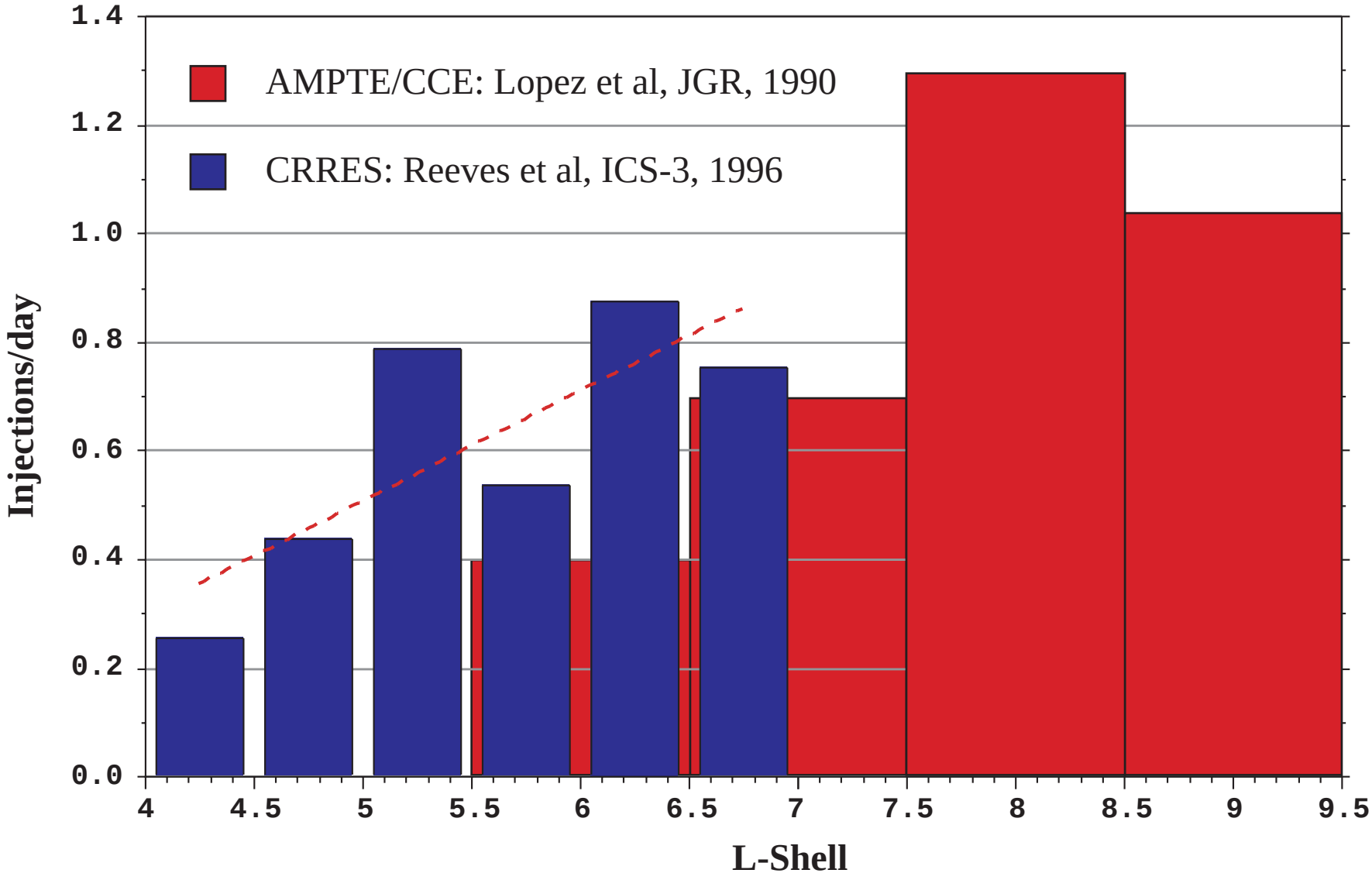
July 31, 1996 (0915 - 1000 UT)





125 degree FOV

Injection Probability vs L



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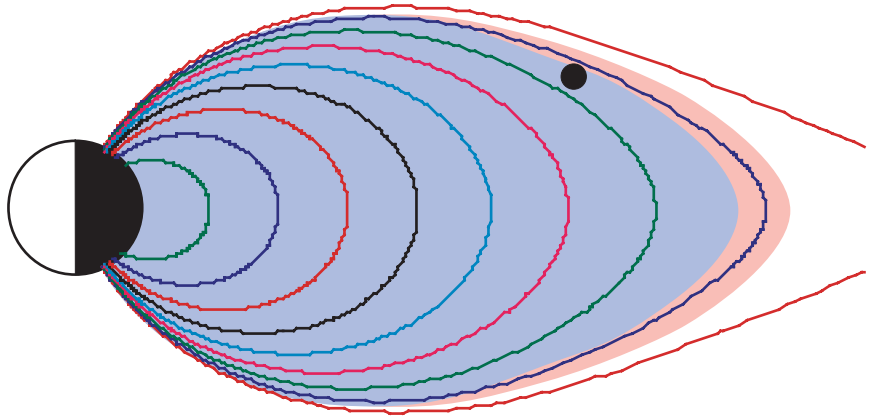
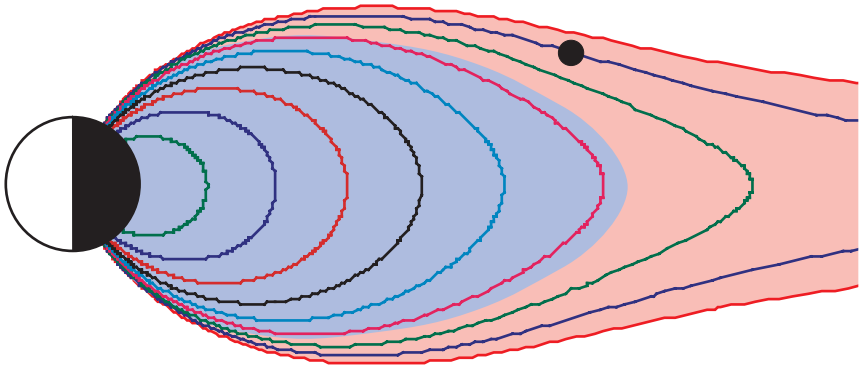


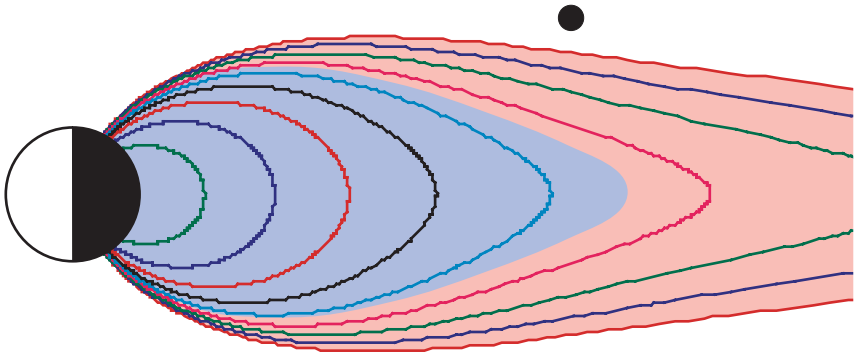
Quiet Field and Particle Boundaries

Field-aligned particles are shwon in pink.
Equatorial particles are shown in blue.
Note that even geosynchronous satellites are off the magnetic equator.



Partial Dropout and Cigar Phase

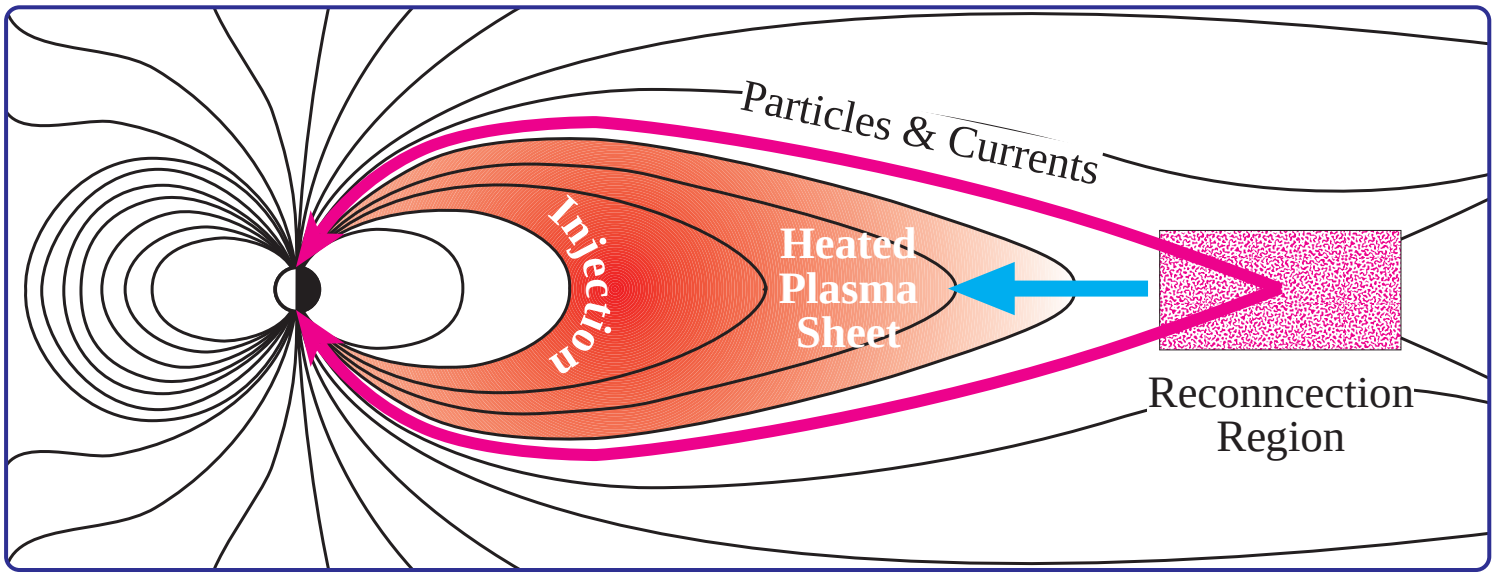
When the field stretches, equatorial particles move earthward while field-aligned particles move tailward. The result is both a dropout of particles and a cigar-like pitch angle distribution.



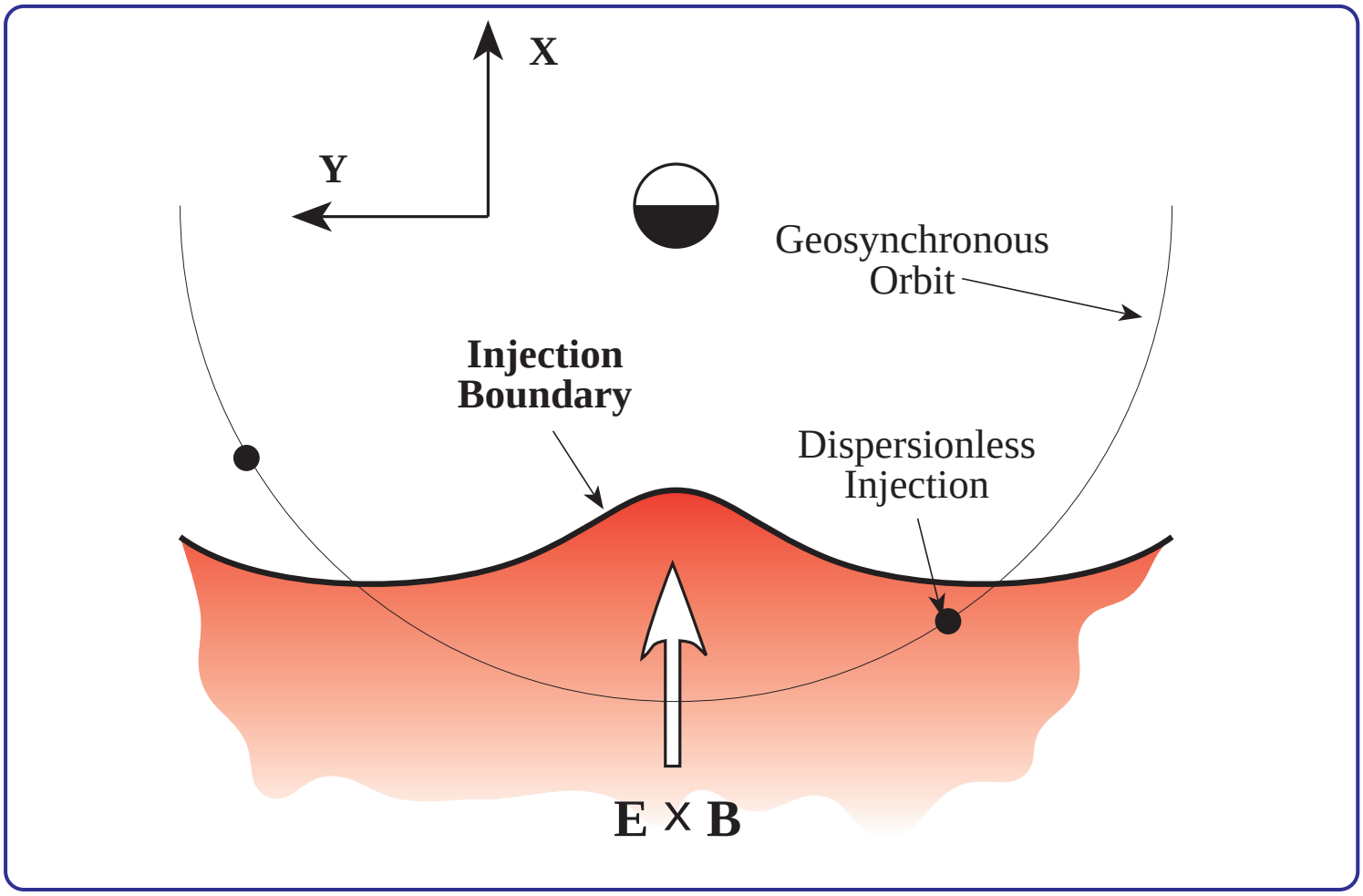
Complete Dropout, Outside Trapping Boundary

Traditional Picture of Substorm Injections

Near-Earth Neutral Line



Convection Surge



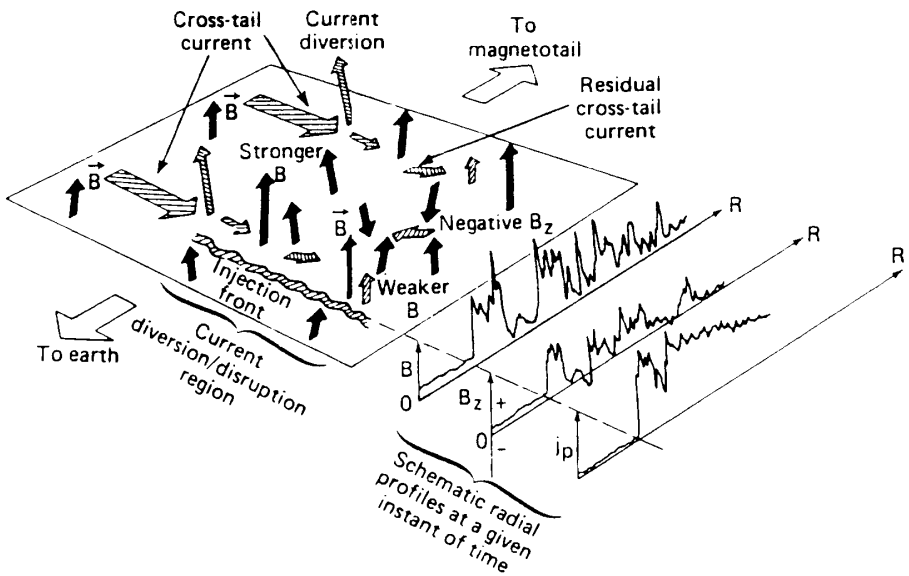
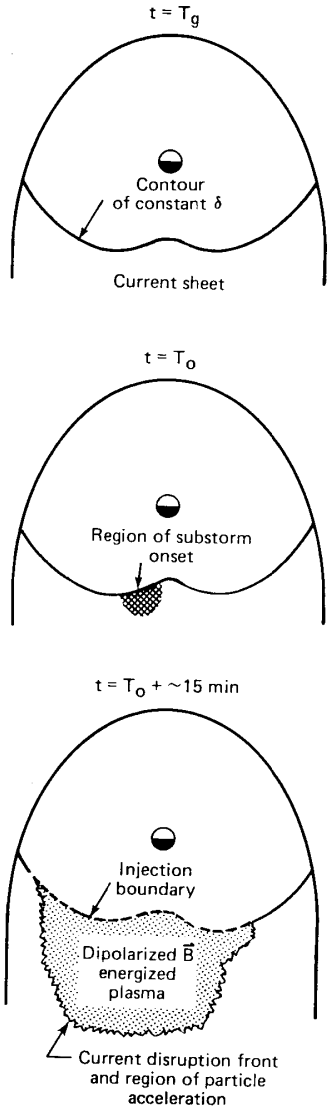


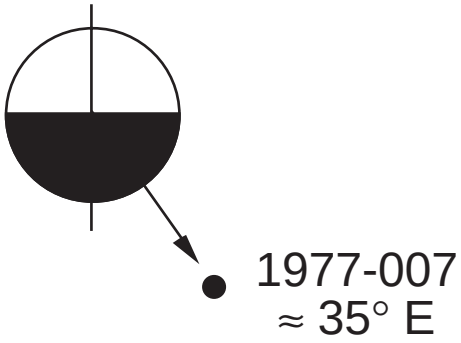
Fig. 4. A schematic diagram illustrating the complex magnetic field geometry and localized sites of particle energization in the near-earth neutral sheet of the current disruption region, as suggested from this analysis.

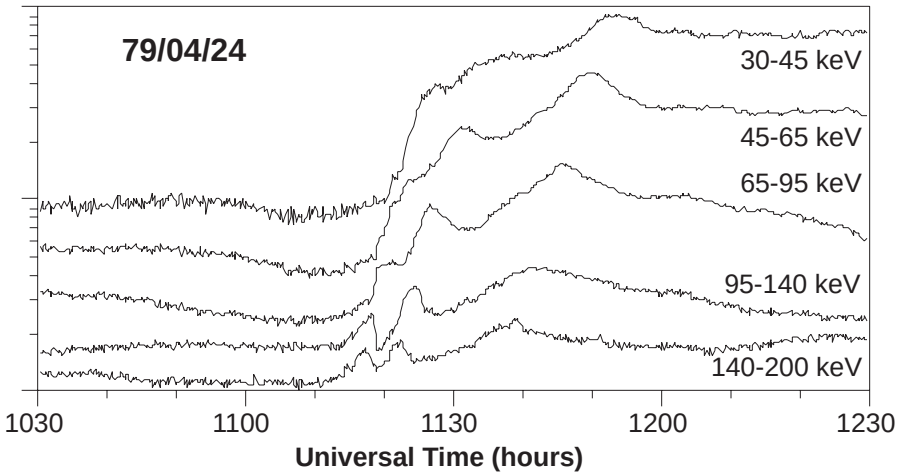
Lui et al., GRL, 1990

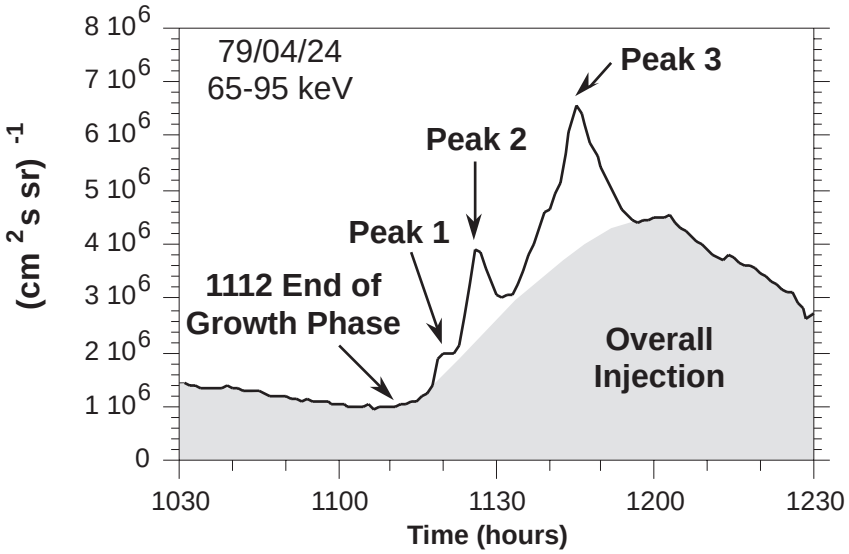


Lopez et al., JGR, 1990

CDAW-7 Substorm: Multiple Injection

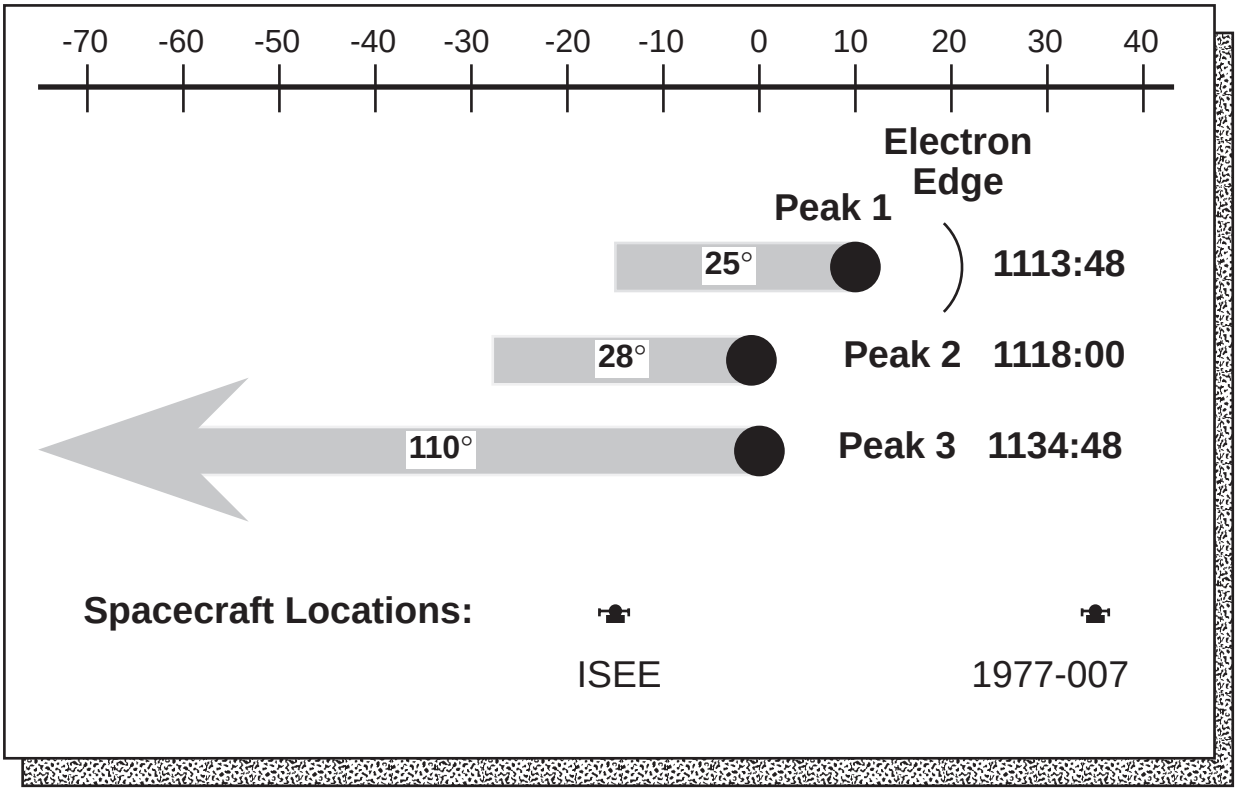


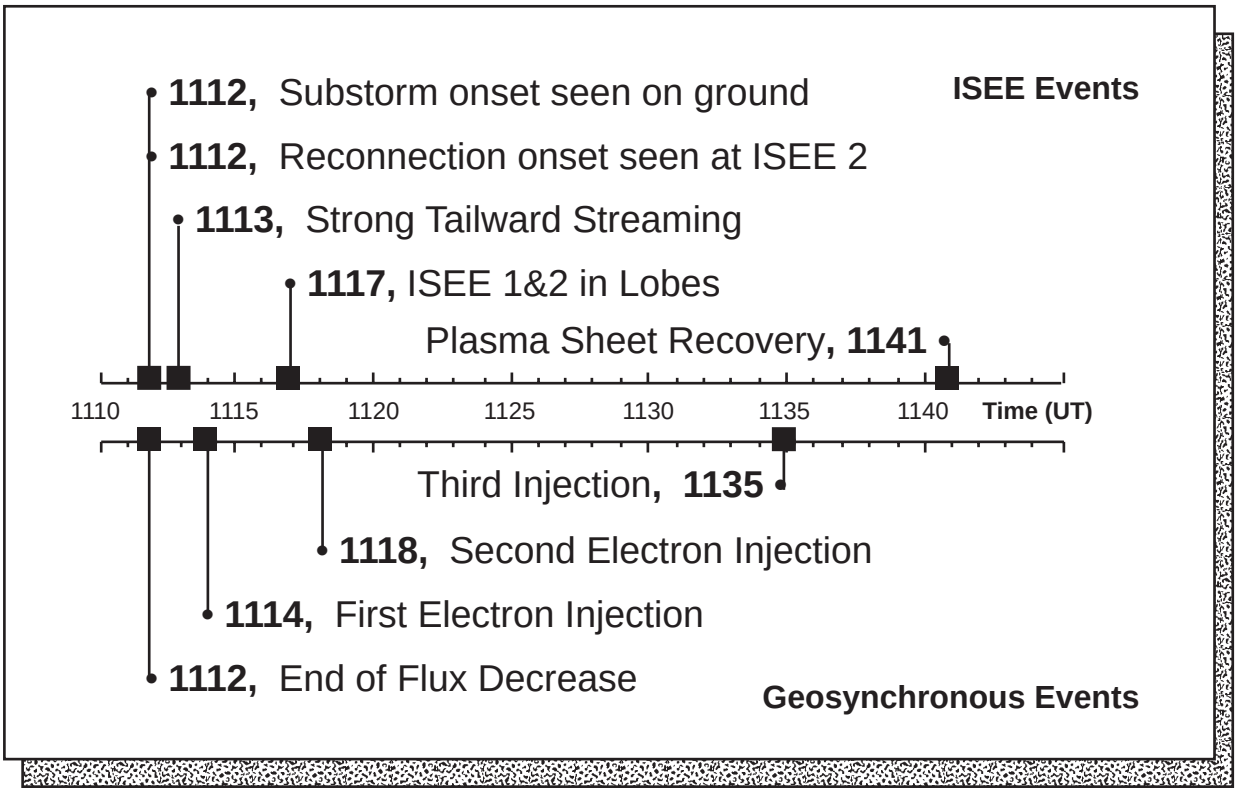




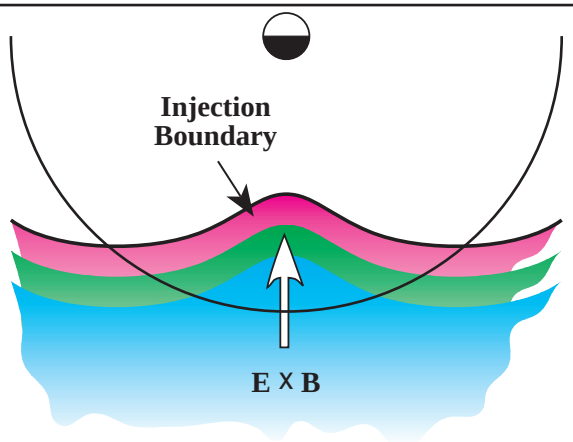
Reeves et al., JGR 1992

CDAW-7 Substorm: Event Timelines

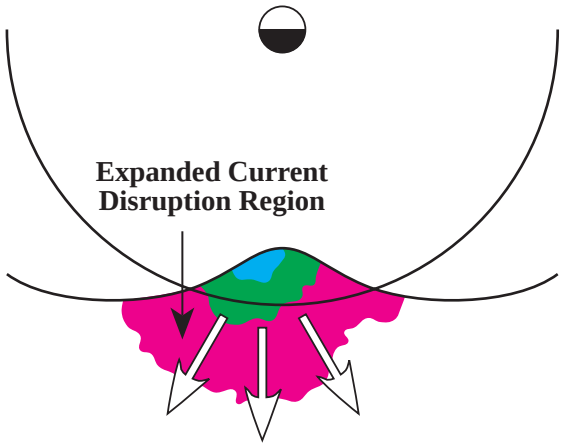




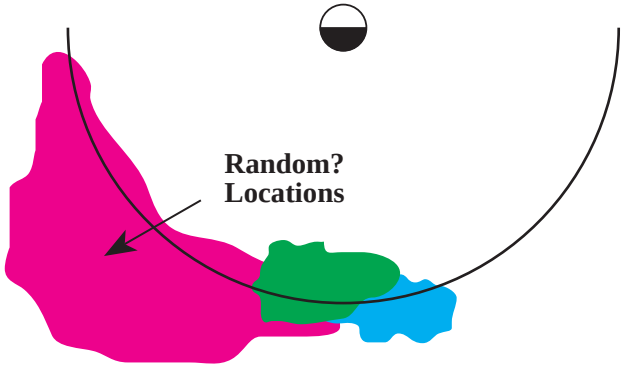
Reeves et al., JGR, 1992



The **Convection Surge** mechanism proposed by Mauk & McIlwain [1974] and Moore et al., [1981] predicts propagation earthward and away from local midnight. The propagation is due to ExB drift from induction as the field dipolarizes.



The "**Current Disruption**" model proposes that the injection boundary is due to a spatial limit on the region of stability. A substorm injection starts on this boundary, near the earth, the apparent direction of propagation is tailward and radially away from midnight [Lopez et al., 1990].



The term **Patchy Injection** was proposed by Reeves et al. [1992, 1993] to explain multiple substorm injections. These study were limited to observing propagation in local time. They found that the injections in multiple onset substorms overlapped in local time.

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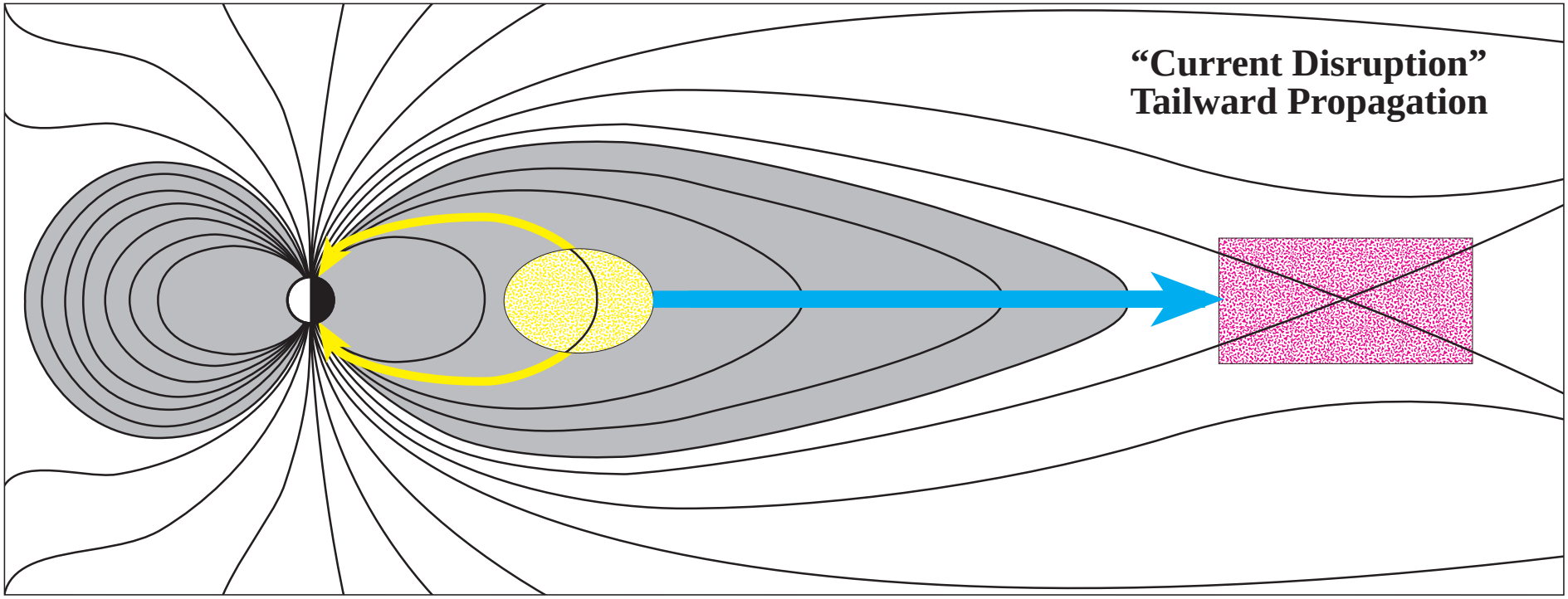
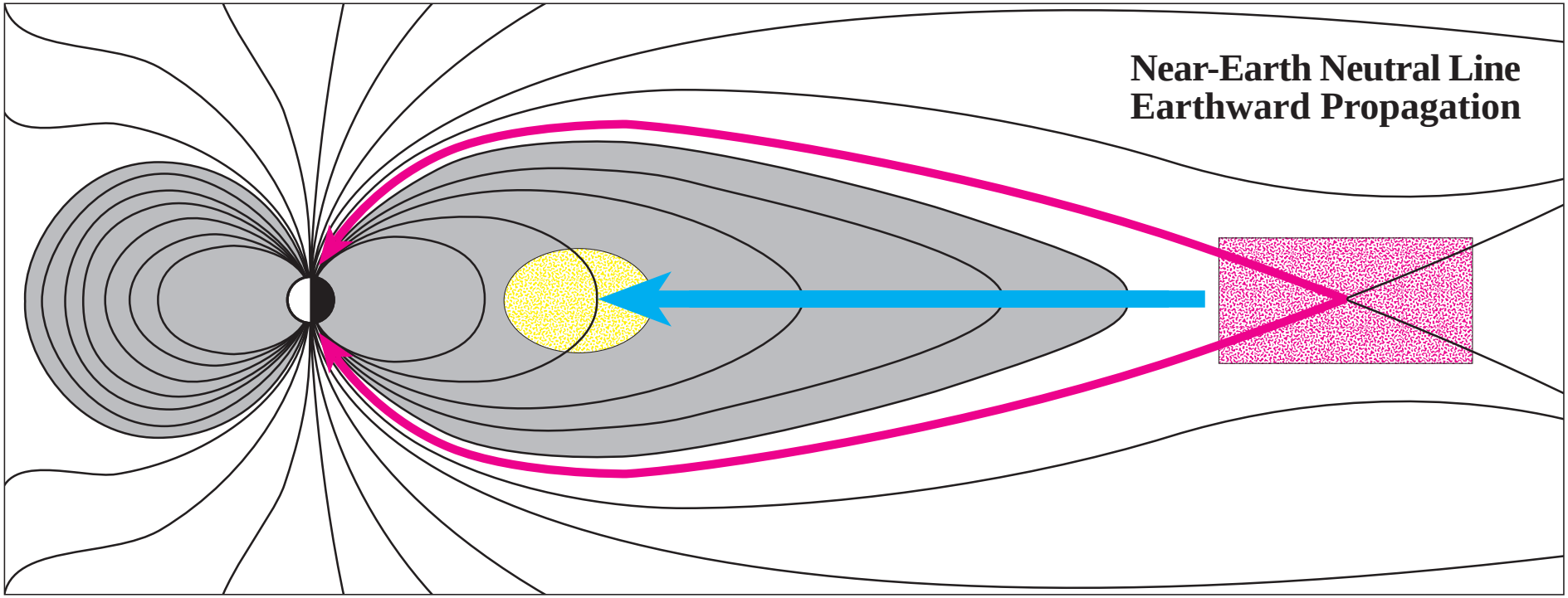
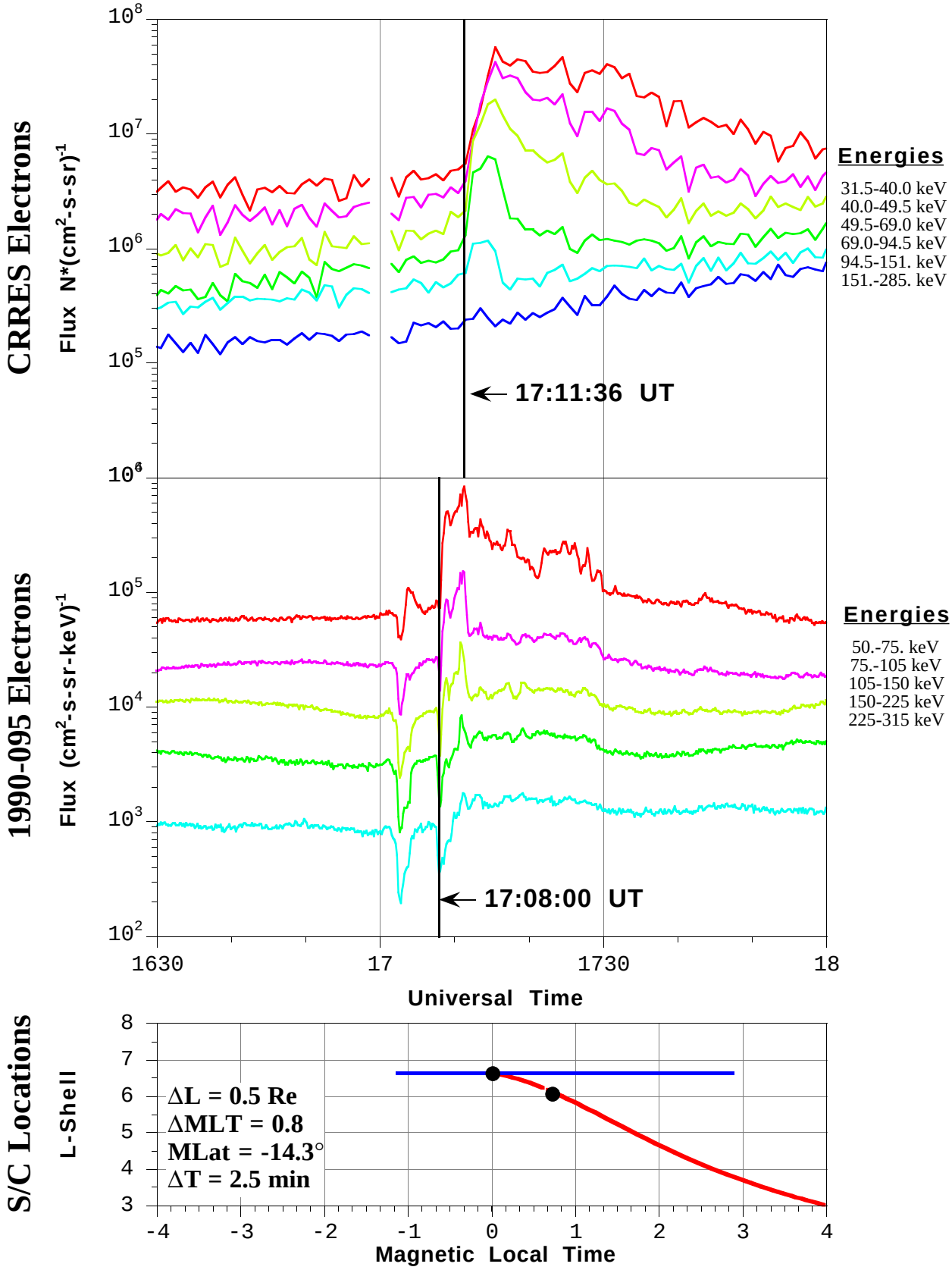




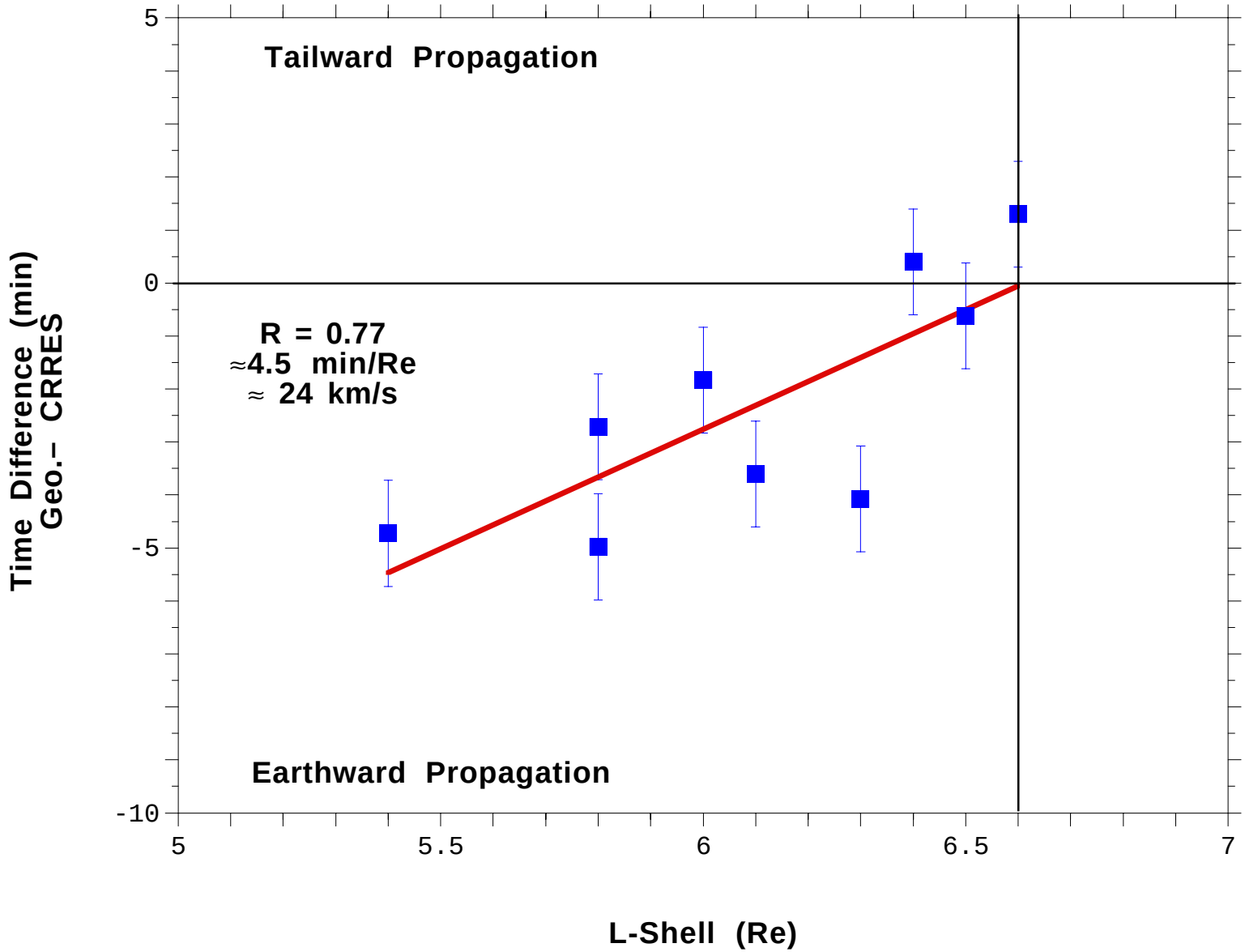
Reeves et al., ICS-3 1996

February 12 1991, CRRES Orbit 491



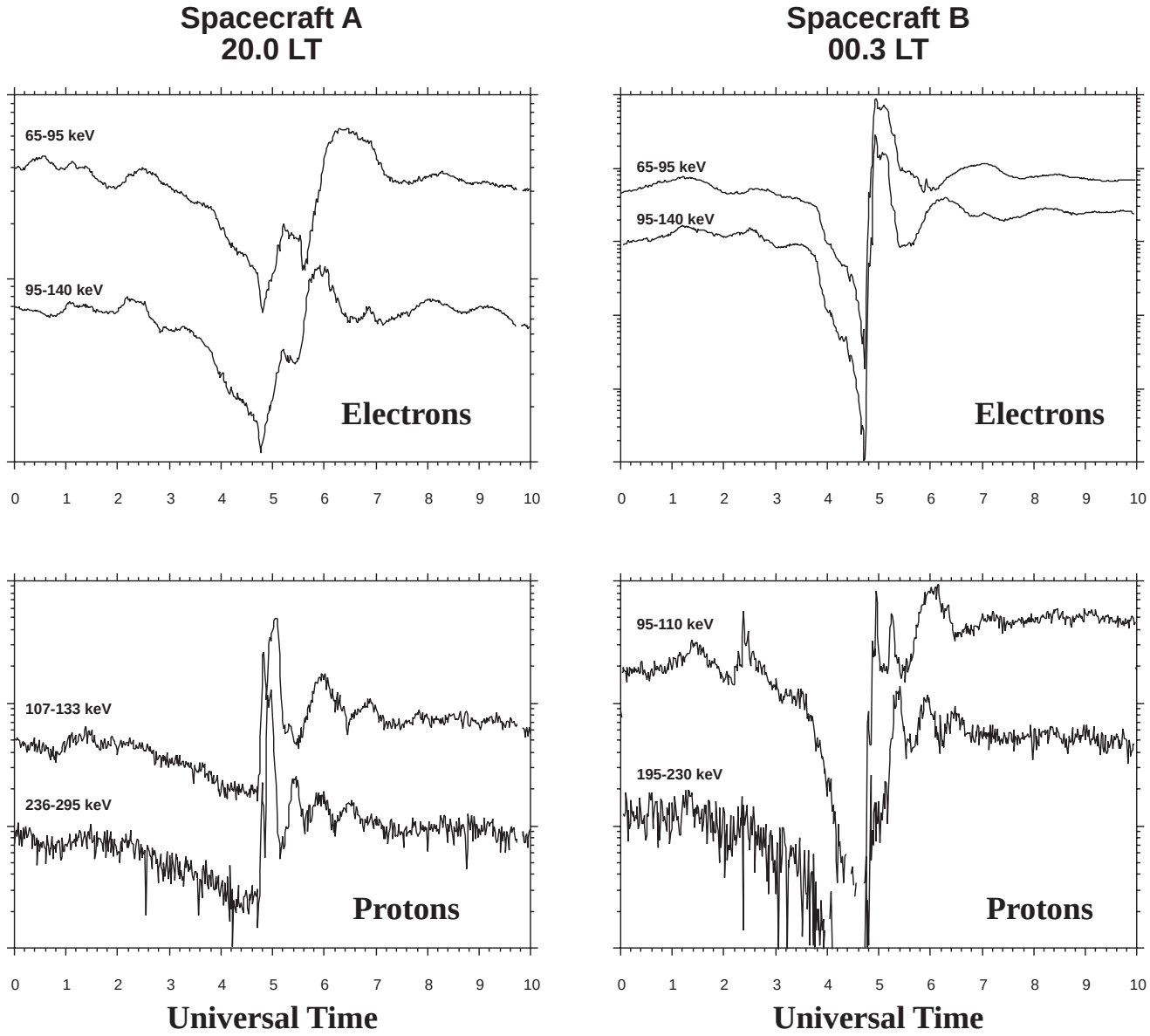
Reeves et al.
ICS-3, 1996

CRRES and LANL Within ±1 hr Local Time

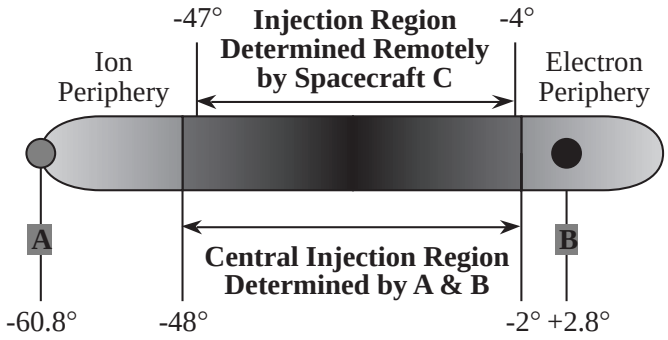


Reeves et al., ICS-3, 1996

Dispersionless proton njections can be observed without dispersionless electron injections (and visa versa).



The Injection Periphery Region



Reeves et al., JGR, 1991

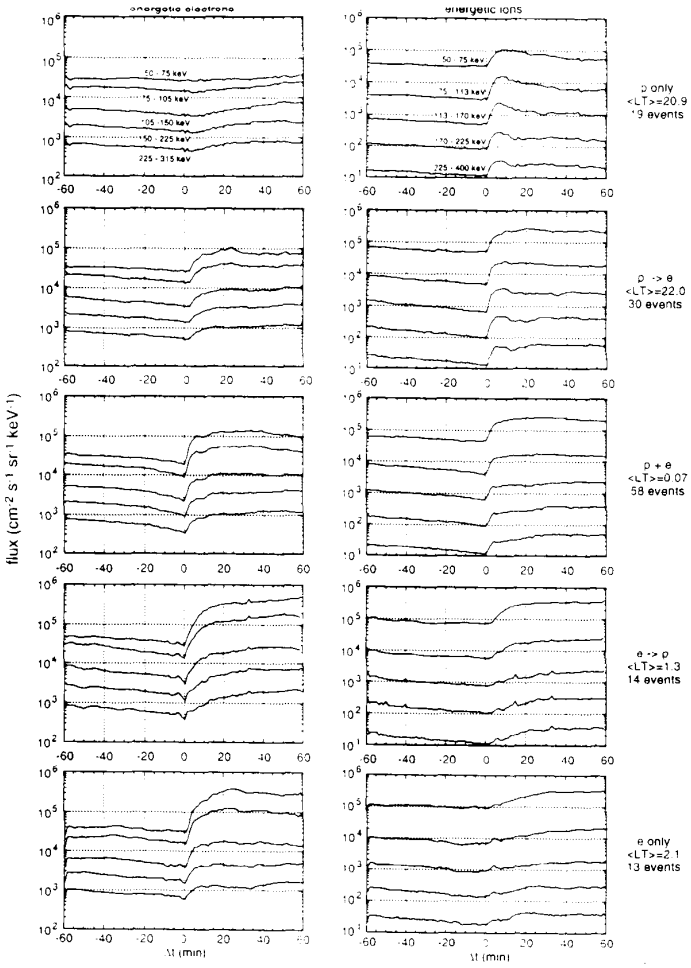


Figure 3. Average fluxes of energetic (left) electrons and (right) ions from the superposed epoch analysis of 134 injection events. The epoch $\Delta t = 0$ represents the onset of the flux increase. Different curves in each plot correspond to different energies as defined in topmost plots; the energy decreases monotonically from the top curve to the bottom curve in each case. The five vertical plots correspond to the five categories of events defined in the text and in the caption of Figure 2. The average local times of the onsets and the number of events in each category are given to the right.

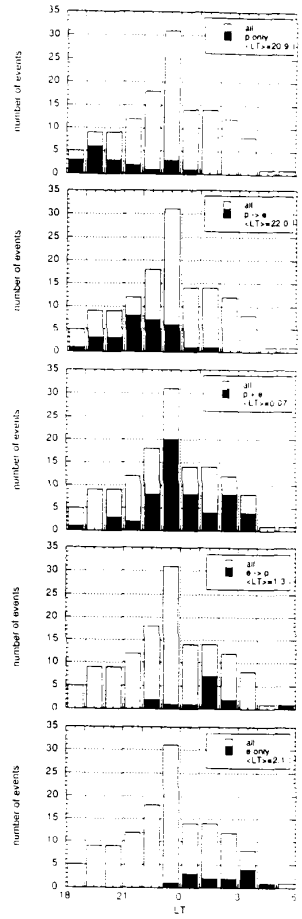


Figure 2. Local time distribution of 134 dispersionless injections in 1990 investigated in the paper. The five plots correspond to five categories of events, as defined in the text, (from top to bottom) pure ion injections without strong accompanying electron injections, ion injections followed by an electron injection with 2-min delay or more ($p \rightarrow e$), simultaneous ion and electron injections ($p + e$), electron injections followed by an ion injection with 2-min delay or more ($e \rightarrow p$), and pure electron injections. The solid bars indicate the number of events in each category, while the open bars show the total number of events in each local time bin.

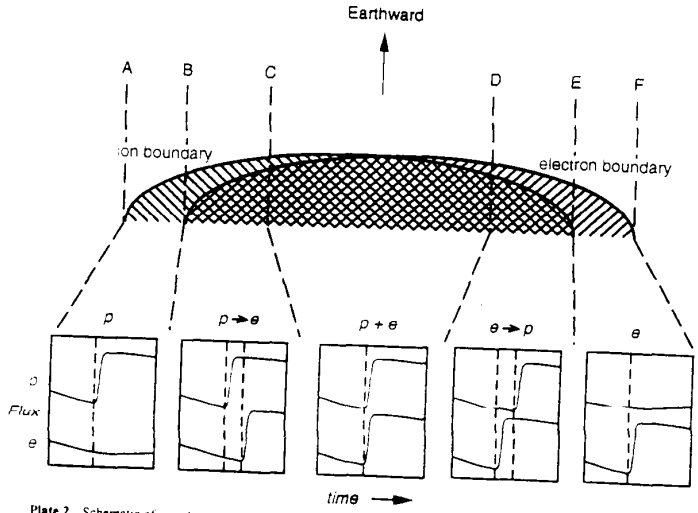
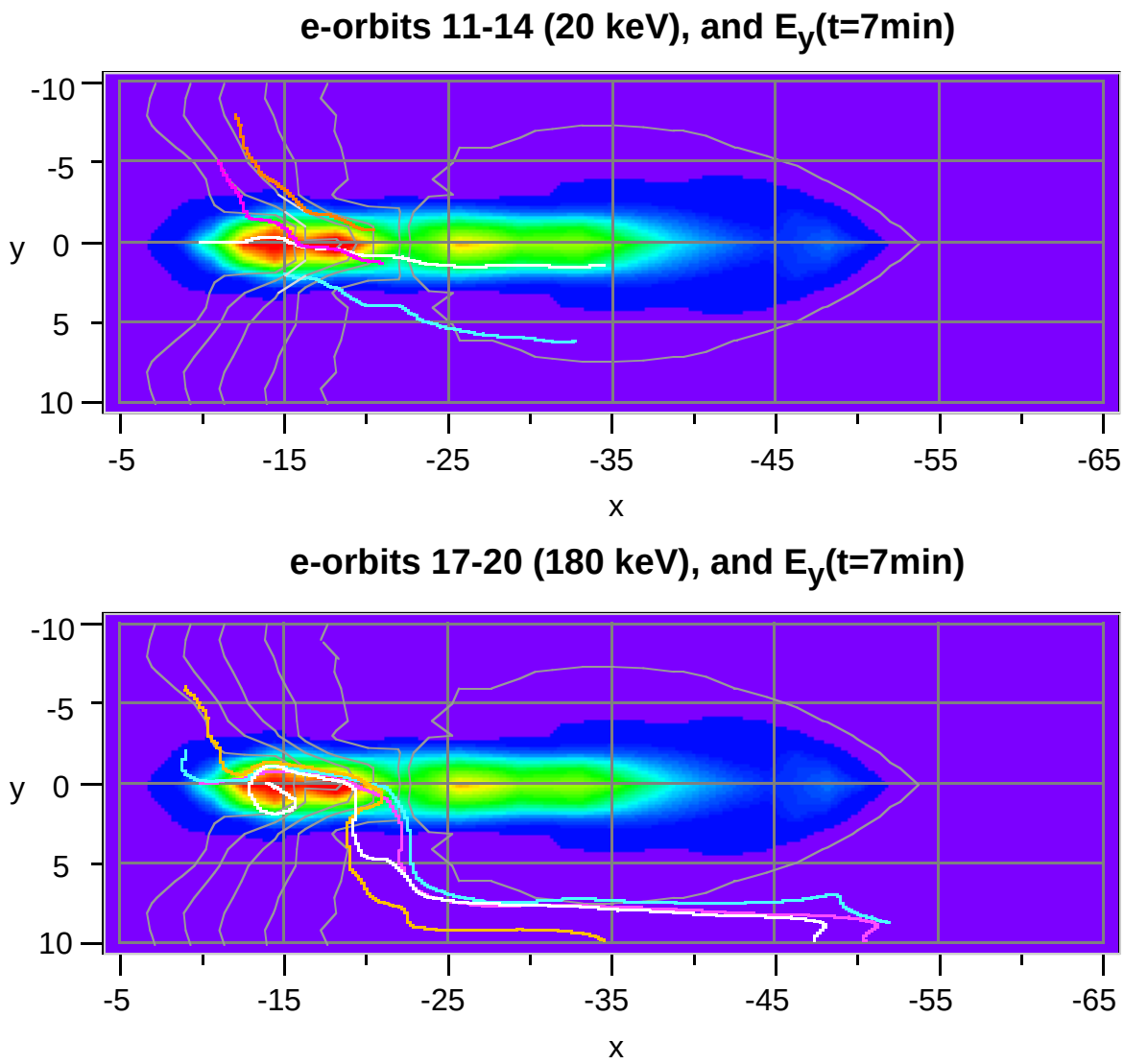
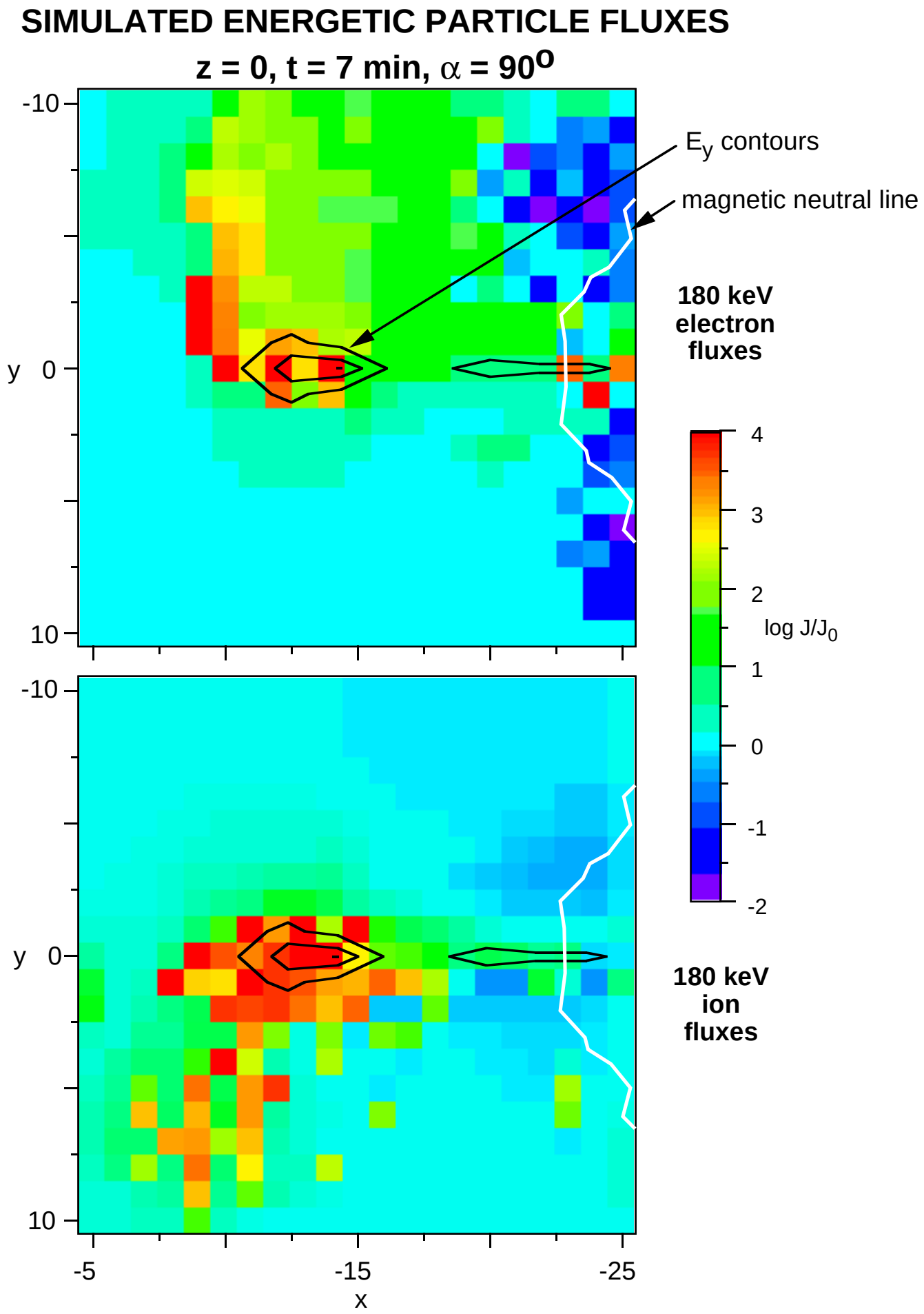
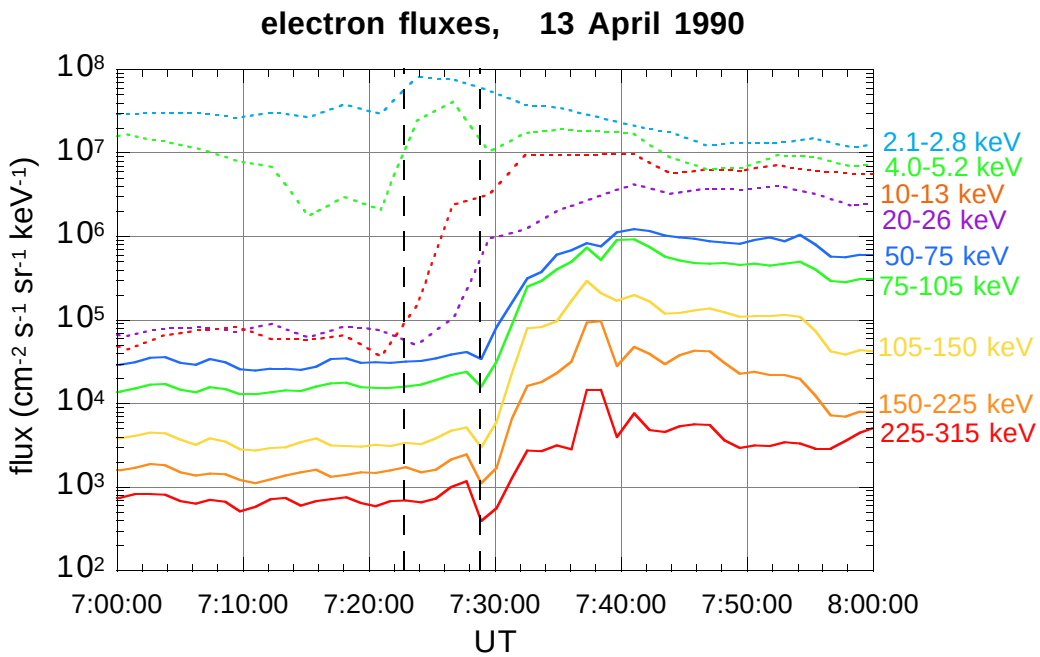


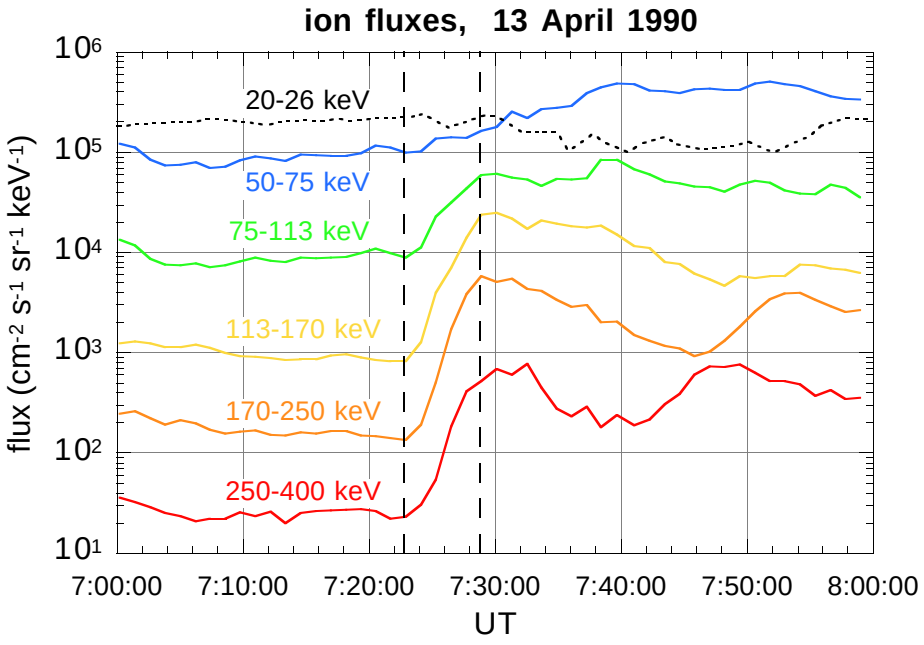
Plate 2. Schematic of nonidentical ion and electron injection boundaries in the equatorial plane. If such boundaries move earthward toward positive x, dispersionless ion injections only would be observed between lines A and B, delayed $p \rightarrow e$ injections between lines B and C, simultaneous $p + e$ injections (within a given time resolution) between lines C and D, delayed $e \rightarrow p$ injections between lines D and E, and electron injections only between lines E and F. Westward (left) of line A one would see dispersed ion events (and highly dispersed electron [illegible] echos) and eastward (right) of [illegible]



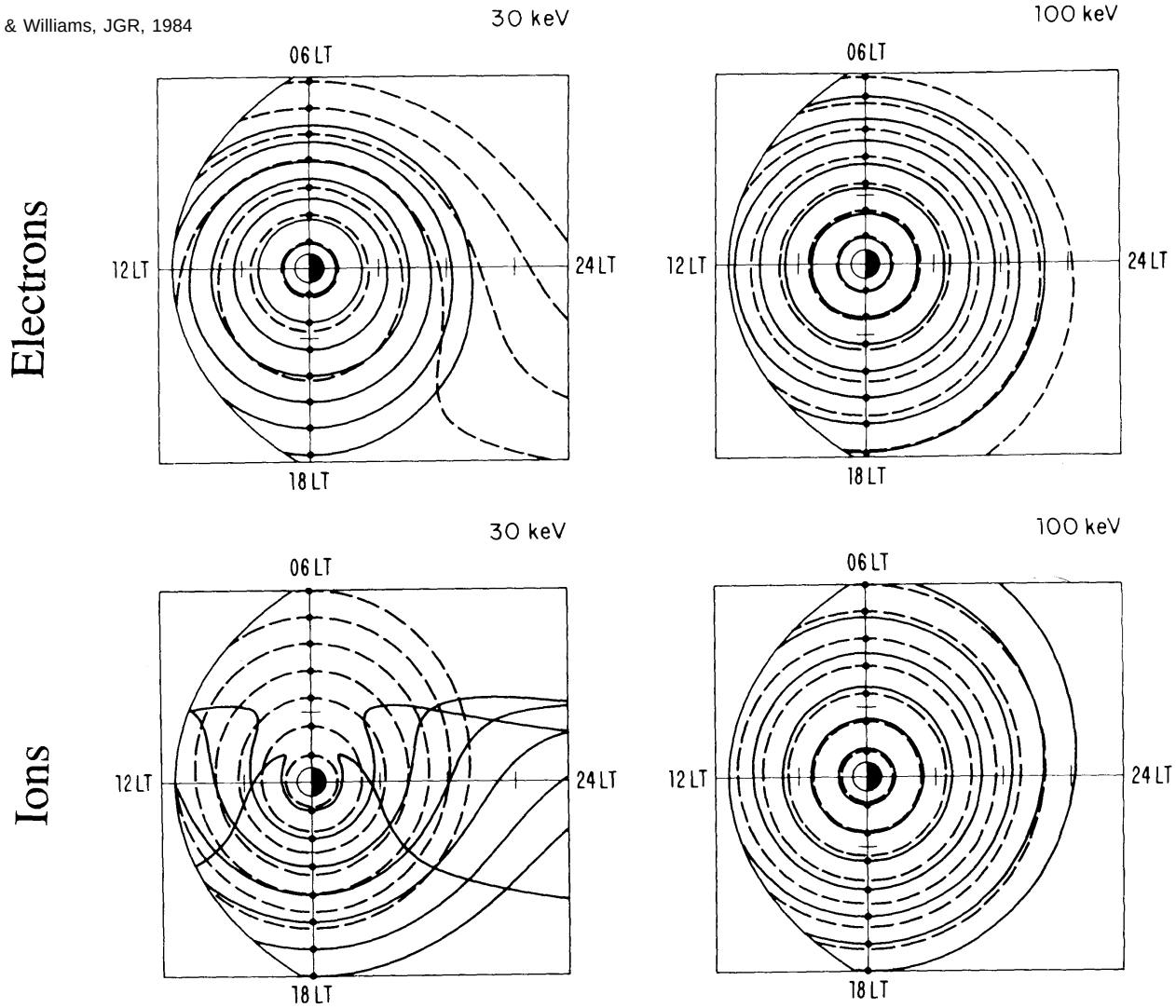
Birn et al., JGR, 1997


SIMULATED ENERGETIC PARTICLE FLUXES
z = 0, t = 7 min, α = 90°
-10
y 0
10
-10
y 0
10
-5
-15
-25
x
E_y contours
magnetic neutral line
180 keV electron fluxes
180 keV ion fluxes
4
3
2
1
0
-1
-2
log J/J_0


electron fluxes, 13 April 1990
flux (cm-2 s-1 sr-1 keV-1)
10^8
10^7
10^6
10^5
10^4
10^3
10^2
2.1-2.8 keV
4.0-5.2 keV
10-13 keV
20-26 keV
50-75 keV
75-105 keV
105-150 keV
150-225 keV
225-315 keV
7:00:00
7:10:00
7:20:00
7:30:00
7:40:00
7:50:00
8:00:00
UT


ion fluxes, 13 April 1990
flux (cm-2 s-1 sr-1 keV-1)
10^6
10^5
10^4
10^3
10^2
10^1
20-26 keV
50-75 keV
75-113 keV
113-170 keV
170-250 keV
250-400 keV
7:00:00
7:10:00
7:20:00
7:30:00
7:40:00
7:50:00
8:00:00
UT

Lyons & Williams, JGR, 1984



What is Known...

* Substorm injections probably occur for all substorms.
* They occur within a few minutes of onset times measured by Pi2, auroral breakup, magnetic bays, or dipolarization.
* They are generally on field lines that map to the auroral zone.
* The source of the particles is the magnetotail – “new” particles
* Injected particles are accelerated and transported in substorm inductive electric fields.
* The injection region propagates slowly earthward at L<6.6. (This helps explain injection “delays”.)
* Injections can penetrate as deeply as L=4.5 but occurrence rate decreases.
* Ions and electrons can be separated in space and can exhibit quite different temporal profiles.

What is Not Known...

* Why are substorm injections so complicated?
  Electron and ion injections are frequently different.
  Pseudo-breakups & multiple injections are the rule.

*What is the precise correlation with: the substorm current wedge, Pi2s, auroral activity?

* What controls the spatial dimension of injections?

* How deeply can they penetrate?

* Do they spread azimuthally?

* What controls the intensity of injections and how should it be measured?

* Are storm-time injections the same as substorm injections?