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Title: GPS Constellation Energetic Electron Observations

Author(s): Reiner Friedel, 120364, ISR-1, LANL
Thomas Cayton, 084731, ISR-1, LANL

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GPS Constellation Energetic Electron Observations

R. Friedel[1], T. Cayton[1]

[1]ISR-1, Los Alamos National Laboratory, USA

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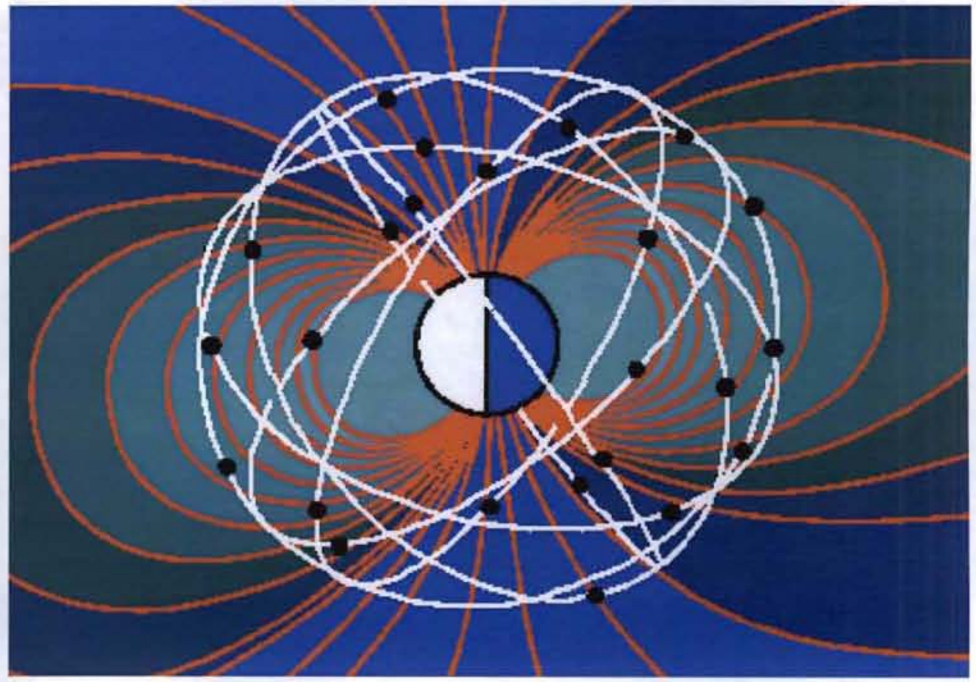
1. Abstract

Los Alamos has been flying energetic particle detectors on the GPS constellation for over two solar cycles. The recent generation of detectors the Combined X-ray Dosimeters (CXD), is currently flying on 9 GPS satellites, with a further two BDD-IIR type detectors on three other GPS satellites. This constellation of detectors delivers unprecedented temporal and spatial particle data in the outer radiation belt from L=4 outward, with a combined 1 hour temporal resolution and 0.1 L resolution in the L=4 to 8 region. This data shows extremely rapid and drastic variations in the outer electron radiation belt, revealing electron loss processes on timescales of an hour or less, and energization processes on timescales of 12 hours or less - both these observations challenging current theories of electron loss and energization processes: The time scale, energy range and radial extend of loss processes is inconsistent with current wave-particle interaction theories (EMIC waves) and challenges existing theories on possible outward radial diffusion rates; while chorus-wave energization processes are generally though to operate on the timescale of days. The GPS energetic electron data offers not only challenges to conventional wisdom in this important area of radiation belt dynamics, but also the most detailed look yet at the rapid environmental variations in this area of near-Earth space.

2a. GPS data, orbit and instruments

GPS ns08	07/1983 – 02/1984	BDD-I
GPS ns10	10/1984 – 11/1992	BDD-I
GPS ns18	01/1990 – 12/1995	BDD-II
GPS ns24	11/1991 – 11/2000	BDD-II
GPS ns28	05/1992 – 09/1996	BDD-II
GPS ns39	07/1993 – 10/2005	BDD-II
GPS ns33	04/1996 – 01/2007	BDD-II
GPS ns41	12/2000 – today	BDD-IIR
GPS ns54	12/2002 – today	CXD
GPS ns56	02/2003 – today	CXD
GPS ns60	07/2004 – today	CXD
GPS ns61	11/2004 – today	CXD
GPS ns59	12/2004 – today	CXD
GPS ns53	10/2005 – today	CXD
GPS ns58	12/2006 – today	CXD
GPS ns55	10/2007 - today	CXD
GPS ns57	12/2007 – today	CXD
GPS ns48	02/2008 – today	BDD-IIR

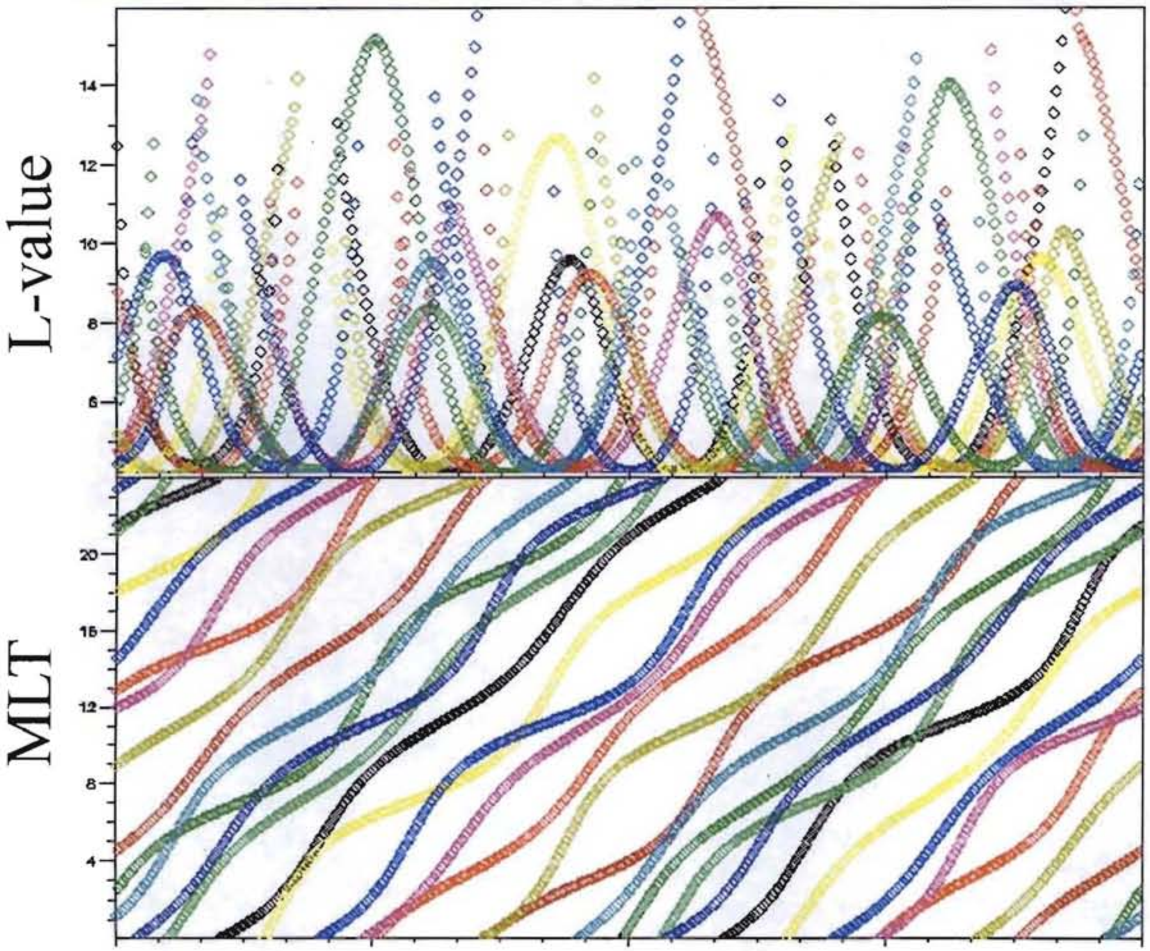
4 R_E circular, 50° inclination



100/200 keV – 10 MeV electrons

5/9 MeV – 60 MeV protons

2b. Multi-satellite orbit coverage – 9 instruments



One day – April 1, 2008

CXD instruments highly inter-calibrated – can be combined in L, time with NO adjustments.

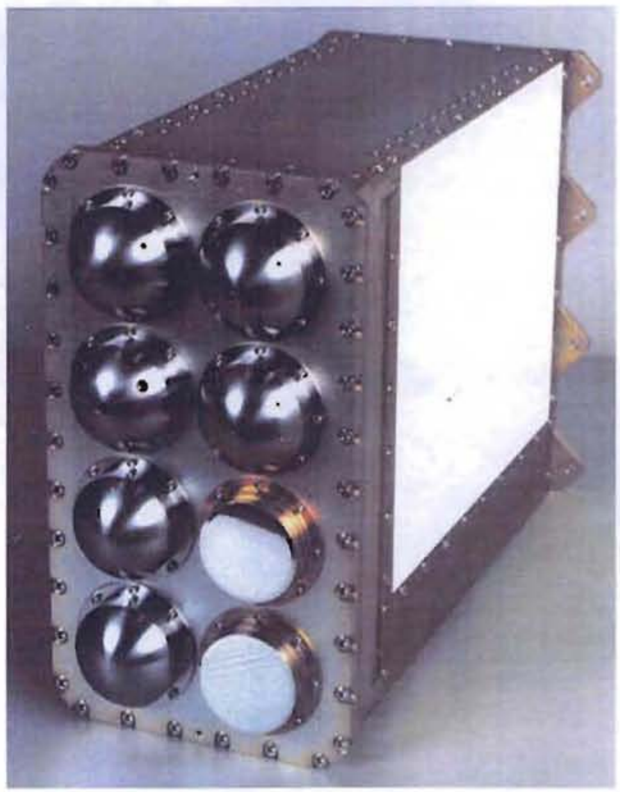
Yields unprecedented temporal and spatial coverage in region L = 4-10:

1hr in time
0.1 in L

2c. GPS environmental Monitoring Systems

BDD
Block II,IIA

BDD Block IIR

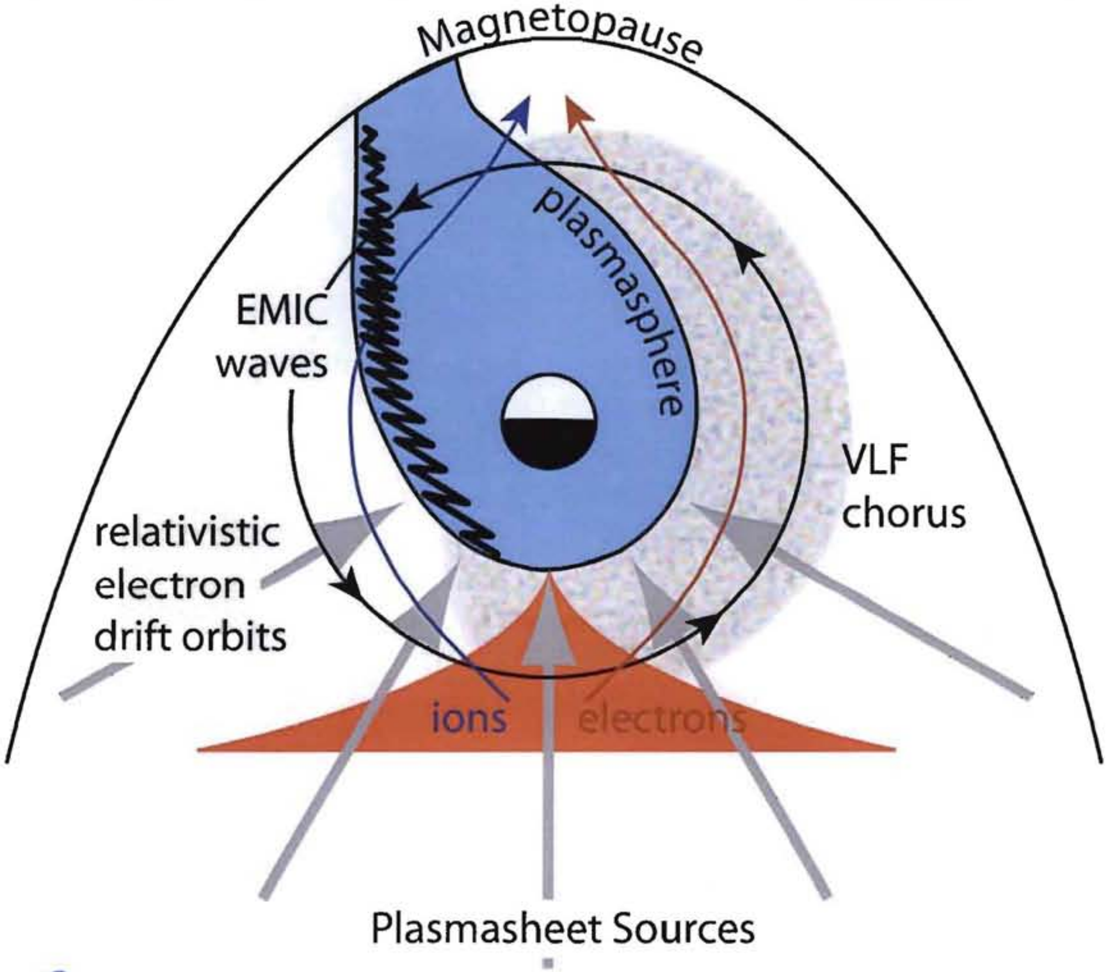


CXD Block IIR

3a. Science Background

- The controlling factors of the trapped energetic electron radiation belts are the balance between transport, loss and energization processes:
  - Radial transport due to magnetic and electric field perturbations can lead to energization by inward transport, or loss to the magnetopause by outward diffusion.
  - Energization can also be due to in-situ heating by wave-particle interactions. Energization is generally though to be caused by interactions with whistler-chorus waves.
  - Loss process can also be due to precipitation to the or magnetopause shadowing. Precipitation is generally thought to be the result of wave-particle interactions with either whistler chorus or EMIC waves, or a combination of both.

3b. Science Background – Current Picture



Plasmasheet:
Source of seed population (convection & impulsive injection)

Magnetopause:
Possible loss mechanism for intersecting distorted drift paths + outward diffusion

Waves:
Drifting electrons encounter several possible wave regions
- Hiss (loss) inside plasmasphere/ plumes,
- Chorus (energization) outside plasmasphere,
- EMIC (strong loss) at edge of plasmasphere / plumes.
- New: magnetosonic waves near equator

3c. Science Background – loss / energization theory

The only waves that are theoretically capable of producing rapid loss are EMIC waves – could lead to significant loss on timescales of the order of drift periods (10 of minutes for relativistic electrons):

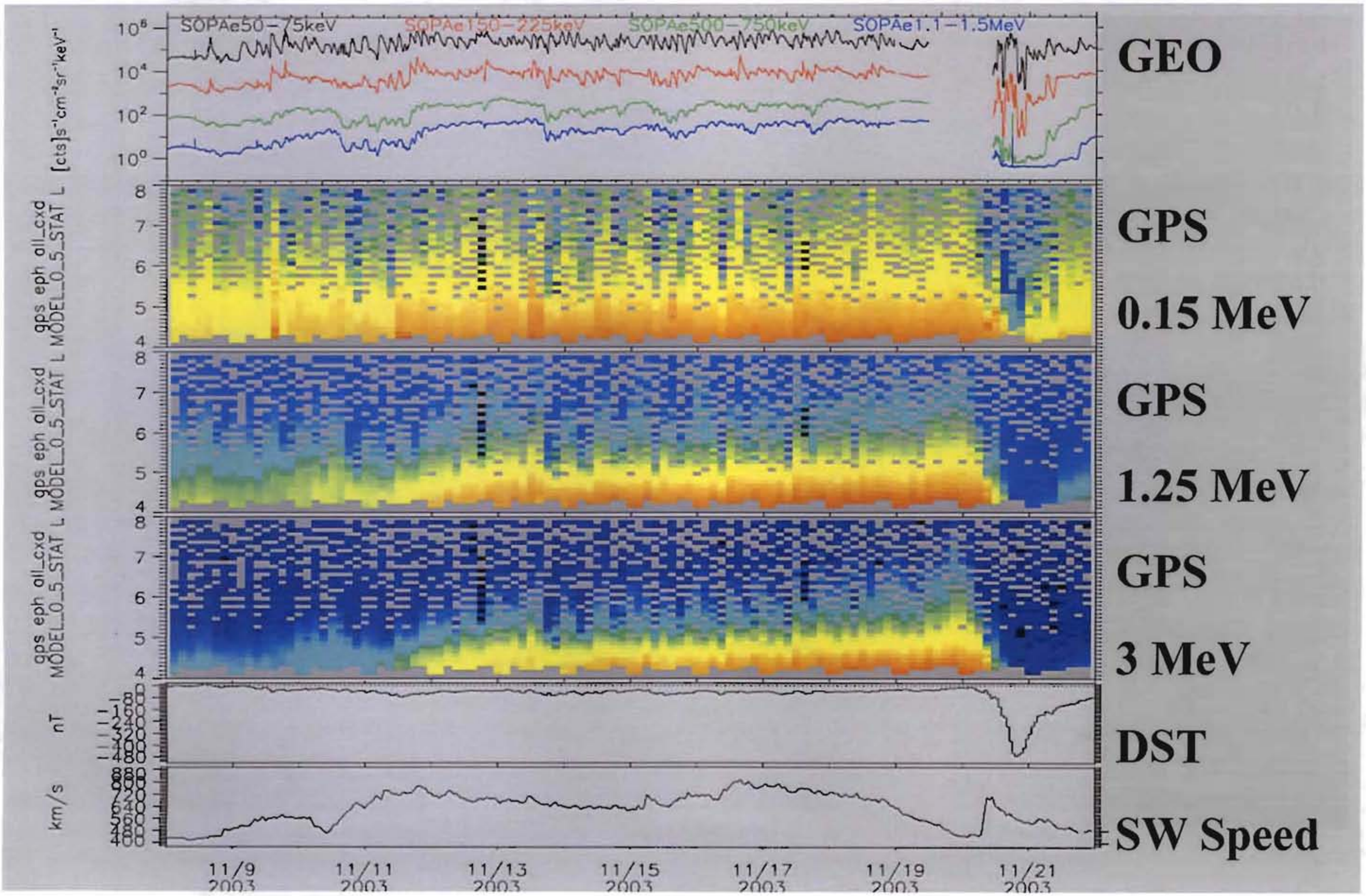
1. Presence of EMIC Waves: From unstable hot ion ring current population.
2. Satisfying resonance conditions: Low magnetic field strength, high density background plasma, elevated background heavy ion composition
3. For (2.) need to be in right region: Plume /L>4, -> L-dependent loss
4. EMIC waves lead to rapid loss of electrons at energies down to 0.5 MeV -> Energy dependant loss.

Whistler chorus waves are theoretically capable of producing energy diffusion leading to relativistic energies:

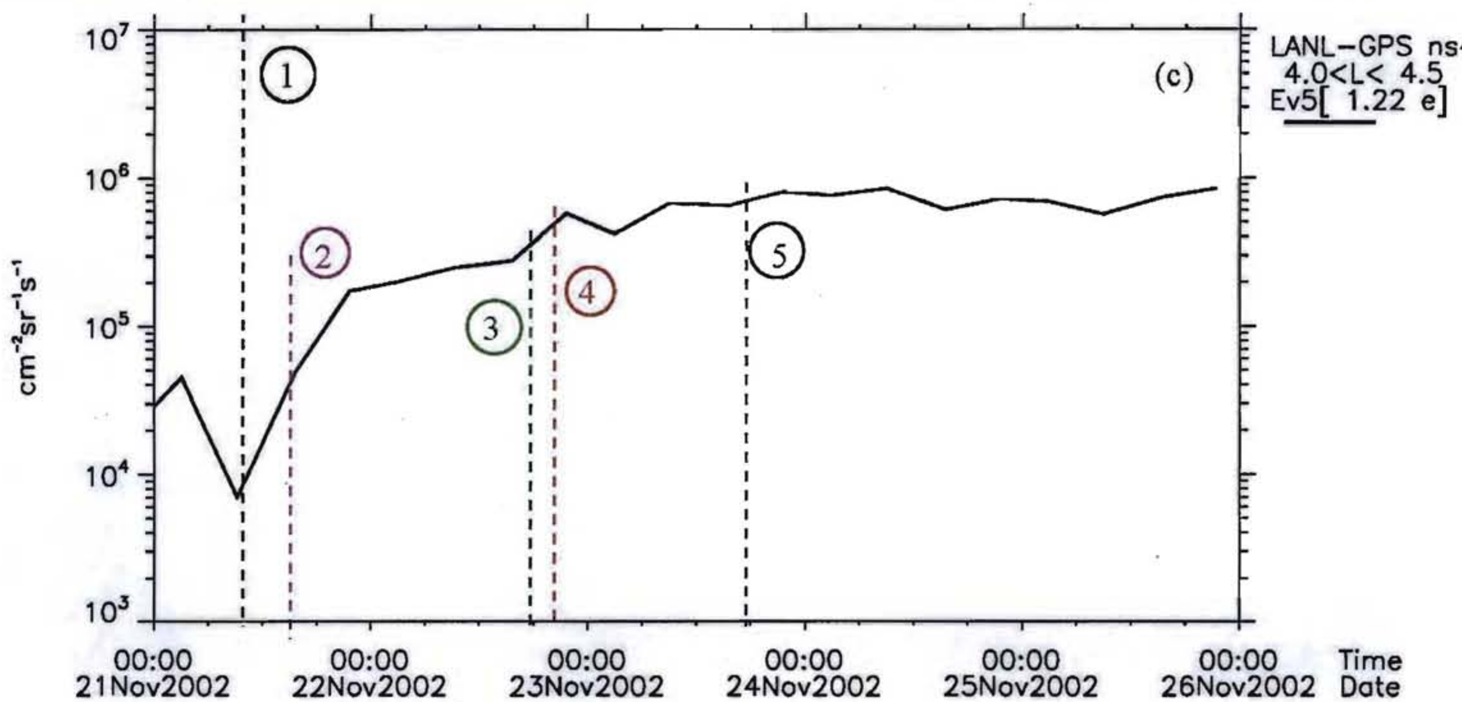
1. Presence of chorus waves: from unstable hot electron ring current injections.
2. Resonance conditions satisfied outside plasmapause.
3. Energization timescales no faster than 24 hrs.

3d. GEOcentric: Not the full picture!

November 2003 High Speed Stream event (3hr, 0.10L)

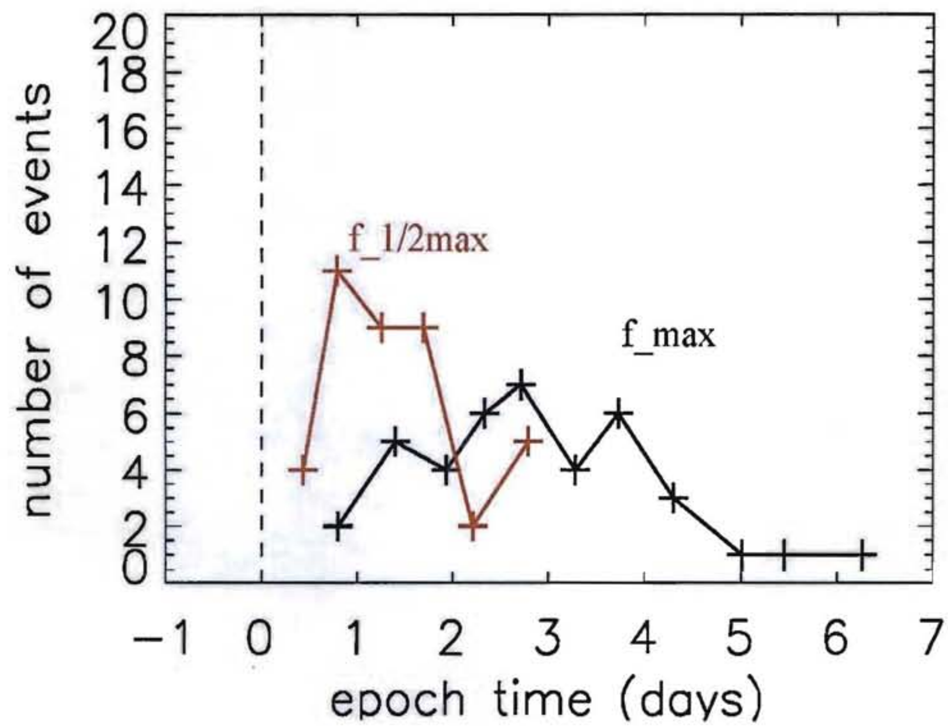


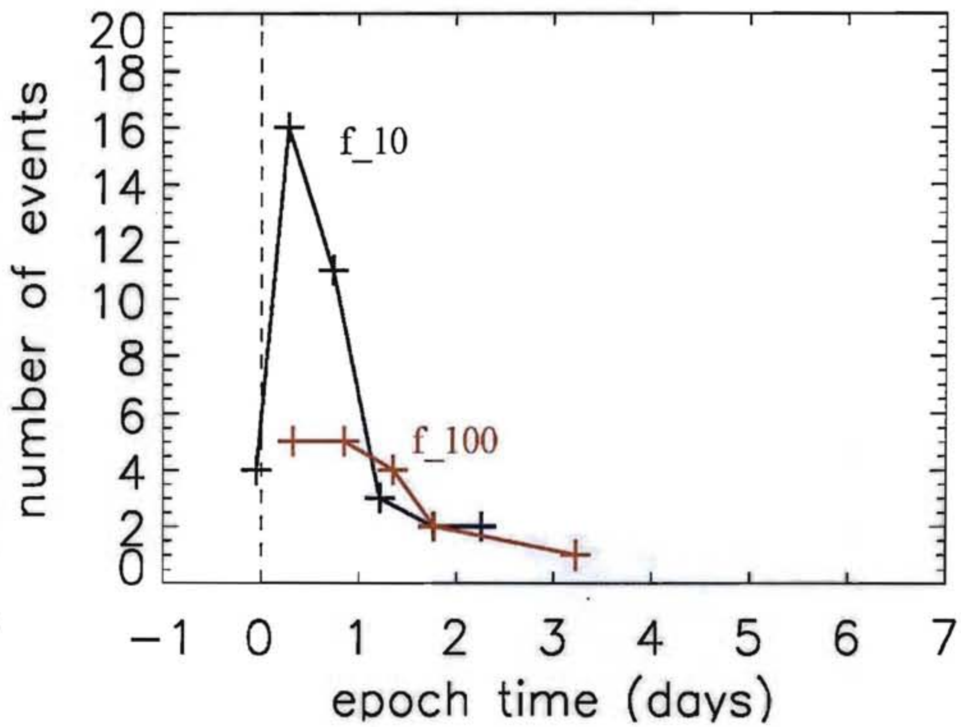
4a. Energetic electron rise times from ns41



(1) is epoch time zero which corresponds to Dst^{min}, (2) time to 10 times the minimum flux, (3) time to 100 times the minimum flux, (4) time to half the maximum flux and (5) time to 90% the maximum flux.

4b. Energetic electron rise times from ns41



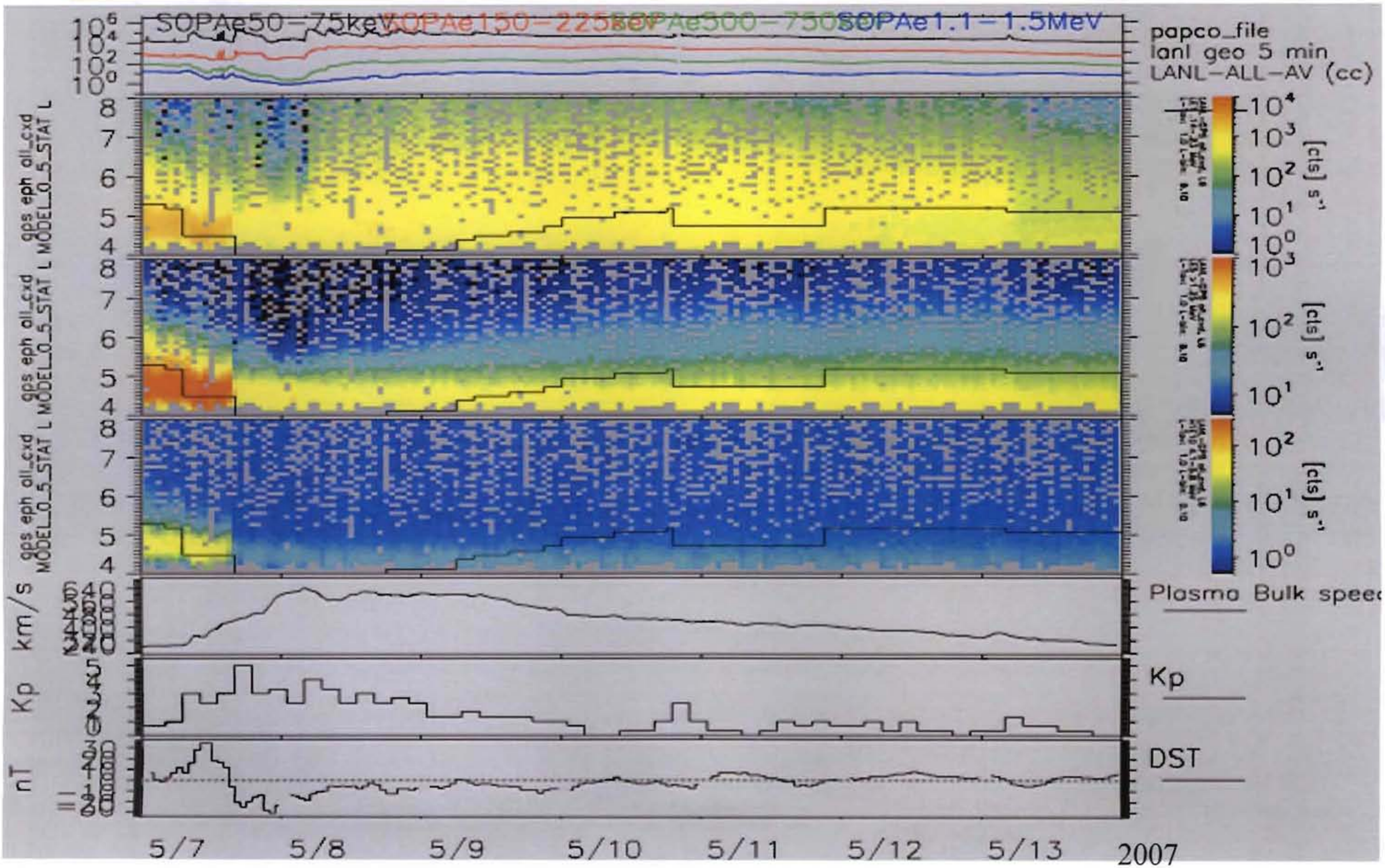


Fast rise times (<12hr) inconsistent with quasi-linear chorus theory (Horne, 2005) of one order of magnitude in 24hrs.

5a. Composite data views of radiation belt dynamics

- Using up to 9 CXD instrument on GPS we assemble composite L versus time slices through the outer radiation belt achieving a time resolution of 1hr (at all L) and an L resolution of 0.1
- The following plots show the following information:
  - Geometric average of all LANL GEO observations for 4 energies
  - L v. Time slices with plasmapause position overplotted for three GPS energy ranges (0.14, 1.25 and 4 MeV)
  - Solar wind data from the OMNI database – Solar wind speed, Kp and Dst.

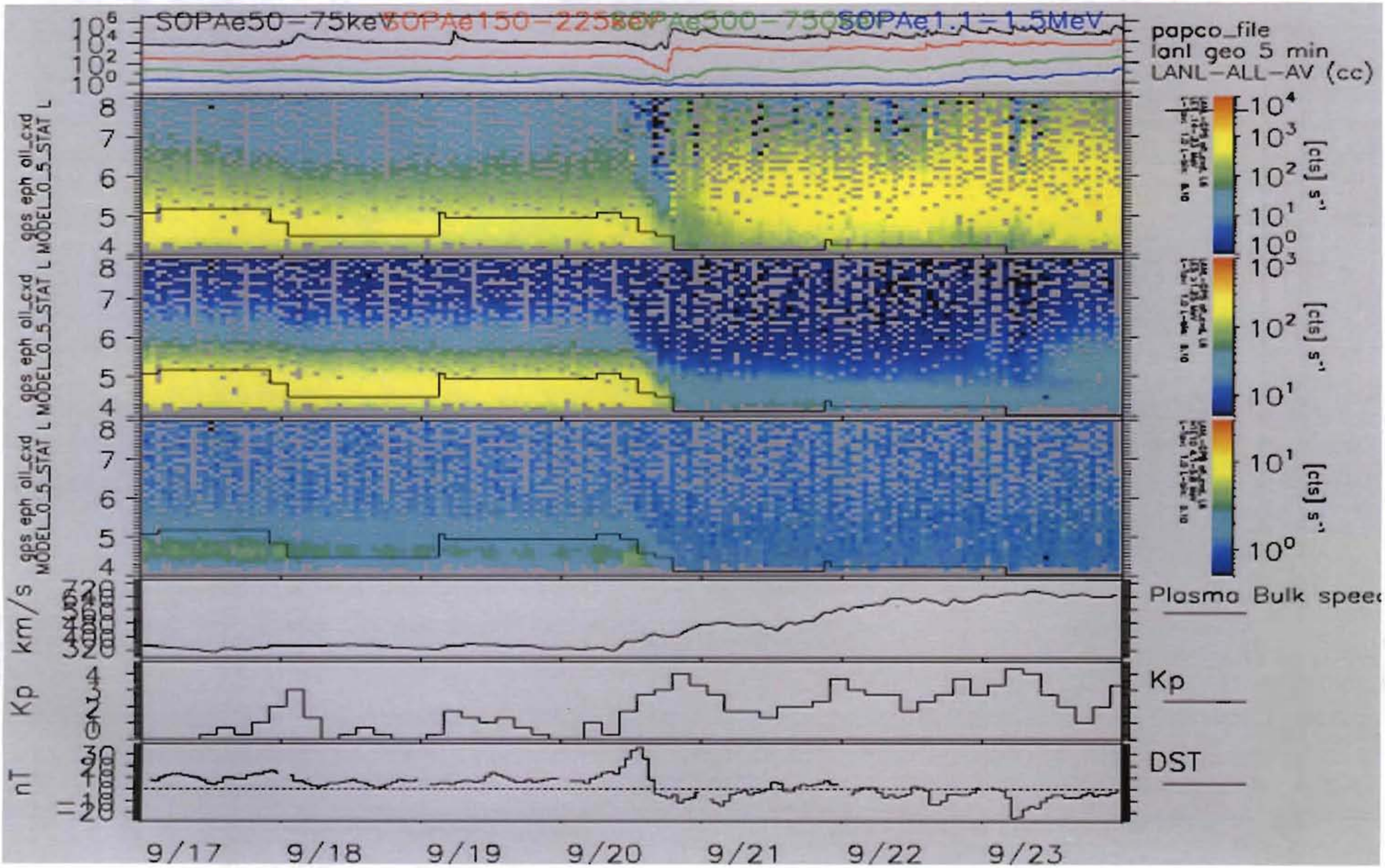
5b. Fast losses at all energies, all L



5c. Fast losses at all energies, all L

- Over the energies samples by GPS (0.1 MeV – 4 MeV) and over the range of L sampled the loss of particles observed on 5/7/2007 occurs over all energies, all L and over a time period of 1-2 hours.
- This is inconsistent with ALL currently proposed rapid loss mechanisms:
  - Magnetopause loss: Compression (DST increase) occurred *before* loss
  - EMIC waves: Favor energies near/above 1 MeV only
  - Field line detrapping: not likely at L=4

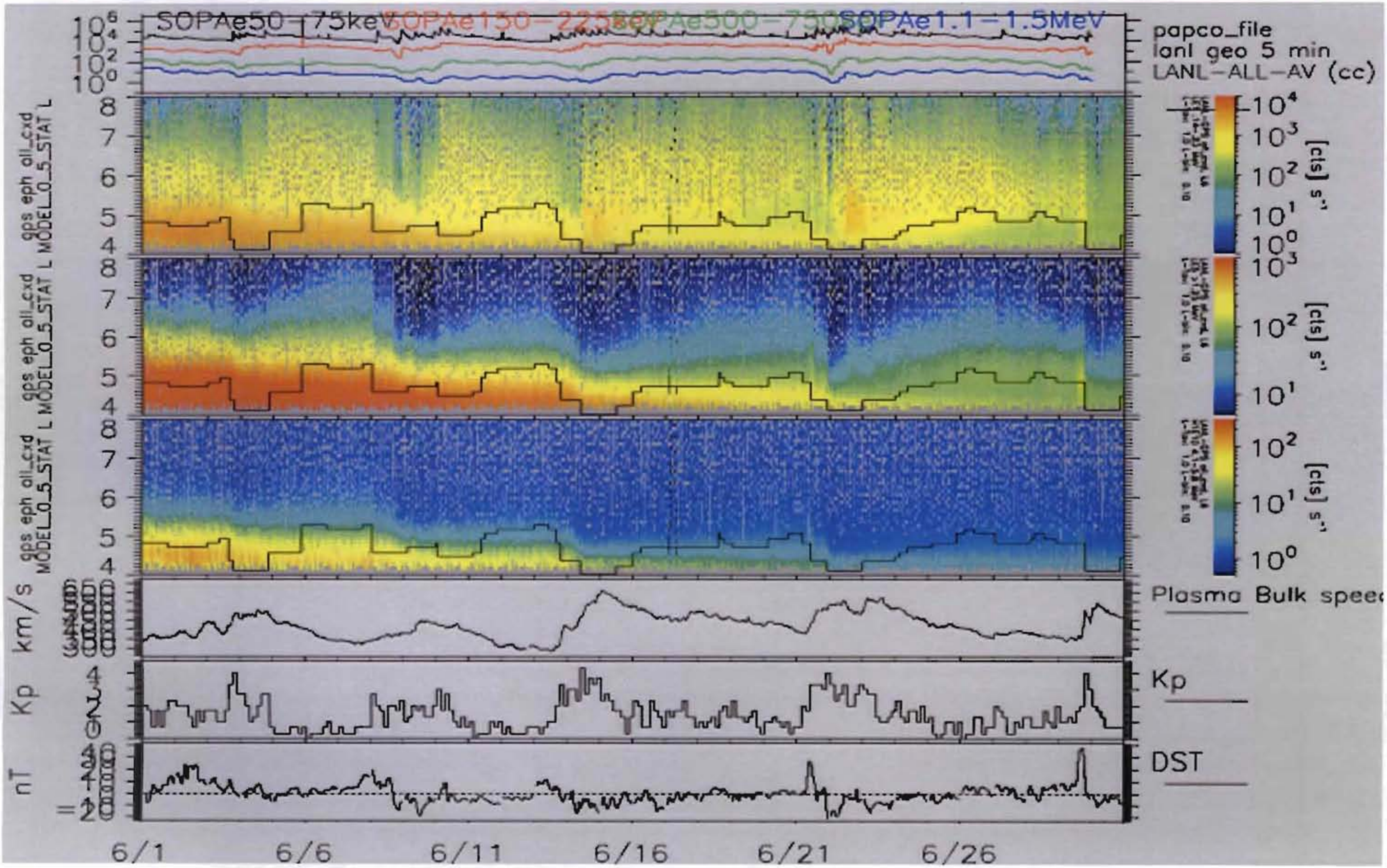
5d. Slow losses at all energies, all L



5e. Slow losses at all energies, all L

- Over the energies samples by GPS (0.1 MeV – 4 MeV) and over the range of L sampled the loss of particles observed on 5/7/2007 occurs over all energies, all L and over a time period of ~8 hours.
- This is still inconsistent with ALL currently proposed loss mechanisms:
  - Magnetopause loss: Compression (DST increase) occurred at beginning of loss, loss continues after DST back to ~0
  - EMIC waves: Favor energies near/above 1 MeV only
  - Field line detrapping: not likely at L=4

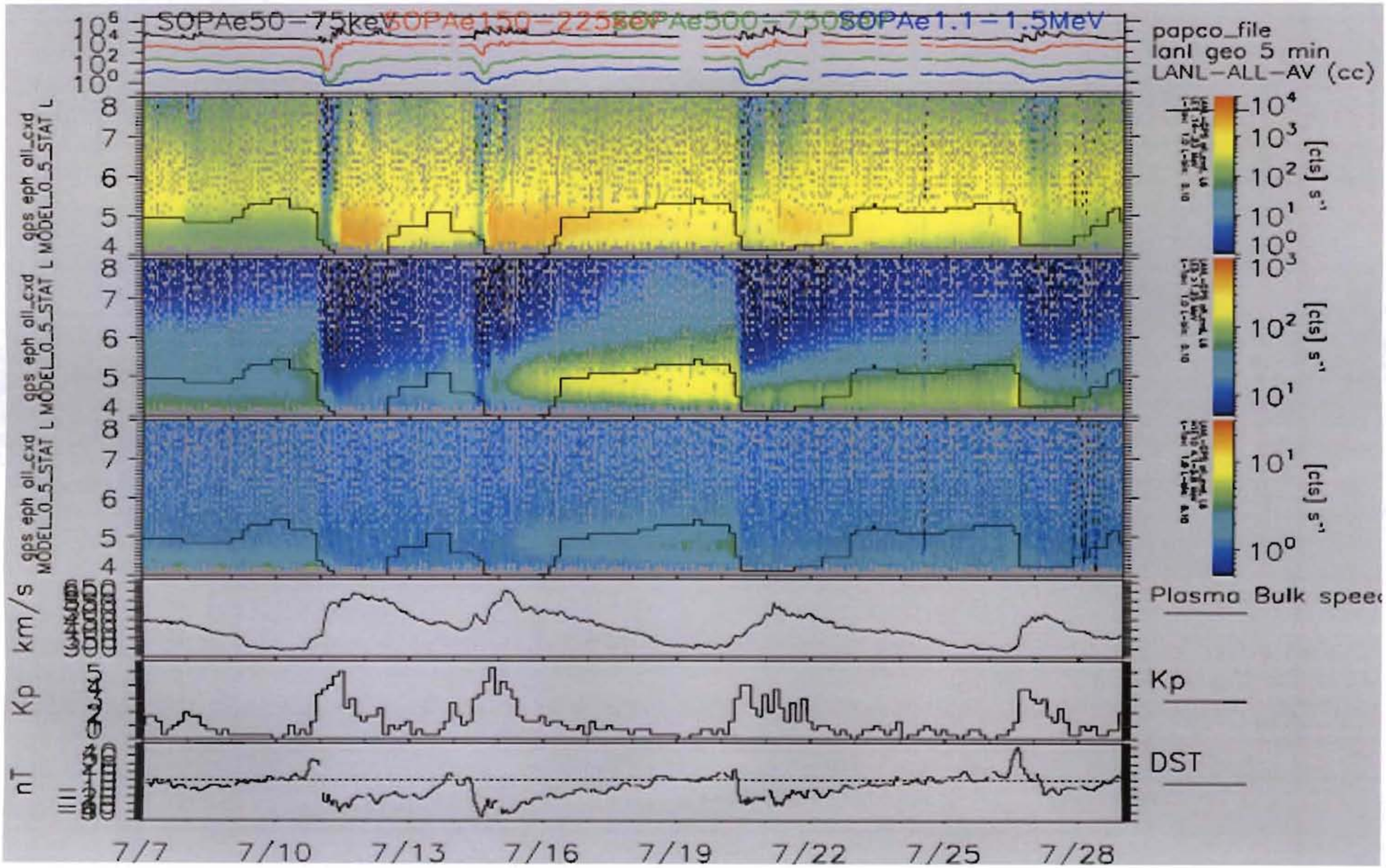
5f. Successive losses



5g. Successive losses

- In spite of good conditions for chorus energization (outside plasmapause, available source population near 100 KeV) there are successive losses of >1MeV electrons in the inner region in three steps.
- Conditions for these losses
  - Enhanced solar wind speeds
  - Elevated KP
  - Very quiet Dst.

5h. 3 storms – similar conditions, different response



5i. 3 storms – similar conditions, different response

- Three successive similar storms; ~ -50 Dst, solar wind speed >500km/h, Kp ~5
- 1st storm "classical": onset loss at al L / all energies, source population of ~100keV electrons, delayed recovery of 1 MeV electrons.
- 2nd Storm shows additional recovery at 4MeV, but occurring mostly *inside* the plasmapause (unfavorable fro chorus energization)
- 3rd storm shows little energization – only outward diffusion after loss.

6. Summary

- Excellent inter-calibration of CXD data allows for seamless combining of data in magnetic coordinate space.
- Composite view of outer Radiation Belt from GPS offers unprecedented spatial and temporal coverage of a highly dynamic region.
- Both rapid and slower loss signatures observed are inconsistent with current understanding of loss processes.
- Even favorable conditions for chorus acceleration do not always lead to energization signature
- Energization occurring inside plasmapause inconsistent with chorus mechanism.