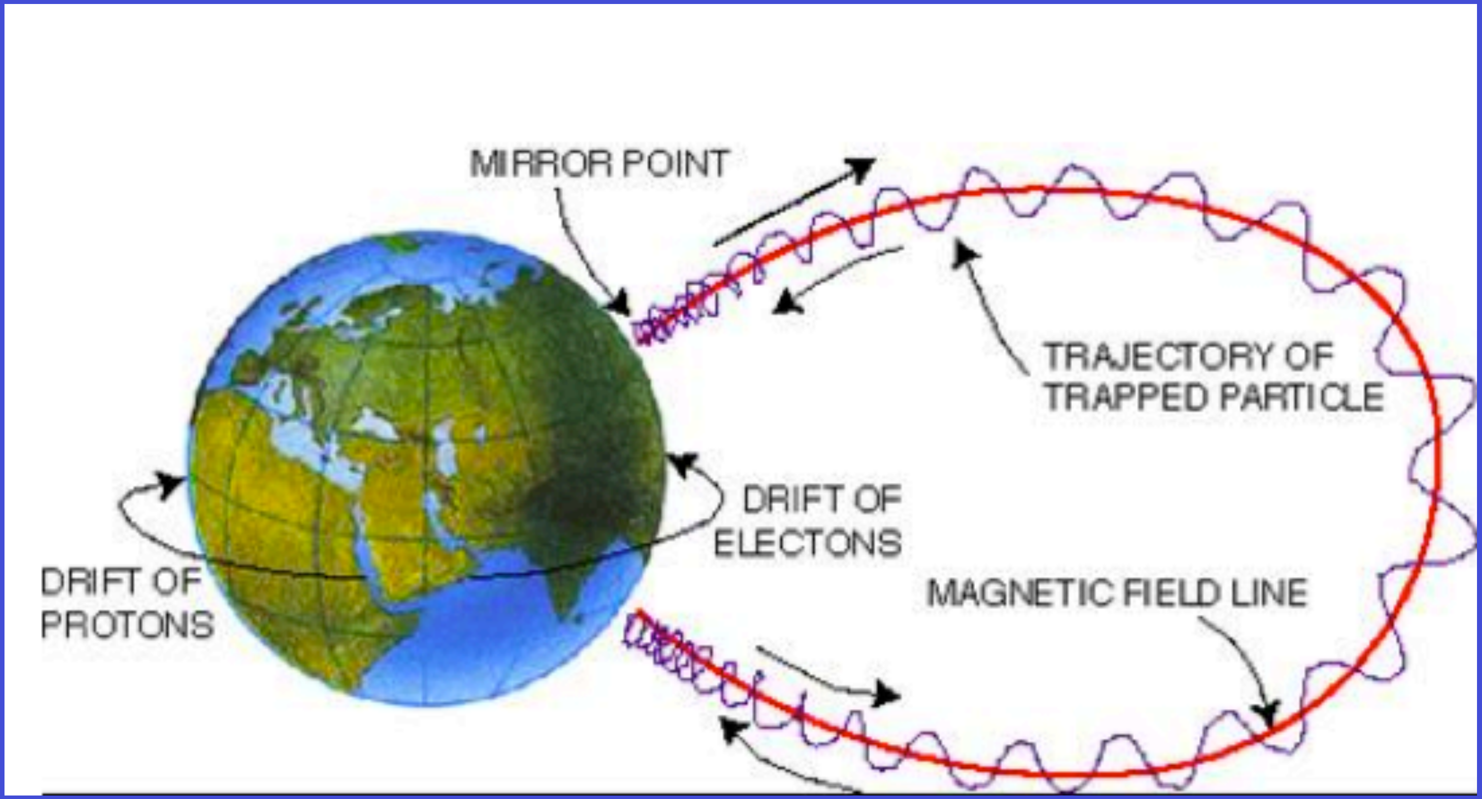
THEMIS' Contribution to Outer Radiation Belt Science

Xinlin Li

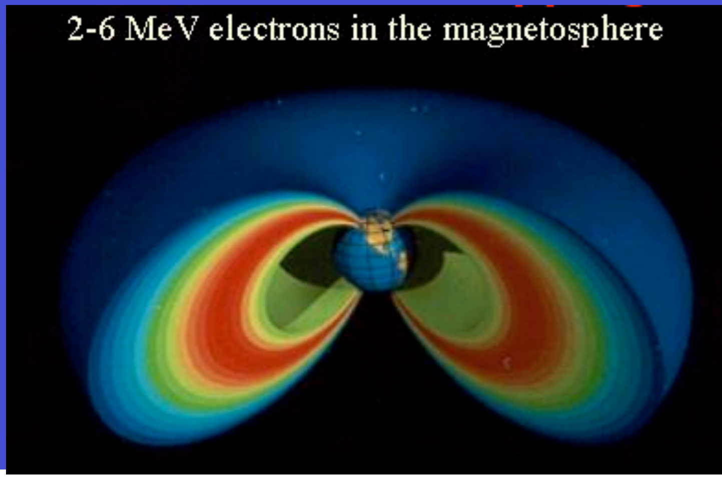
LASP and Dept. of Aerospace Engineering Sciences of University of Colorado at Boulder

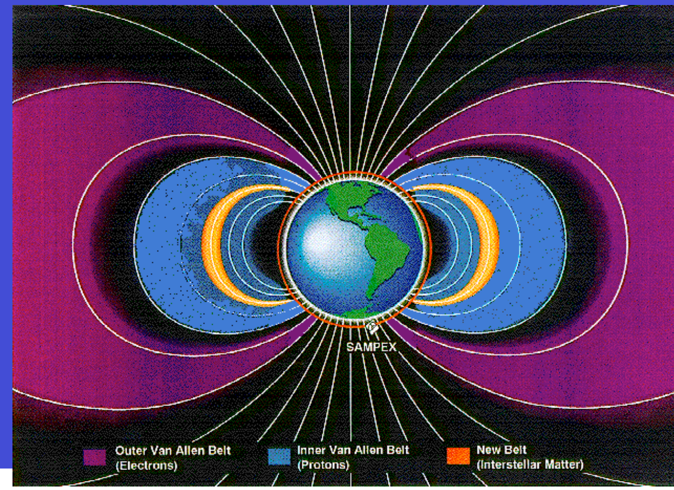
What we know?

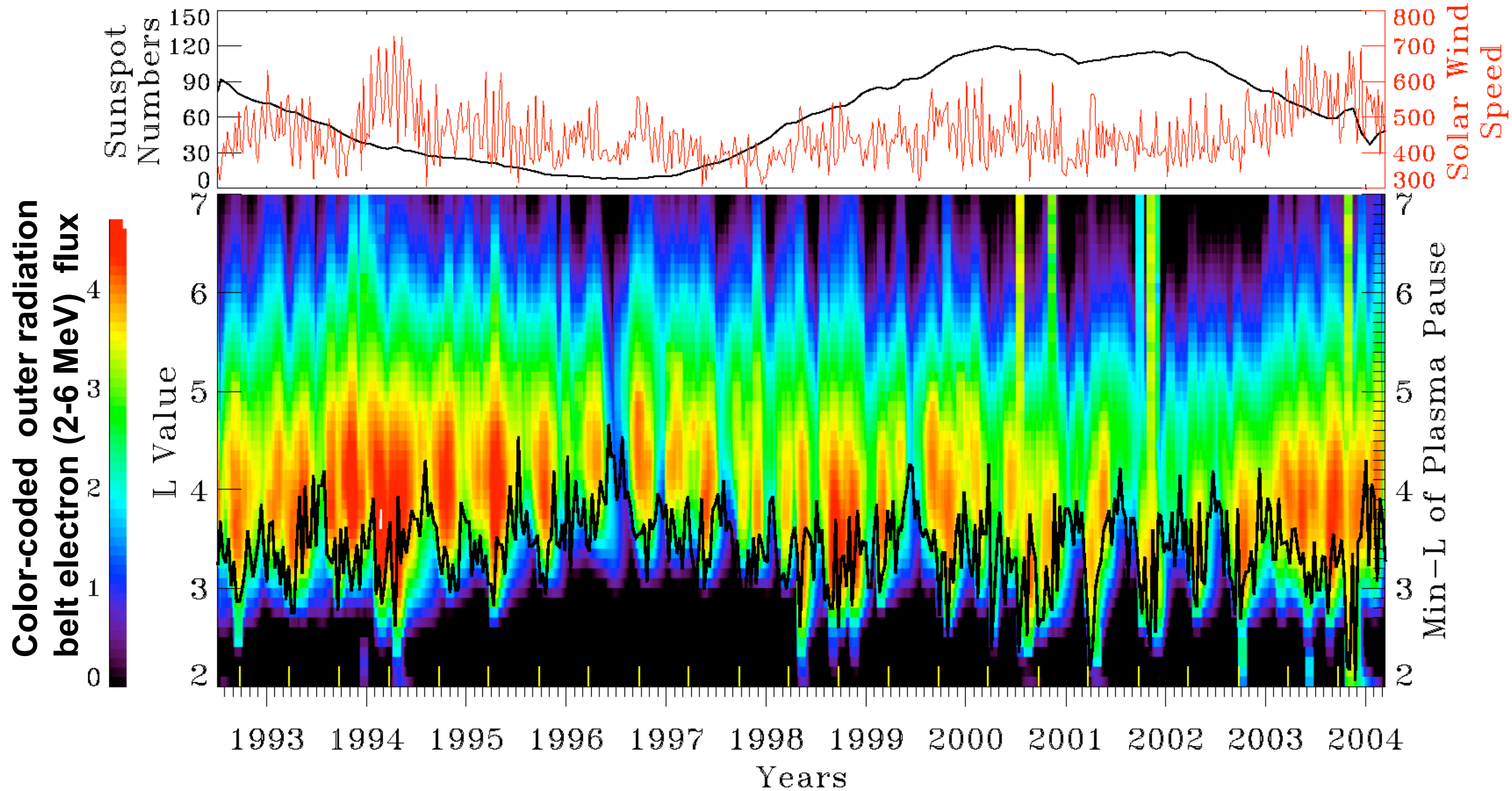
Charged Particle Motions in Earth's Magnetic Field



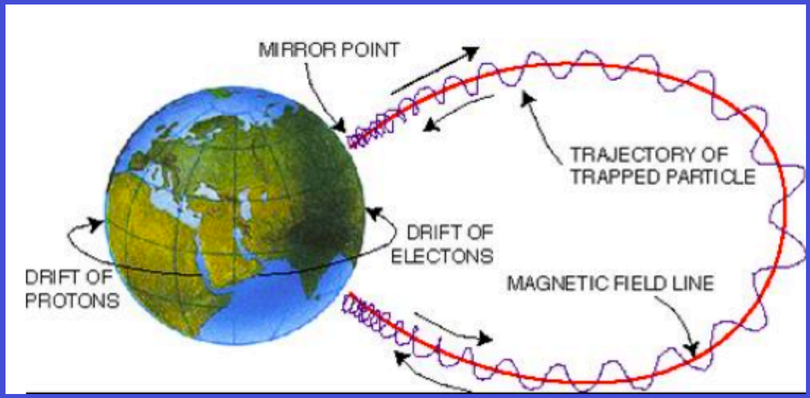
- Gyromotion motion: $\mu = p^2_{\perp}/2mB$ (1st), $T\_g \sim 10^{-3}$ sec
- Bounce Motion: $J = \int p_{||} ds$ (2nd), $T\_b \sim 10^{0}$ sec
- Drift motion: $\Phi = \int B dA$ (3rd) , $T\_d \sim 10^{3}$ sec

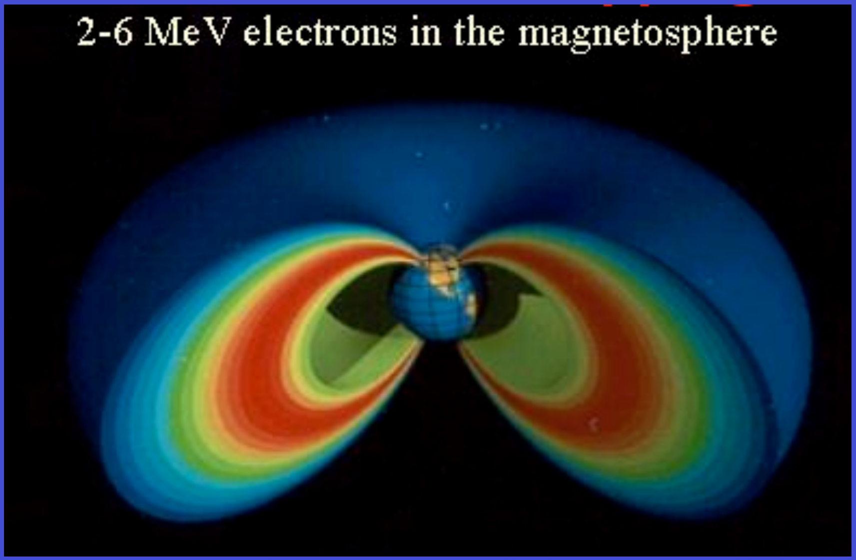

2-6 MeV electrons in the magnetosphere


SAMPEX
Outer Van Allen Belt (Electrons)
Inner Van Allen Belt (Protons)
New Belt (Interstellar Matter)


Sunspot Numbers
150
120
90
60
30
0
Solar Wind Speed
800
700
600
500
400
300
Color-coded outer radiation belt electron (2-6 MeV) flux
0
1
2
3
4
L Value
Min-L of Plasma Pause
2
3
4
5
6
7
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
Years

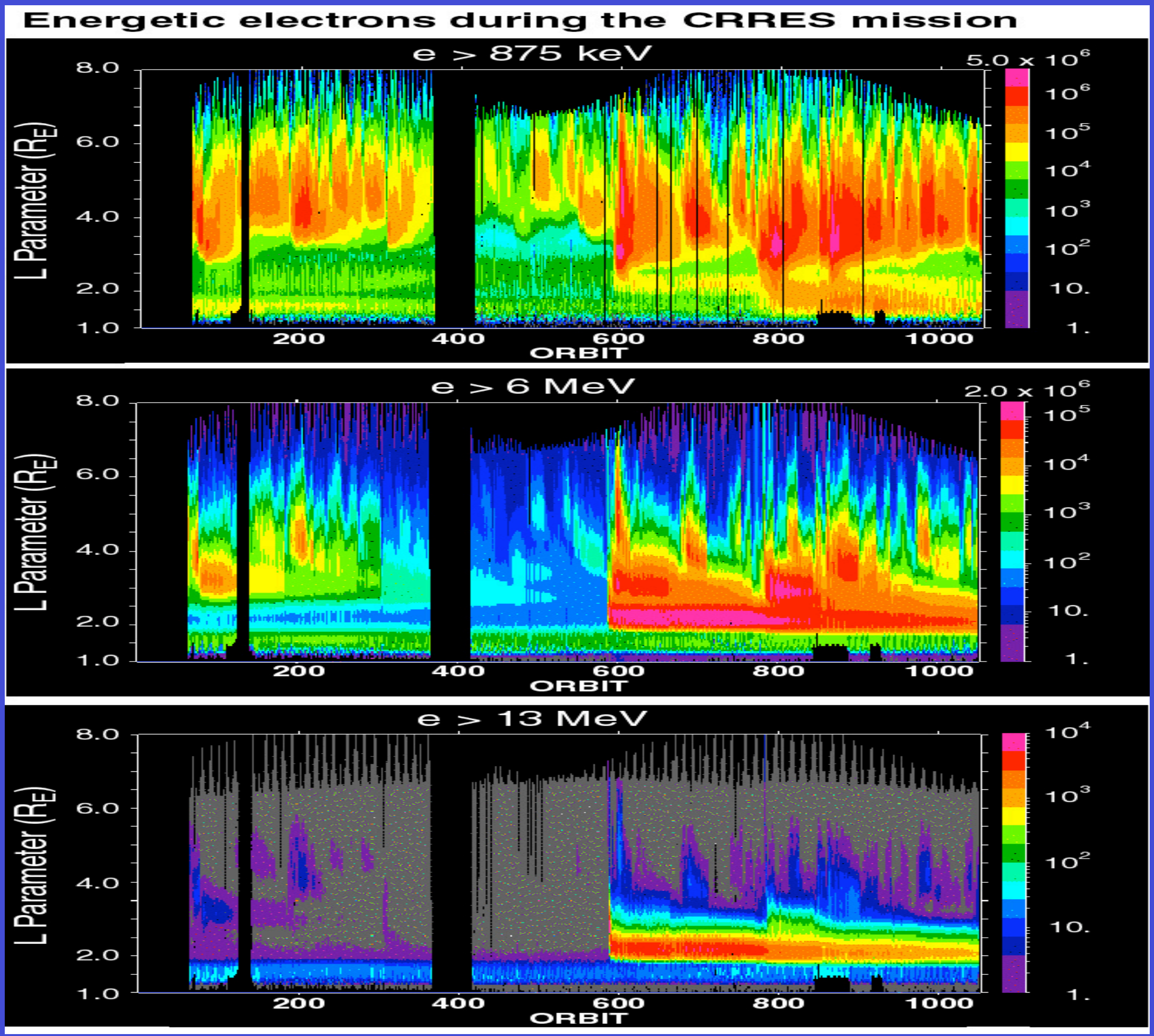
What else we know?





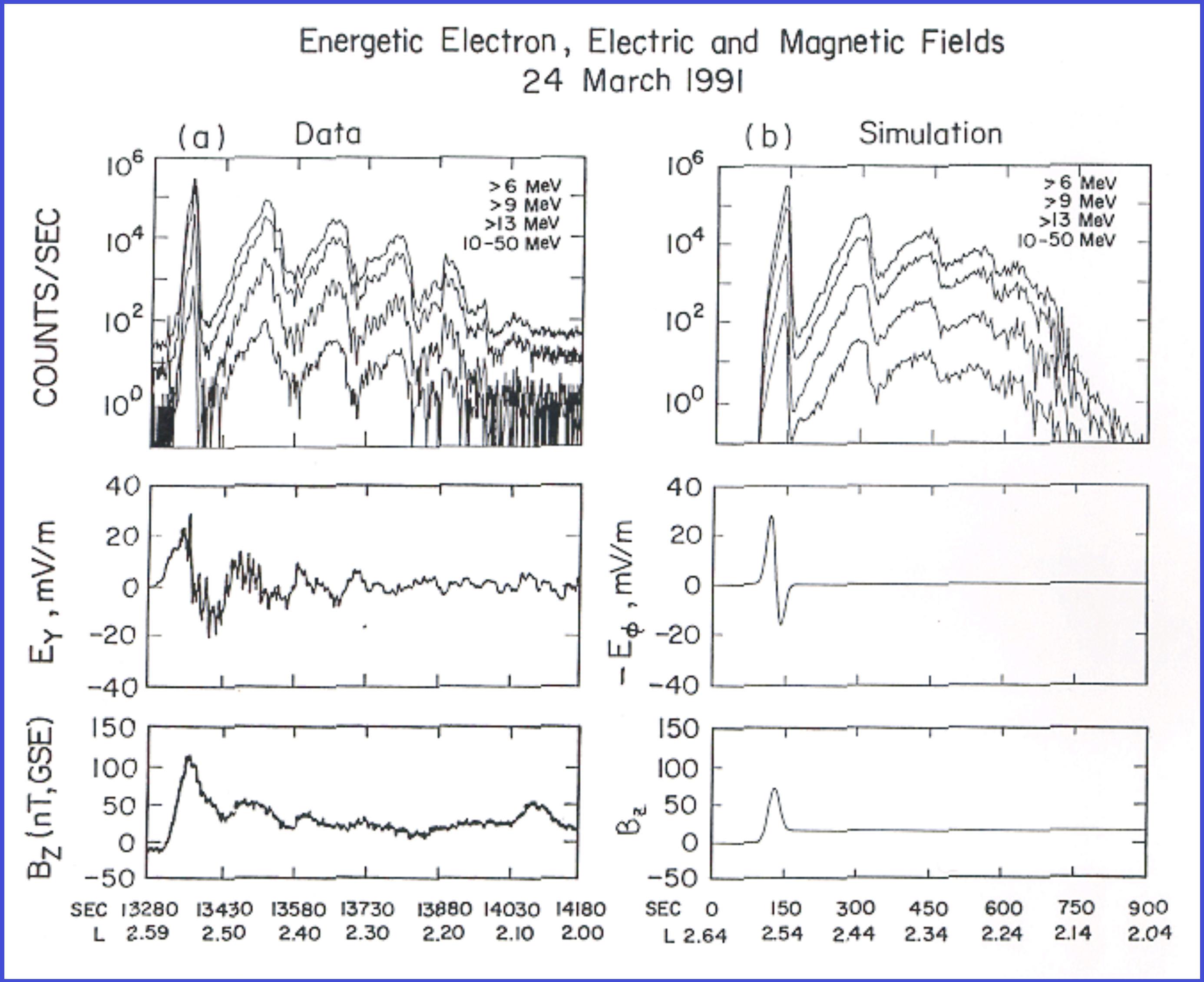
- A charged particle will gain energy if transported to a stronger magnetic field region.
- The observed electron population is the net result of a balance among energization, transport, and loss.
- It is difficult to determine the relative contribution of radial transport and in situ heating to the observed electron enhancements.

• **Some observations and models, however, do provide insight into acceleration mechanisms.**



July 1990 (Courtesy of J. B. Blake) Oct. 1991

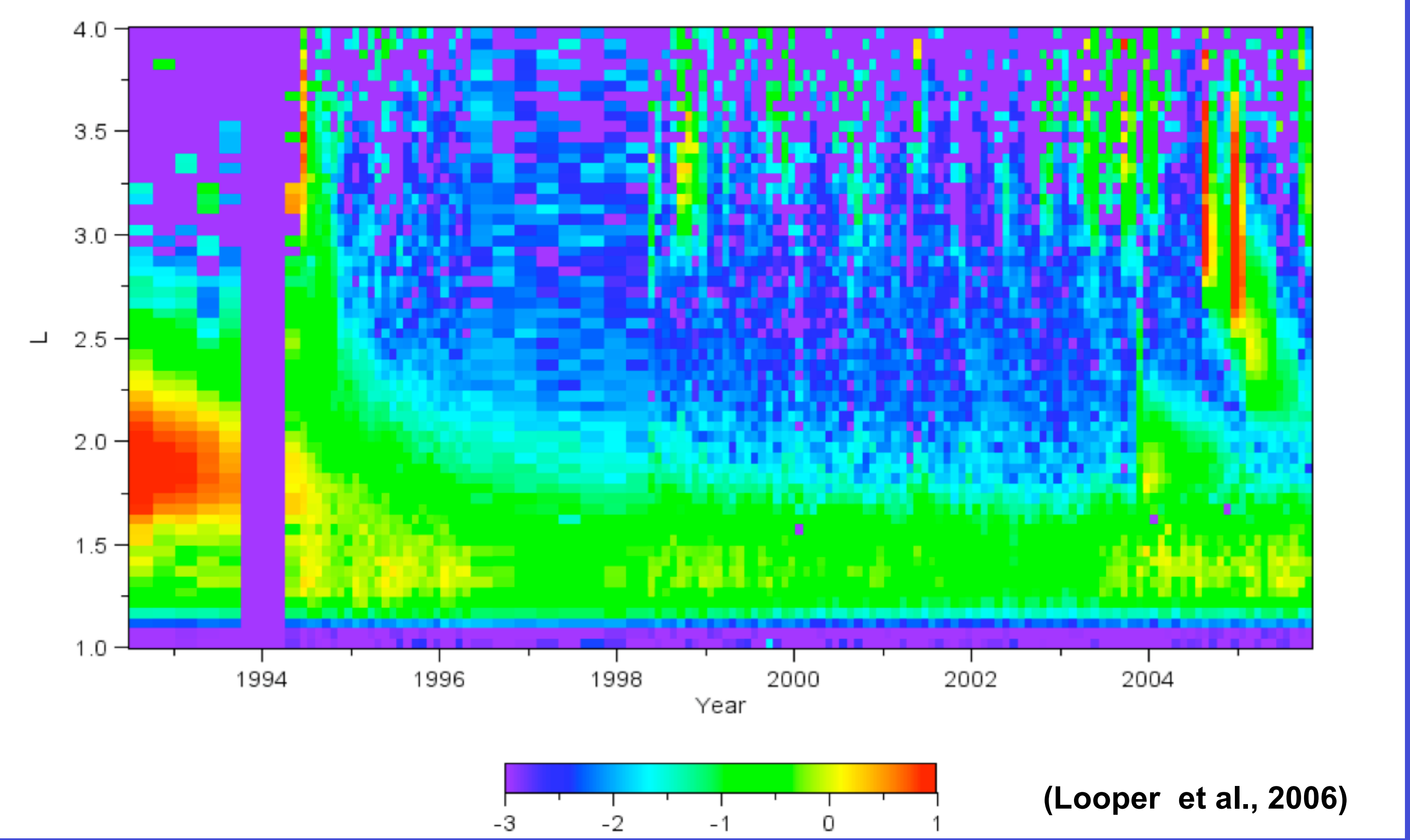
Limited success in modeling, but relying assumptions that have not been verified due to the single point measurement of CRRES.



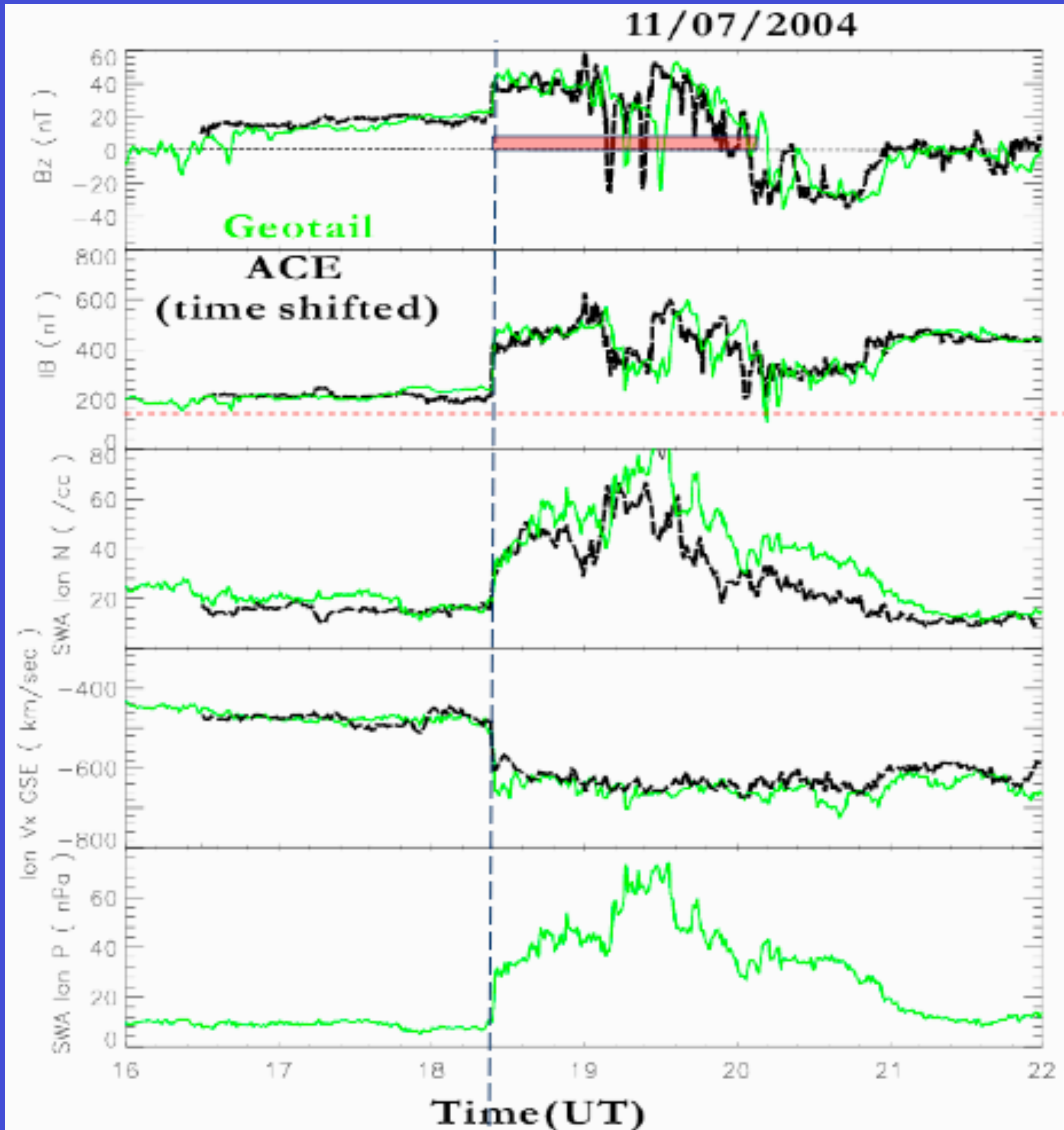
(Li et al., 1993)

• **Other shock-associated events, but usually not long lasting.**

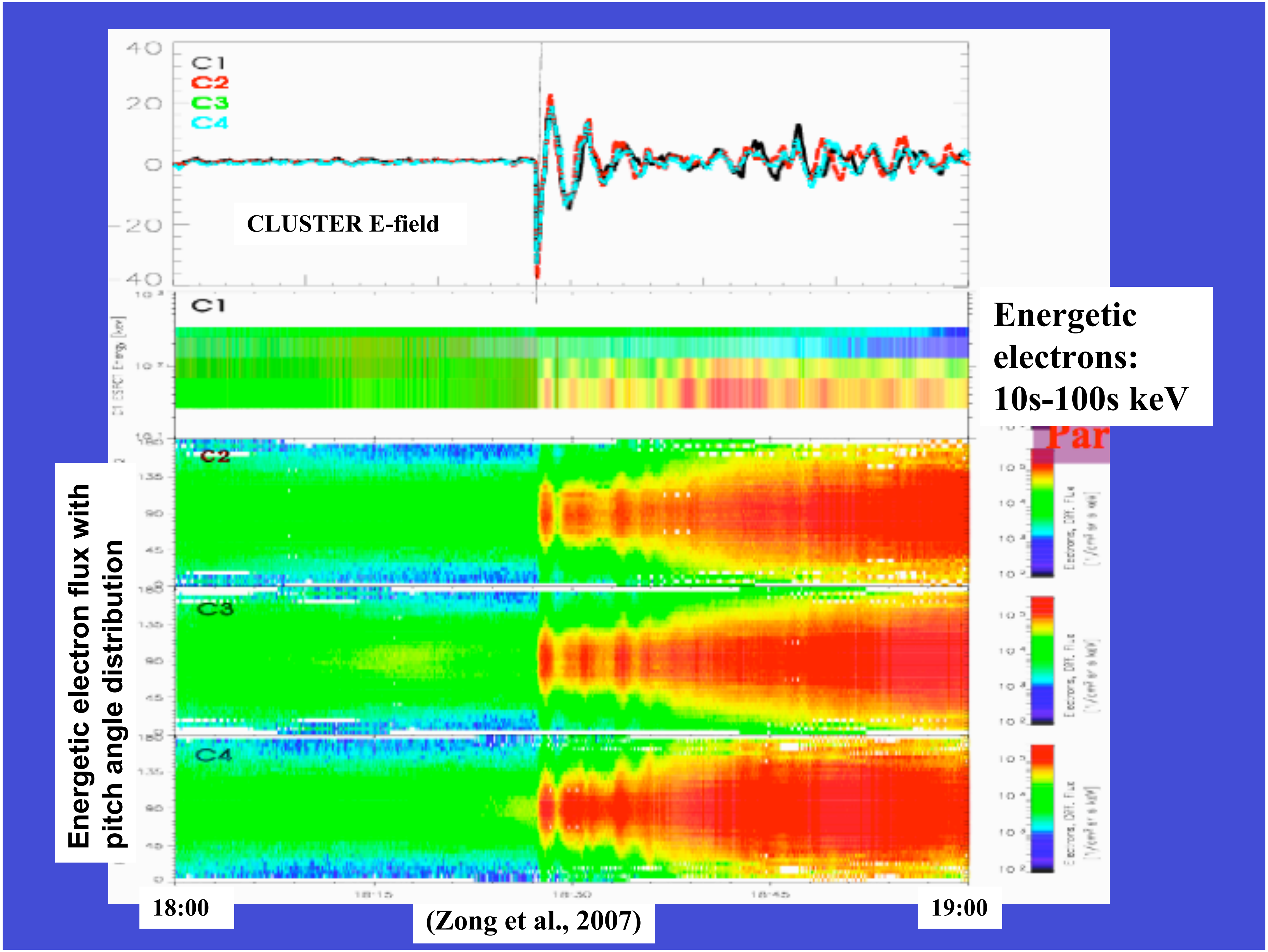
SAMPEX measurements of 10-20 MeV electrons mirroring near 475 km, 1992-2005



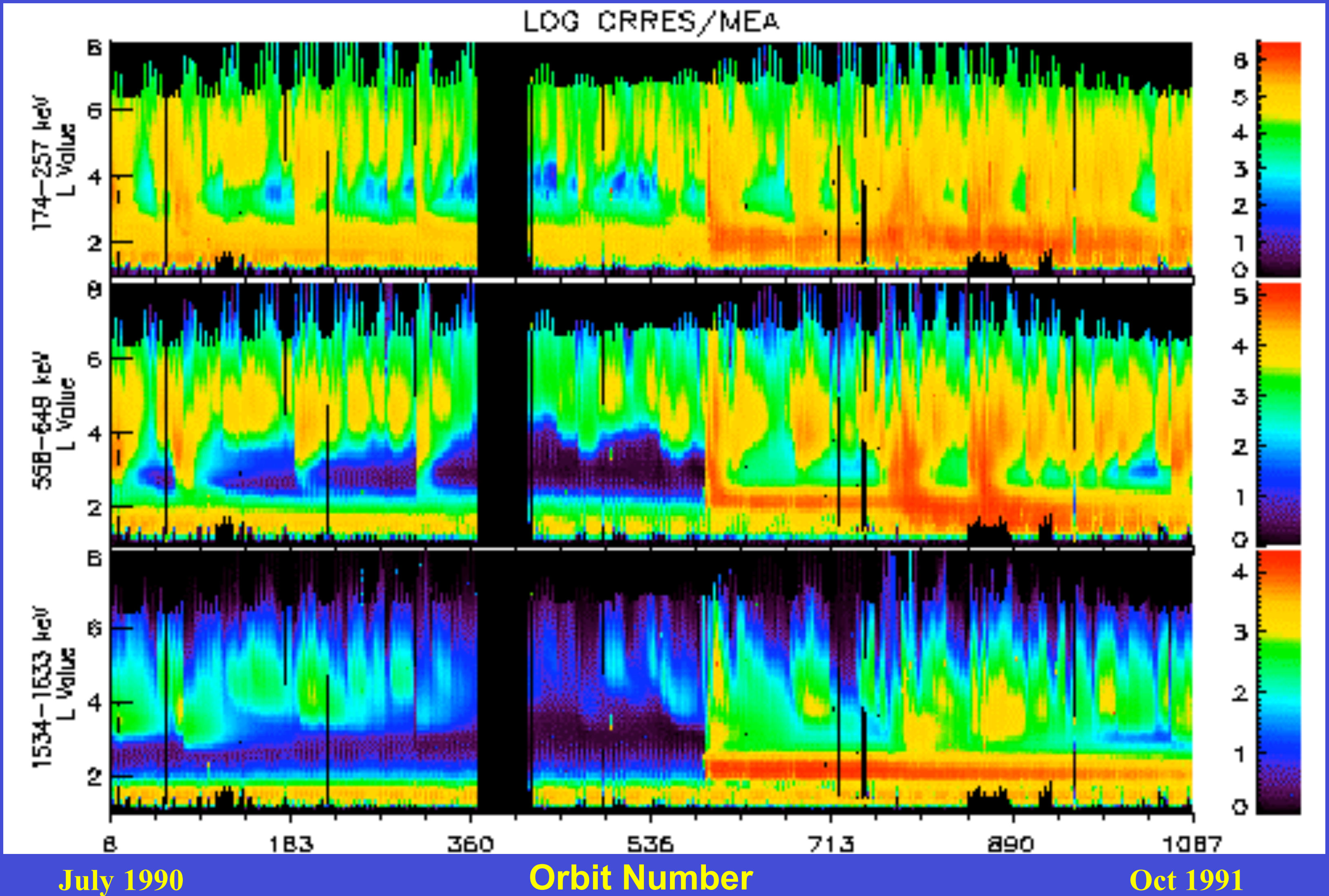
(Looper et al., 2006)



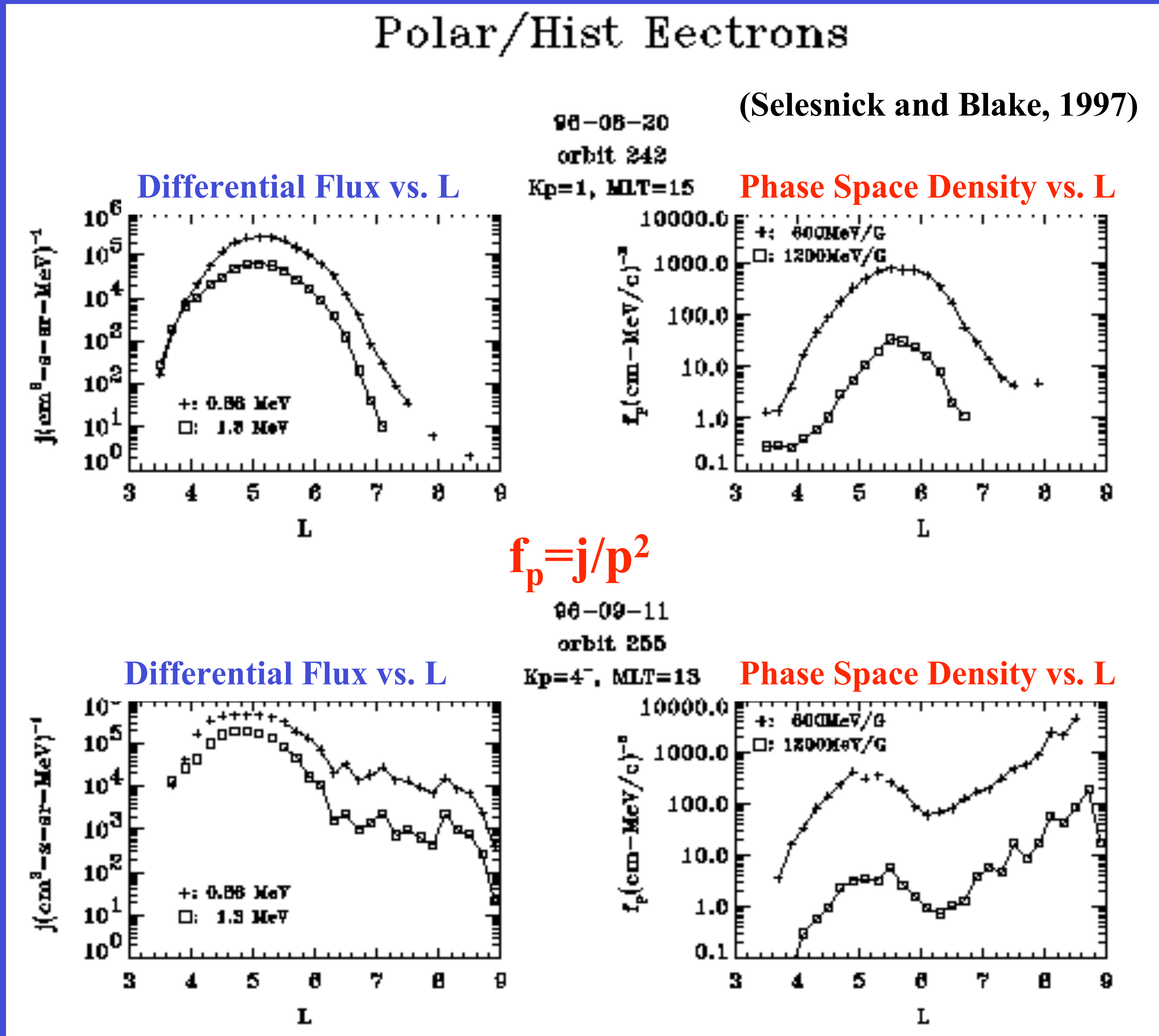
(Zong et al., 2007)


CLUSTER E-field
C1
C2
C3
C4
Energetic electrons: 10s-100s keV
Energetic electron flux with pitch angle distribution
18:00
19:00
(Zong et al., 2007)

- where do the 100s' keV to ~1 MeV electrons come from?
- 10s' keV electrons in the solar wind are not the direct source (Li et al., 1997).



(Li and Temerin, Space Sci. Rev. 2001)

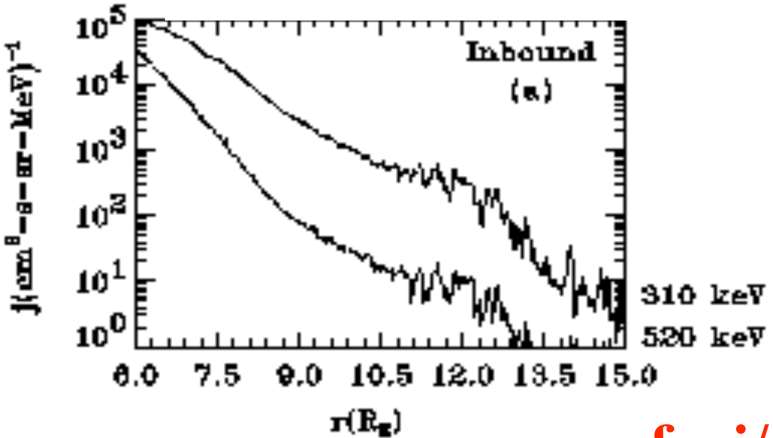

Polar/Hist Eectrons
(Selesnick and Blake, 1997)
96-08-20
orbit 242
Kp=1, MLT=15
Differential Flux vs. L
Phase Space Density vs. L
+: 0.86 MeV
□: 1.3 MeV
+: 600MeV/G
□: 1200MeV/G
j(cm^2-s-sr-MeV)^-1
f_p(cm-MeV/c)^-3
L
f_p=j/p^2
96-09-11
orbit 255
Kp=4^-, MLT=13
Differential Flux vs. L
Phase Space Density vs. L
+: 0.86 MeV
□: 1.3 MeV
+: 600MeV/G
□: 1200MeV/G
L

WIND/3D Electrons

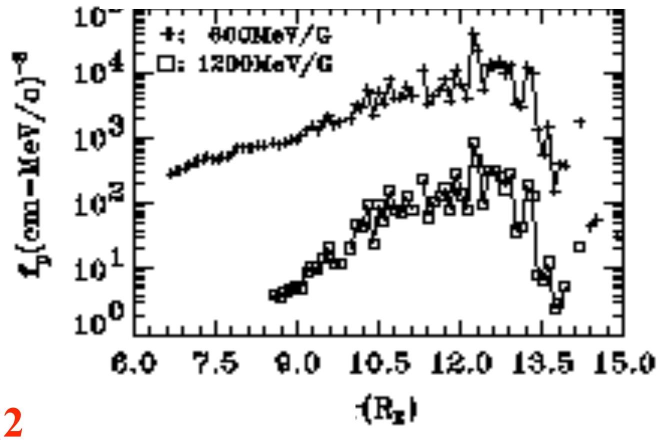
(Courtesy of D. Larson)

96–08–20
Kp=1

Differential Flux vs. r



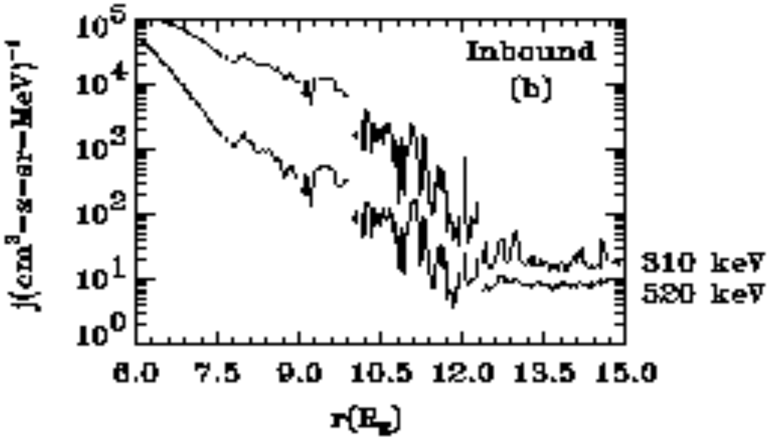
Phase Space Density vs. r



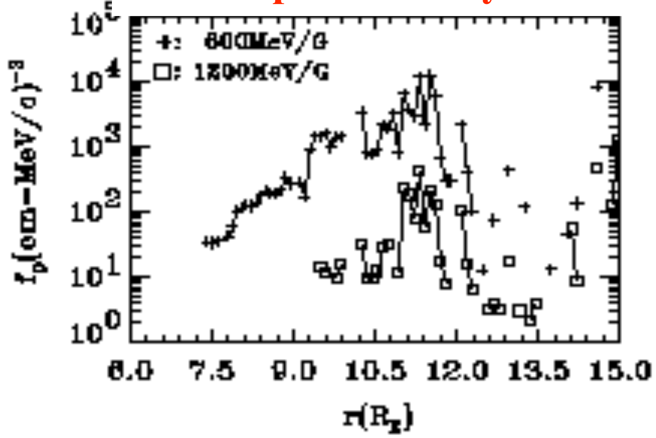
$f_p = j/p^2$

96–09–11
Kp=4⁻

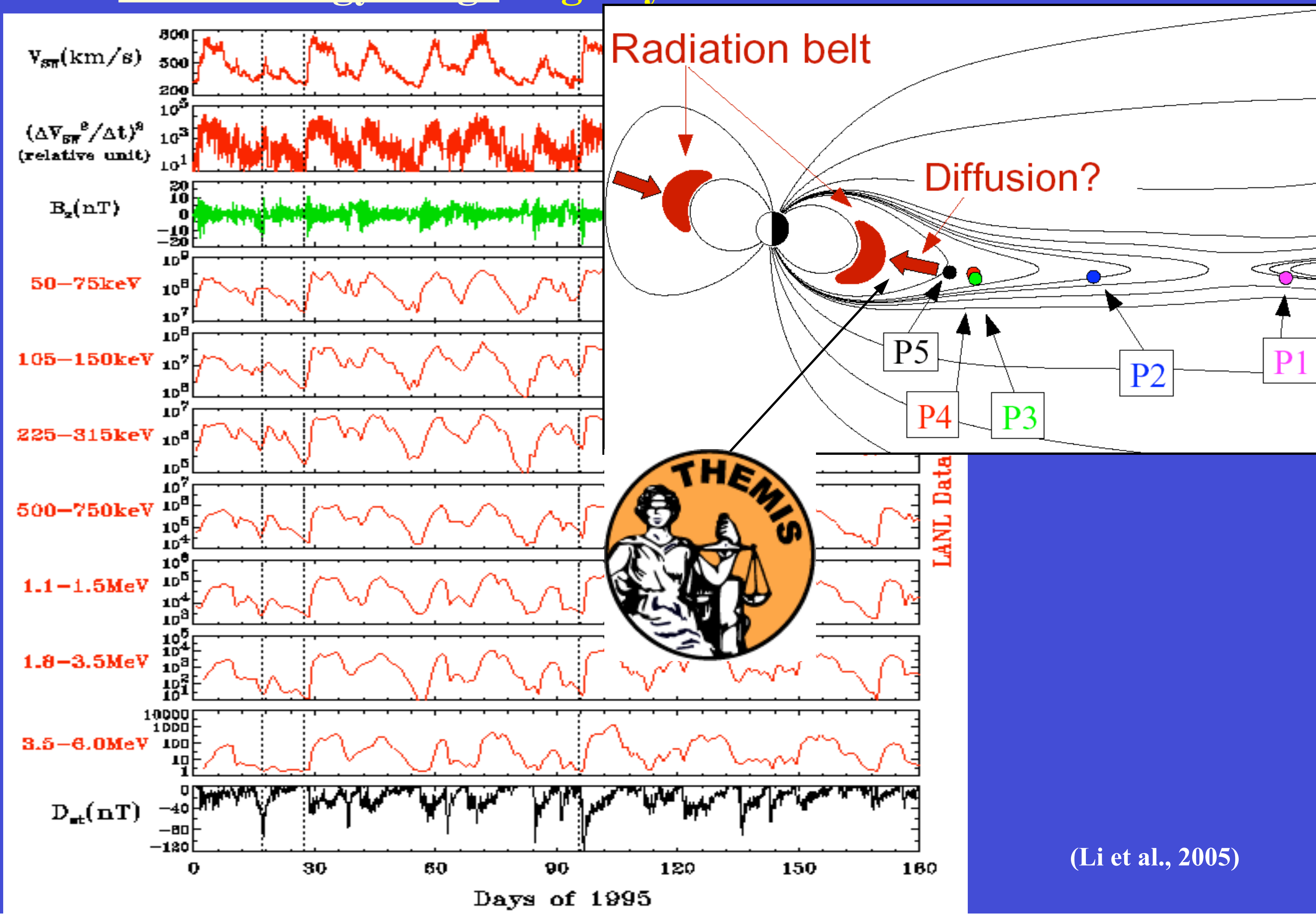
Differential Flux vs. r



Phase Space Density vs. r



Correlation of solar wind and electrons over a <u>broad energy range</u> at geosynchronous orbit



(Li et al., 2005)

- **Radial diffusion model were developed to predict MeV electrons at geosynchronus orbit.**

$$\frac{\partial f}{\partial t} = L^2 \frac{\partial}{\partial L}\left(\frac{D_{LL}}{L^2}\frac{\partial f}{\partial L}\right) - \frac{f}{\tau}$$

f: electron phase space density for given μ and J.

$$f = j/p^2$$

p: momentum, j: differential flux

$L_{in} = 4.5$ and $L_{out} = 8$

$f_{out} = C_s \times (v/v_0)^{\gamma_{1s}} \times [1 + ((v_x b_z + |v_x b_z|)/v b_0)^2]^{\gamma_{2s}}$

$D_{LL} = D_0 (L/6.6)^{10}, \tau = \tau_0 (6.6/L)^{6.8}$

$D_0 = C \times (v/v_0)^{\gamma_1} \times [1 + ((v_x b_z + |v_x b_z|)/v b_0)^2]^{\gamma_2} \times [(\frac{\Delta v^2}{\Delta t})^2]^{\gamma_3}$

$\tau_0 = 2.35\text{day}$

The difference between the predicted results and the measurements is minimized by least square fitting χ^2 defined as:

$$\chi^2 = \frac{1}{N}\sum_i^N [log_{10}(j_i^l) - log_{10}(j_i)]^2$$

where the j_i^l is from LANL measurement and j_i is from the model.

$$< j^l > = \frac{1}{N}\sum_i^N j_i^l$$

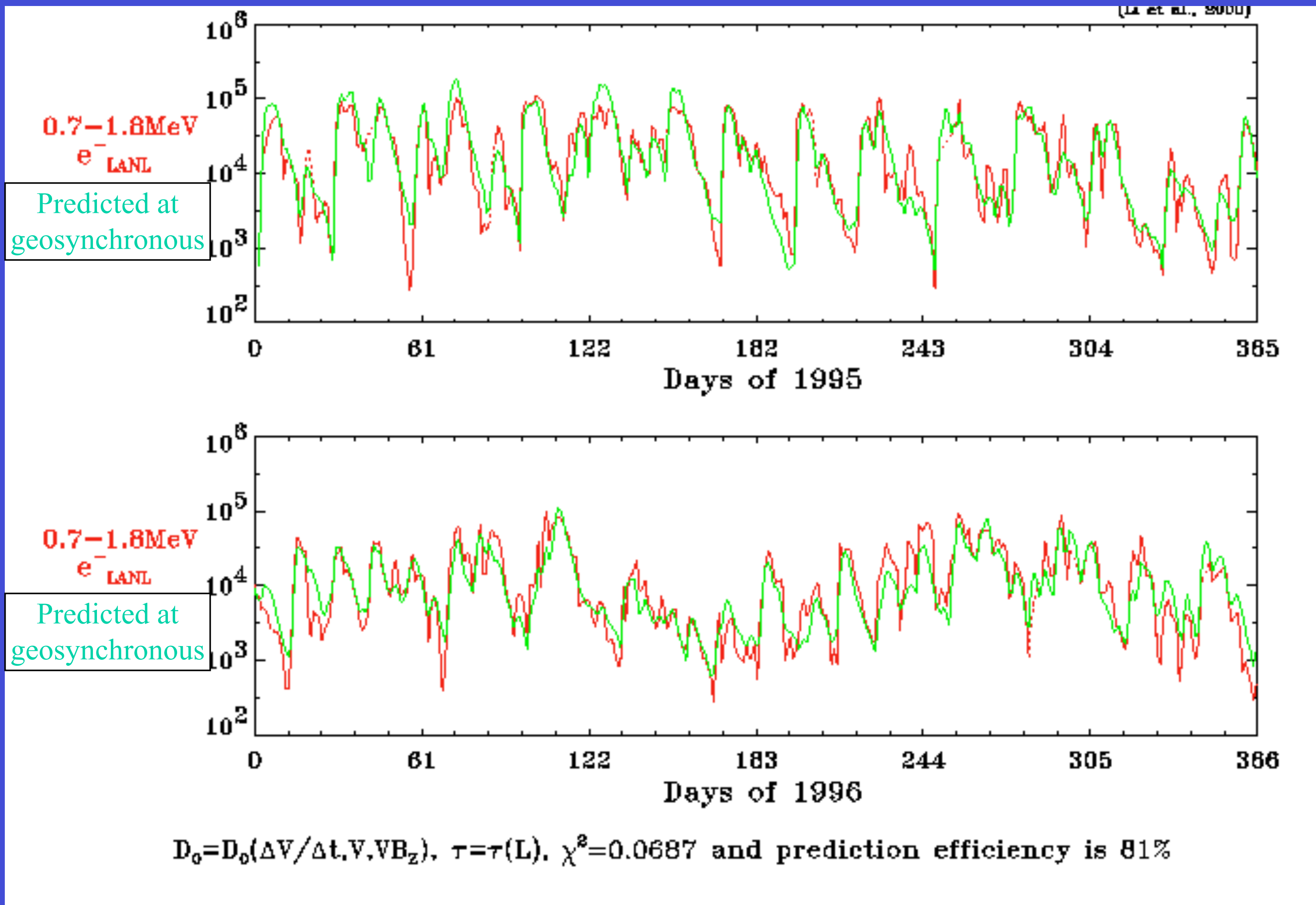
$$< \chi^2 > = \frac{1}{N}\sum_i^N [log_{10}(j_i^l) - log_{10}(< j^l >)]^2$$

$$\text{Prediction Efficiency} = (1 - \frac{\chi^2}{< \chi^2 >}) \times 100\%$$

Outer Boundary set to L=8, and the source at L=8 is a function of solar wind,

So is the diffusion coeff.

A comparison between measured and predicted MeV electrons at Geosynchronous orbit



(Li et al., 2003)

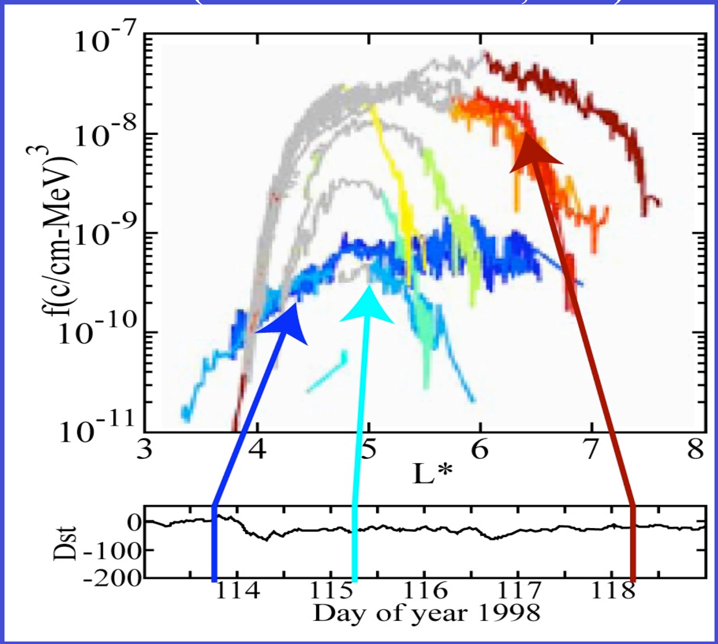
• Simultaneous observations at geosynchronous orbit and L=4.2 (GPS) show that the phase space density is almost always higher and increases first at geosynchronous orbit, and then enhances at L=4.2 (Hilmer et al. 2000).

• Phase space density analysis on Polar/HIST data (Selesnick and Blake, 2000; Green and Kivelson, 2004) suggested that a peak of the phase space density usually occurs between GEO orbit and L=4.2 ==> The electrons can be energized in situ (violating their first adiabatic invariant) inside GEO orbit.

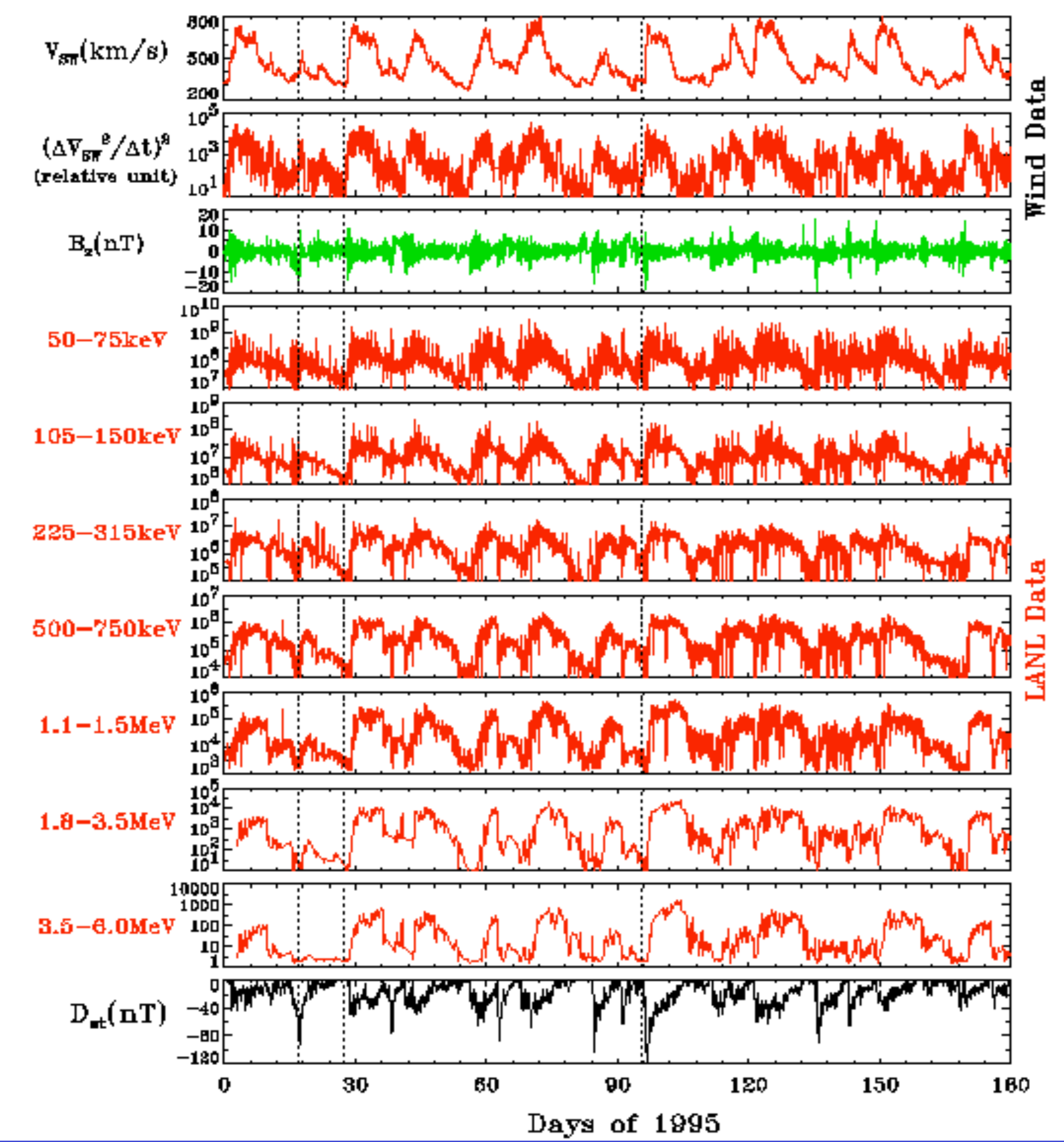
‘Multi-point measurements’ are required to examine the evolution of PSD.

‘Multi-point measurements’ of E and B fields are required to examine the pitch angle scattering, as well as in situ acceleration.

(Green and Kivelson, 2004)

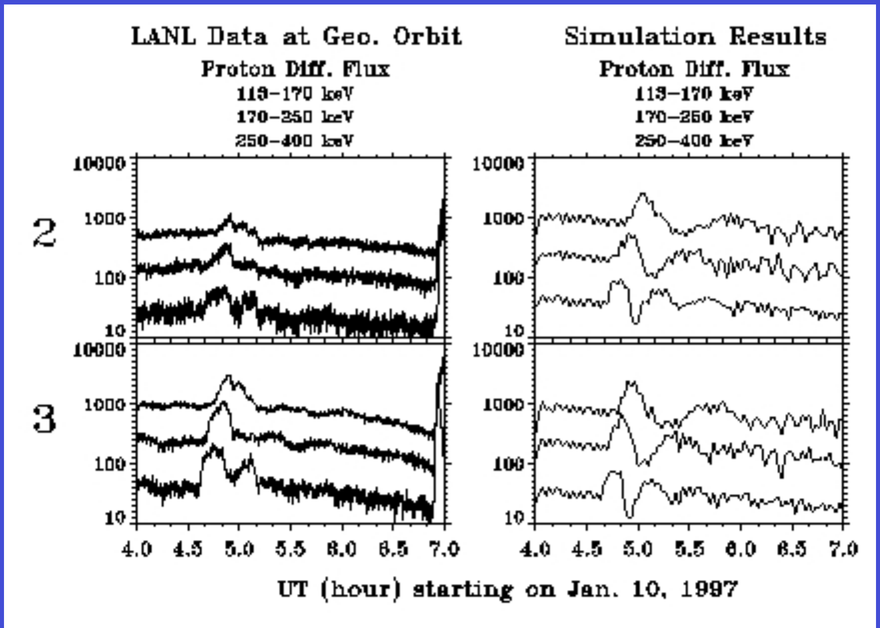


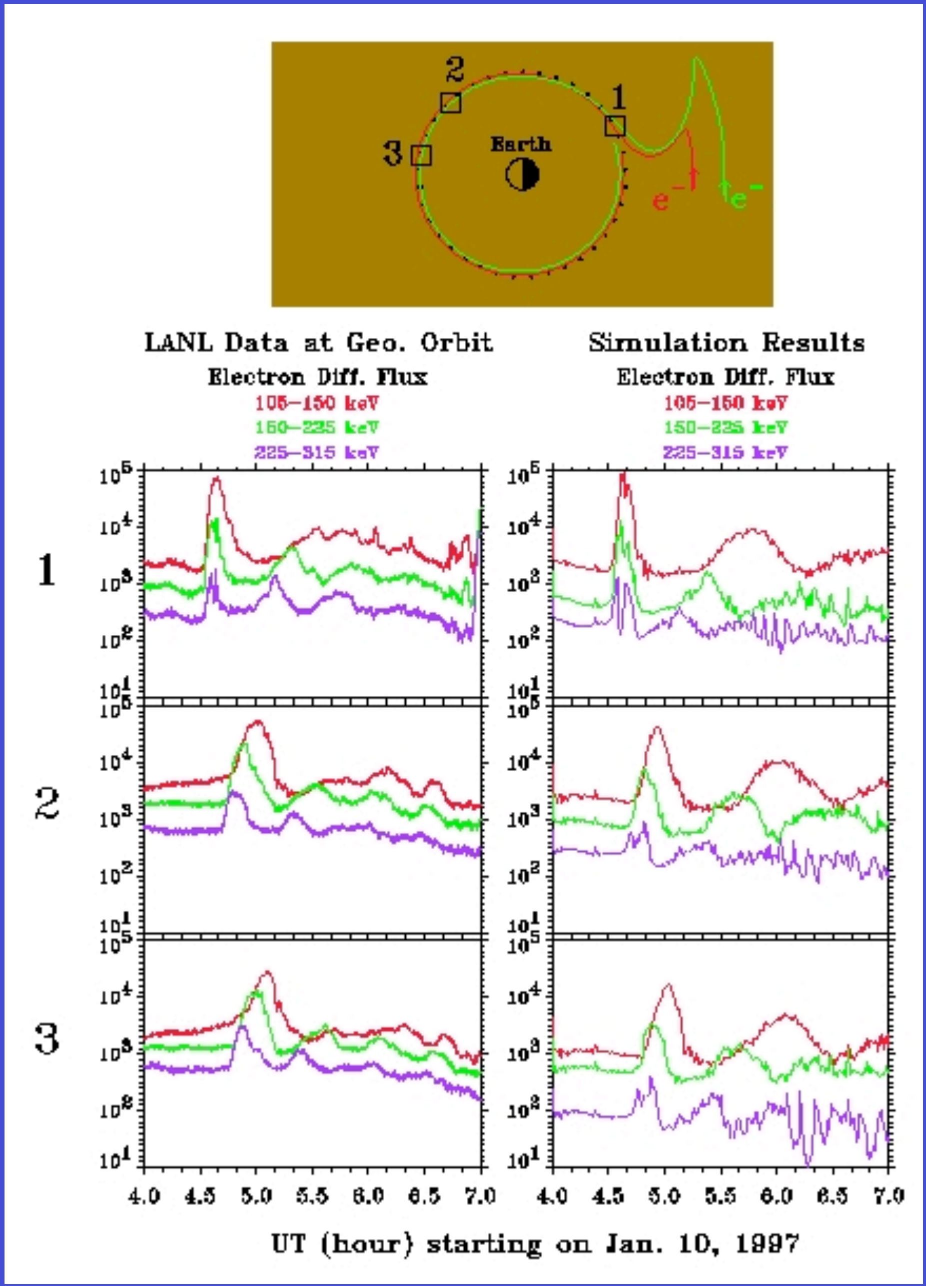
Correlation of solar wind and electrons over a broad energy range at geosynchronous orbit



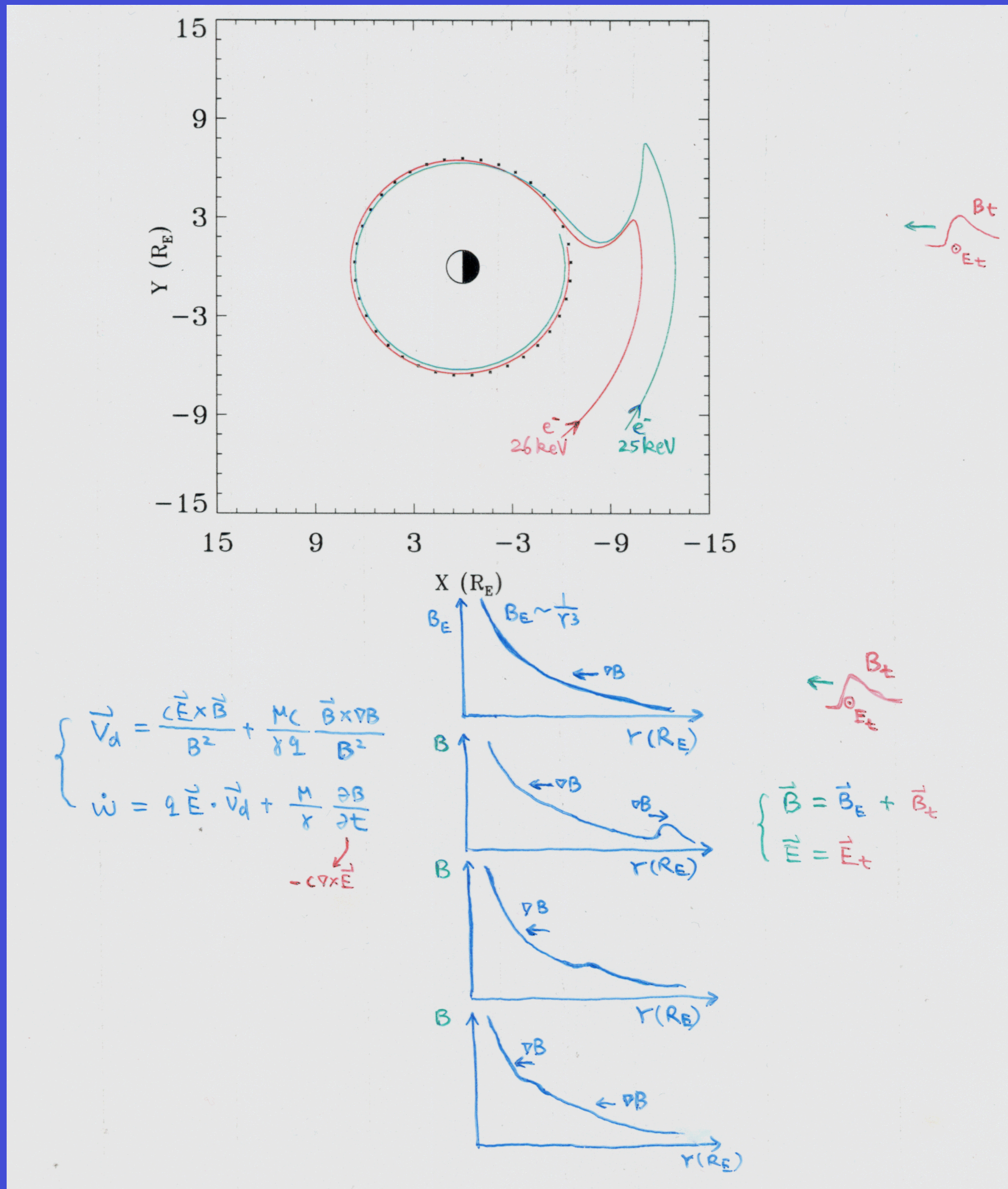
Substorm Particle Injections

▪ particles from **plasma sheet** are injected into the inner magnetosphere, enhancements of energetic particles (10s—100s keV) are often observed by satellites at geosynchronous orbit.



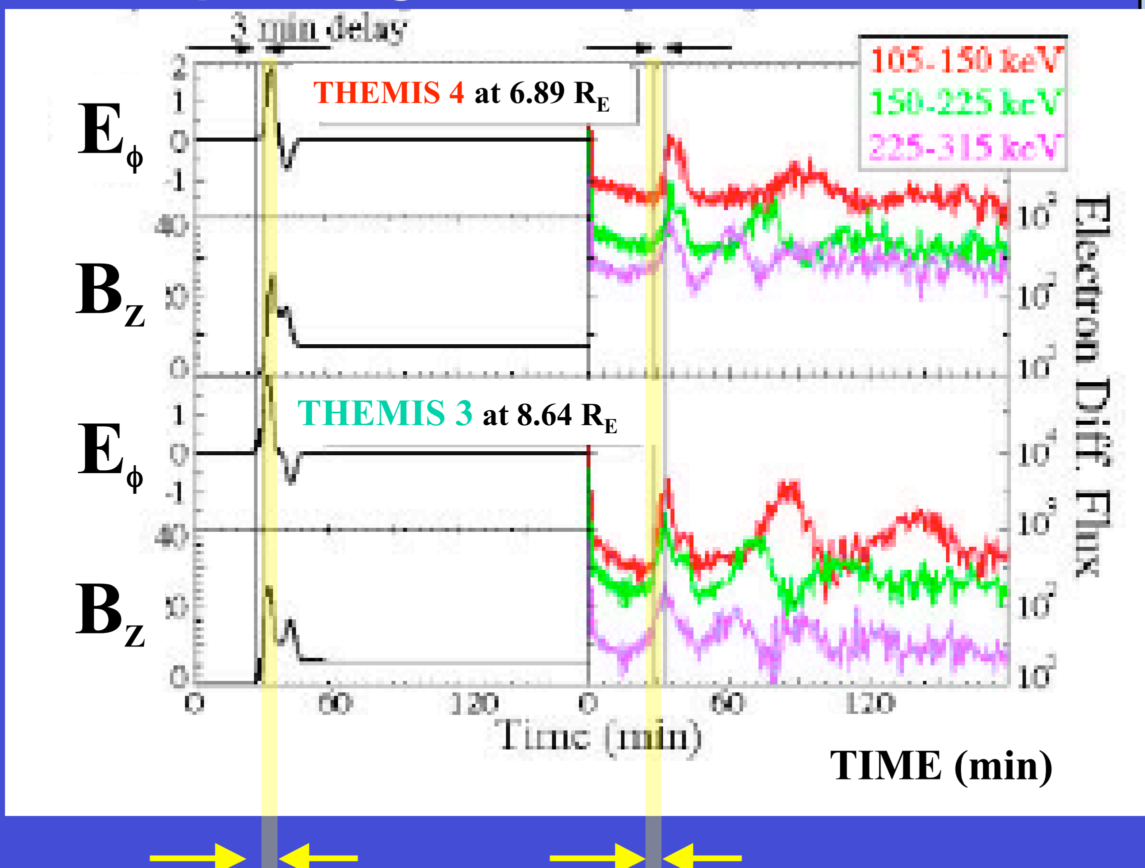


(Li et al., 1999)

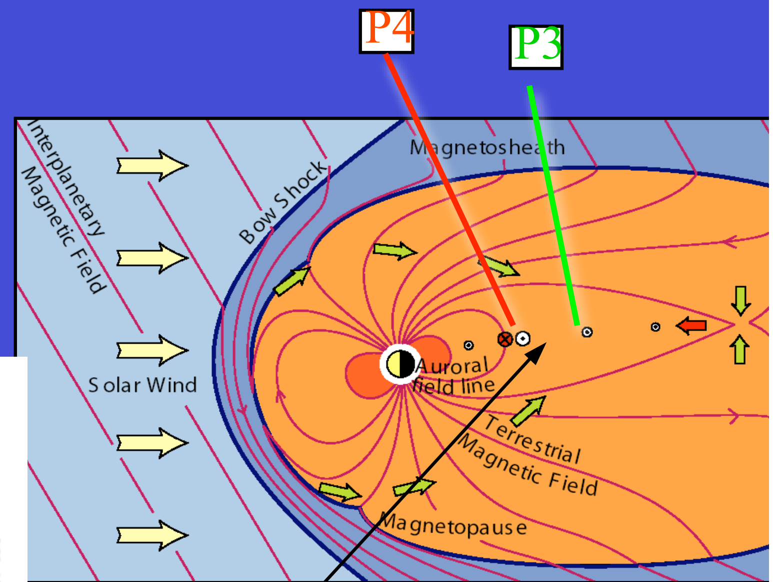


15
9
3
−3
−9
−15
Y (R_E)
X (R_E)
e⁻ 26 keV
e⁻ 25 keV
Bt
Et
B_E
B_E ~ 1/r³
∇B
r(R_E)
B
B_t
E_t
V_d = cE×B/B² + Mc/γq B×∇B/B²
ẇ = qE·V_d + M/γ ∂B/∂t
−c∇×E
B = B_E + B_t
E = E_t

An electric field and magnetic field pulse passes through a background model field produces particle spectra that evolve from one THEMIS probe to another. Field variations and spectral index and fluxes will be compared against THEMIS data.



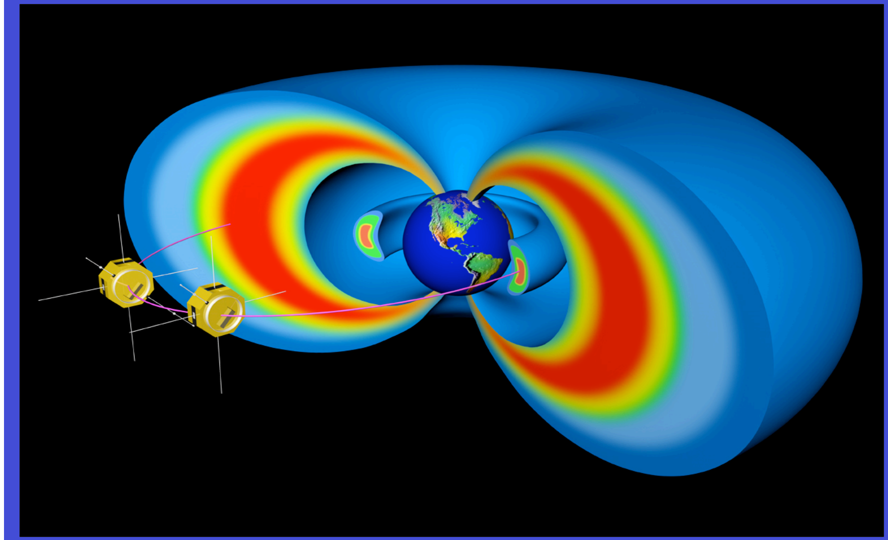
3-min delay

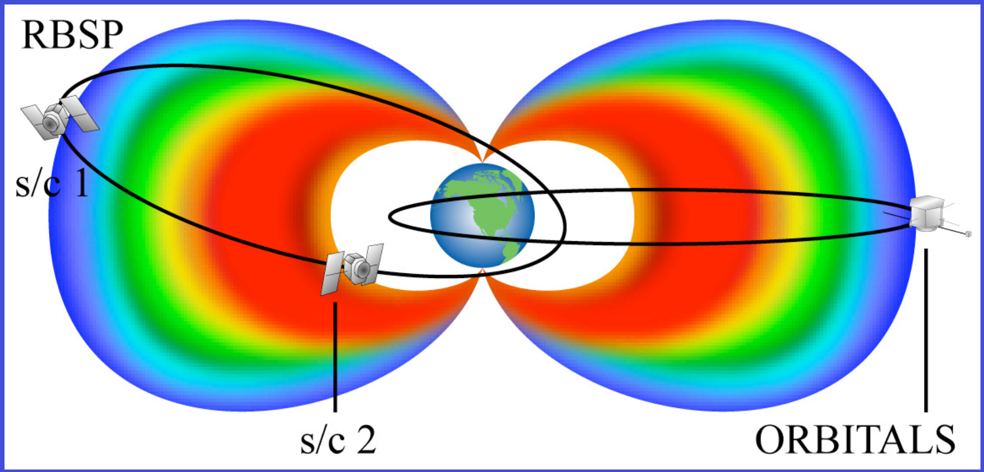


LWS/RBSP (2012) Science Objectives:

• Differentiate among competing process affecting the acceleration, transport and loss of radiation belt electrons.

- **Phase space density, PSD, measurements at different L are required to differentiate in-situ acceleration vs. radial transport**
- **Wide local time and L coverage allow observations of the global wave fields associated with acceleration and loss.**





The final triumph: THEMIS stays healthy and RBSP & ORBITALS & ERG are launched on 'schedule' !!