Earth's outer electron radiation belt and its dynamic behavior

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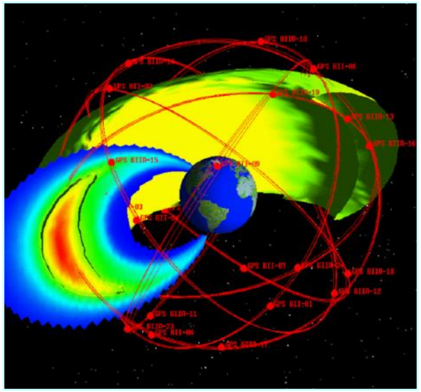

Courtesy of U.S. Air Force Phillips Laboratory

Self-Organized Criticality and Turbulence, ISSI Team Meeting 2, Bern, Switzerland, 16-20 Sept. 2013

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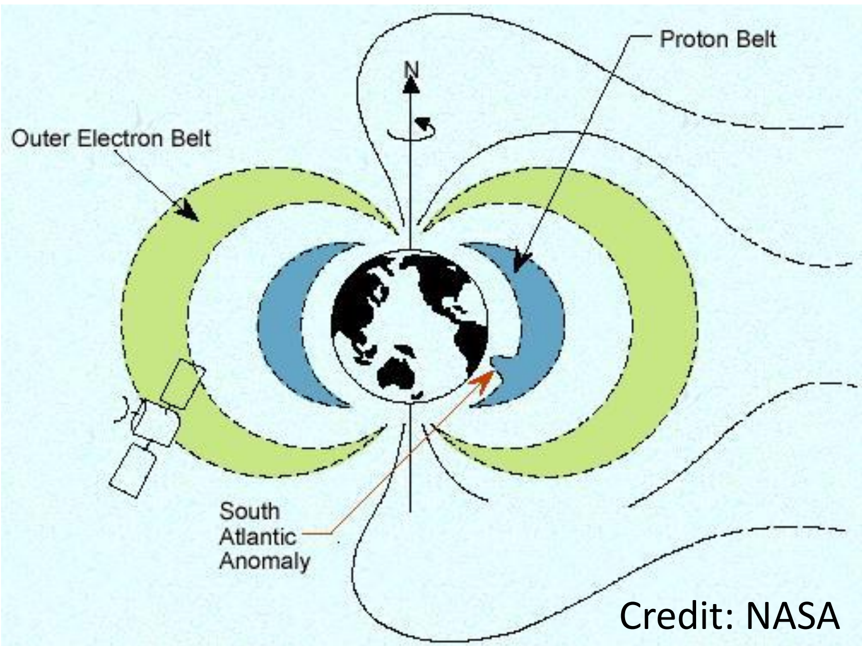
EARTH'S RADIATION BELTS

Trapped particle populations



Proton Belt: 1.3 R_E

Electron Inner Belt: 1.5 - 2.5 R_E
Electron Outer Belt: 3-9 R_E

Protons: Tens keV – couple of hundreds of MeV

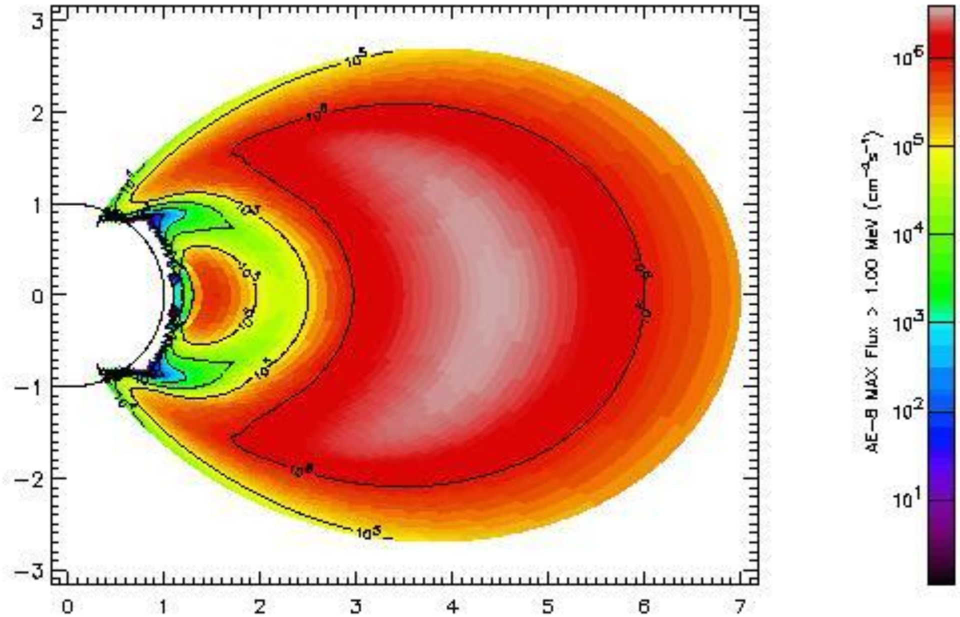
Electrons: Tens keV – several MeV

EARTH'S ELECTRON RADIATION BELTS

from STATIC MODELS to Dynamic Behaviour
(on all spatial- and time-scales)

L-shell, L-value, or McIlwain L-parameter (McIlwain, 1961):

Motions of low-energy charged particles in the Earth's magnetic field can be usefully described in terms of McIllwain's (B,L) coordinates [B: magnitude (or length) of the magnetic field vector].

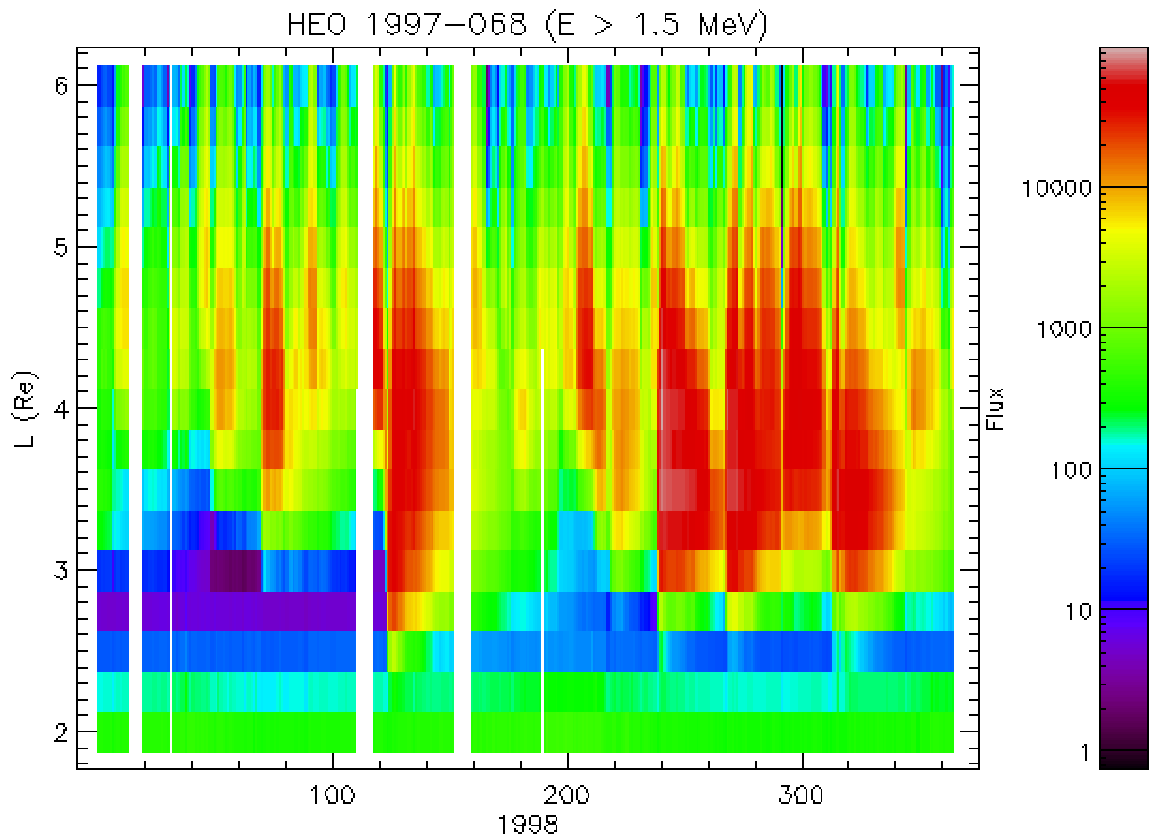


Invariant coordinate map of the AE-8 MAX integral electron flux >1 MeV. The semi-circle represents the surface of the Earth, distances are expressed in Earth radii.

Courtesy of SPENVIS (http://www.spenvis.oma.be/)

Outer electron radiation belt is highly variable.

L= Earth's Radius
= 6371 km



Daily Averaged Electron Outer Radiation Belt
Count Rate Data

HEO data courtesy of The Aerospace Corporation

Theories of electron acceleration include shock acceleration, classical radial diffusion, ULF enhanced radial diffusion, large- and small-scale recirculation, direct substorm injection, and Landau and cyclotron resonant acceleration by wave-particle interactions.

Horne et al., 2006

Kellerman and Shprits, “On the influence of solar wind conditions on the outer-electron radiation belt”, JGR, 117, 2012

Investigated the dependence of outer radiation belt electron fluxes upon solar wind velocity and density using the OMNI solar wind database and LANL-GEO geosynchronous satellites.

“The findings support a model whereby solar wind velocity drives convective transport of source and seed electrons, to the inner magnetosphere, where local acceleration and subsequent radial diffusion is responsible for the enhanced fluxes.”

Any successful model should be able to explain
[or at least to reproduce]
the results of statistical studies performed on the data.

THE ANALOGY – PART 1

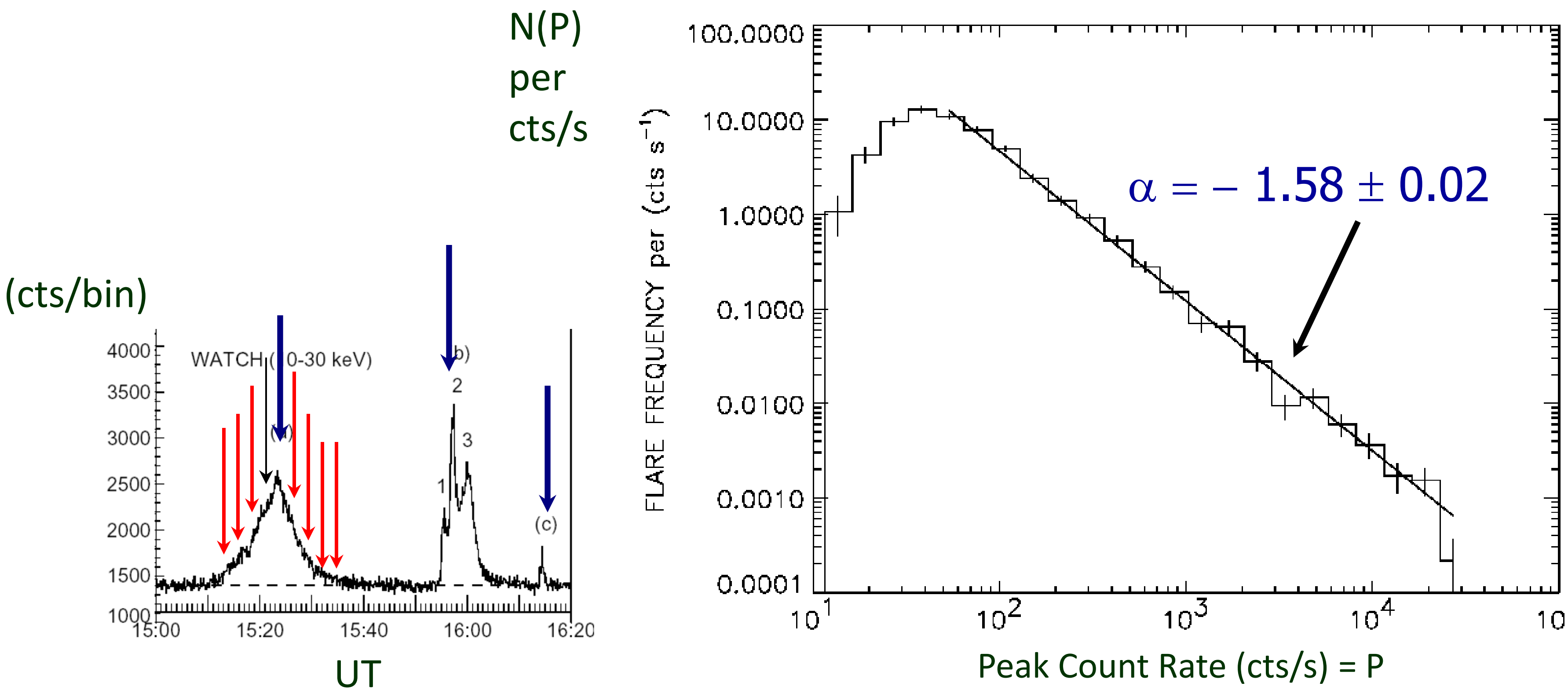
Count rate frequency distribution of more than 5000 hard X-ray structures (less than 1 s) detected in 640 solar flares was found to be well-represented by a powerlaw with a slope of −1.84 (Aschwanden et al., 1995).

This is identical with what was found for the global frequency distribution behaviour of solar flare hard X-rays (e.g. Dennis, 1985; Crosby et al., 1993).

From a scale-invariant model like the avalanche model one would expect that the individual pulses that make up an "avalanche" would also show powerlaw behavior and that the slope values would be similar.

SOLAR FLARES [WATCH/GRANAT]

1990, April-Dec.1991, Jan.-April, July 1992



Crosby N., Vilmer N., Lund N., Sunyaev R., *Astron. Astrophys.*, 334, 299, 1998

THE ANALOGY – PART 2

Even though there are no individually defined "avalanches" in the outer radiation belt, as there are, for example, in the case of the solar corona (e.g. solar flares), one can imagine that the outer radiation belt acts as one individual system "one flare".

The analogy is that the pulses that make up the outer radiation belt are identical with the burst structures making up a flare "individual avalanche".

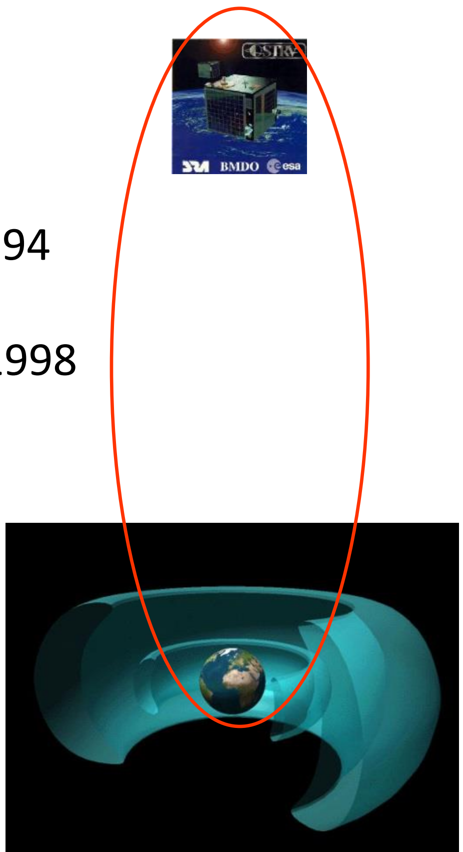
Bearing this in mind and the fact that the outer electron radiation belt is indeed dynamical on all spatial and temporal scales, one can speculate if perhaps the outer electron radiation belt also exhibits powerlaw behavior, thus exhibiting itself as a candidate for SOC behavior.

RADIATION BELTS

CID/STRV-1a

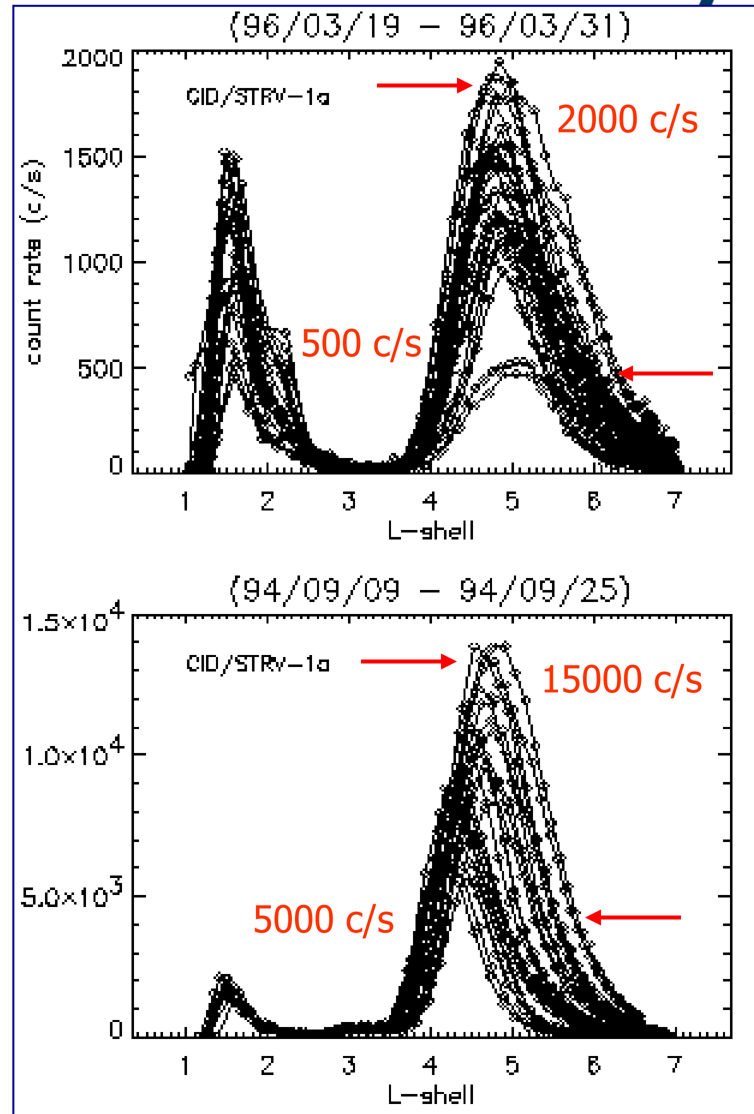
(measures electrons > 750 keV)

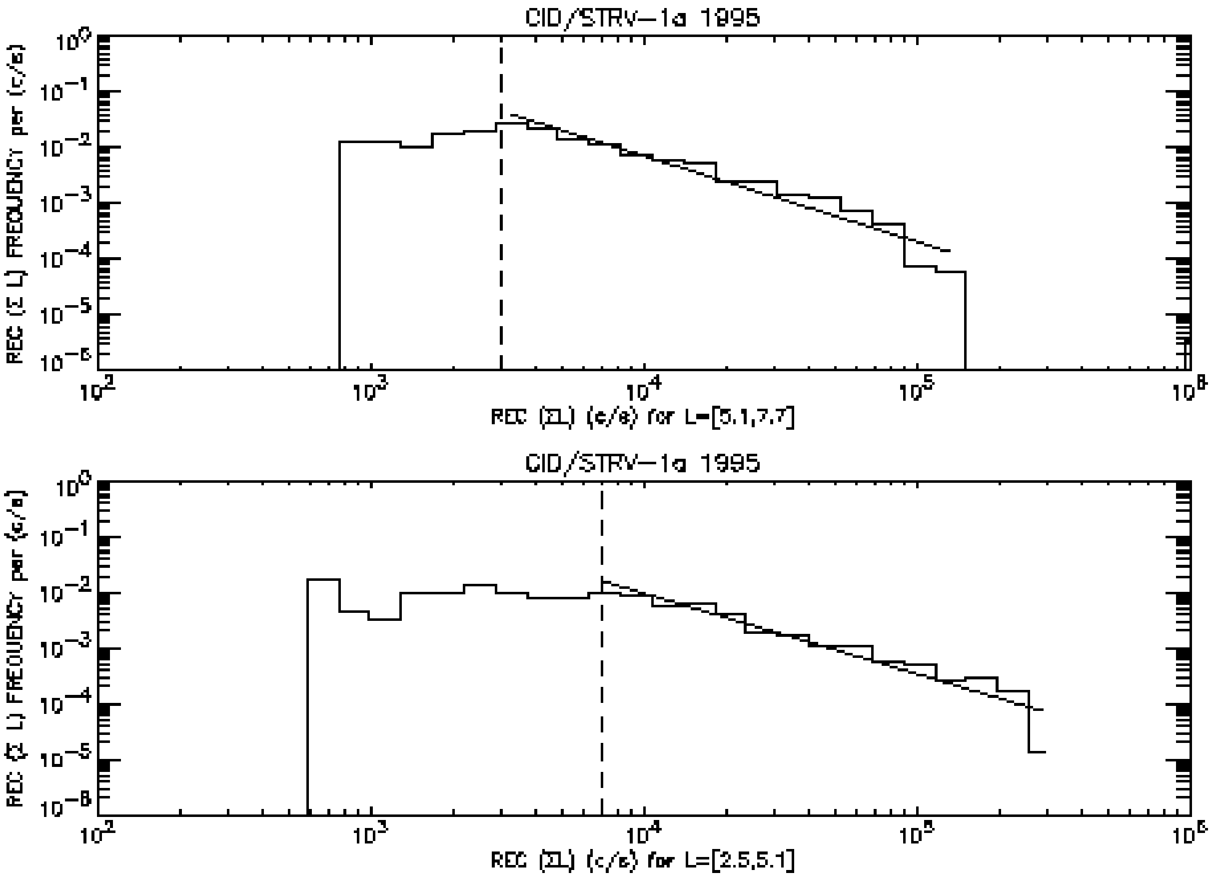
Apogee: 35795 km



Sept. 1994
through
March 1998

Perigee: 200 km





L=[5.1,7.7]

L=[2.5,5.1]

Total Relativistic Electron Count (Σ L)

Total Relativistic Electron Content (TREC)

To take into account the non-symmetric aspect of Earth's magnetic field the Total Relativistic Electron Content (TREC) is computed for the three Years (1995, 1996, 1997):

Count rate data is :

- Initially binned as a function of L by averaging in steps of $\Delta L = 0.2$
- Then approximated by $T(L)=C(L)\times L^2$, where the factor L^2 makes an allowance for the volume occupied between dipolar shells L and $L+\Delta L$

(for more details see Iles R.H.A., Fazakerley A.N., Johnstone A.D., Meredith N.P. and Bühler P, *Ann. Geophys.*, 20, 7, 957-965, 2002)

The TREC is computed as a function of day for the following three radiation belt intervals:

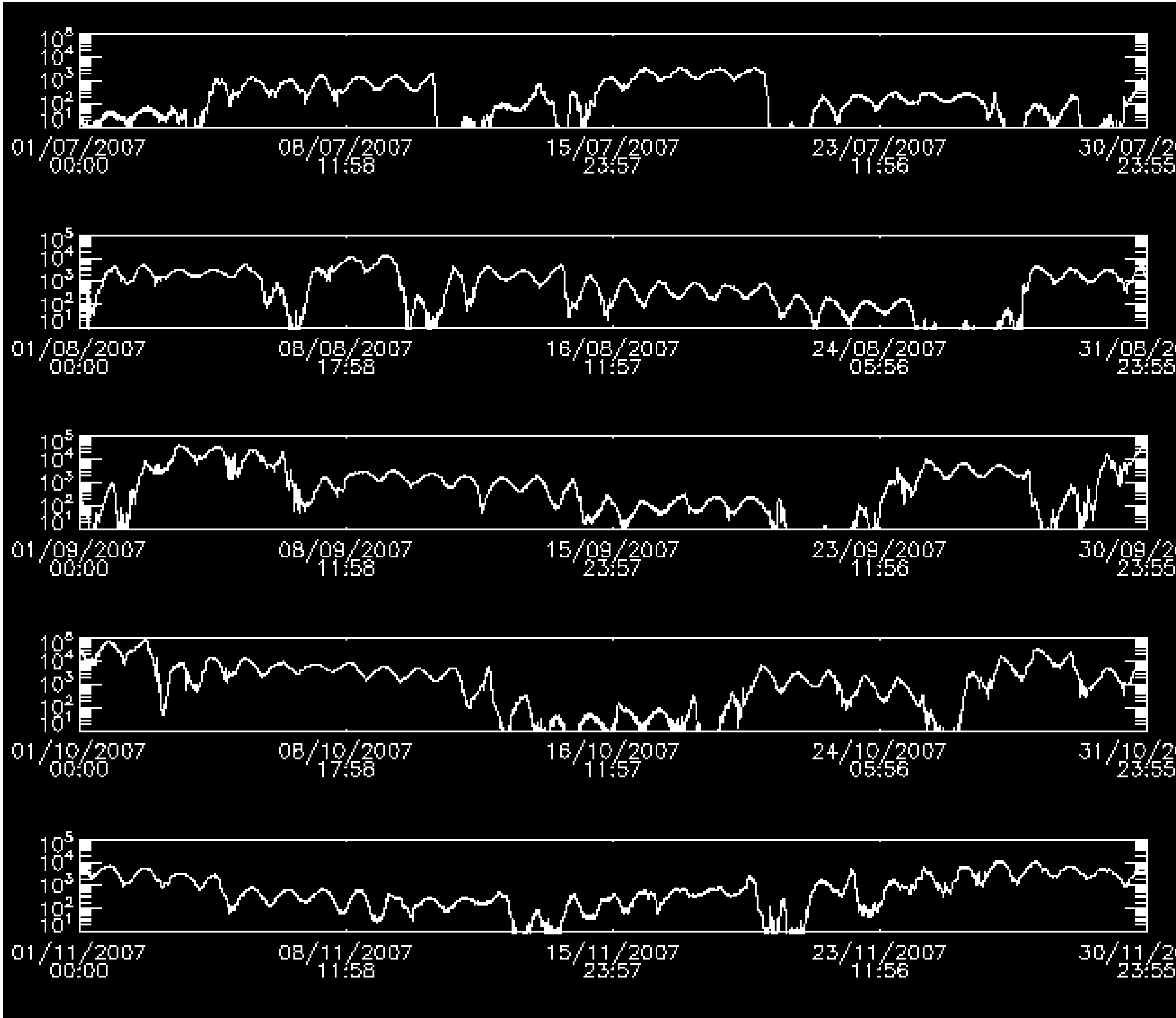
$L=[4.1,5.5]$, $L=[5.5,7.7]$ and $L=[4.1,7.7]$

OUTER ELECTRON RADIATION BELT – SOLAR WIND

	CID/STRV-1a Outer Electron Radiation Belt Data			OMNI Solar Wind Data	
Year	T_{REC} (ΣL) 4.1 < L< 7.7 slope	T_{REC} (ΣL) 4.1 < L< 5.5 slope	T_{REC} (ΣL) 5.5 < L < 7.7 slope	Vsw (-Bz & +Bz) slope	Vsw (-Bz) slope
1995	-1.195+/-0.060	-1.254+/-0.069	-1.548+/-0.122	-5.54+/-0.15	-5.66+/-0.19
1996	-1.535+/-0.082	-1.430+/-0.104	-2.074+/-0.193	-10.45+/-0.27	-10.59+/-0.35
1997	-1.739+/-0.092	-1.950+/-0.119	-2.675+/-0.234	-13.76+/-0.59	-13.44+/-0.74

Crosby N., Meredith N., Coates A., Iles R., NPG, 12, 993, 2005

GOES-11: > 2 MeV Electron Flux



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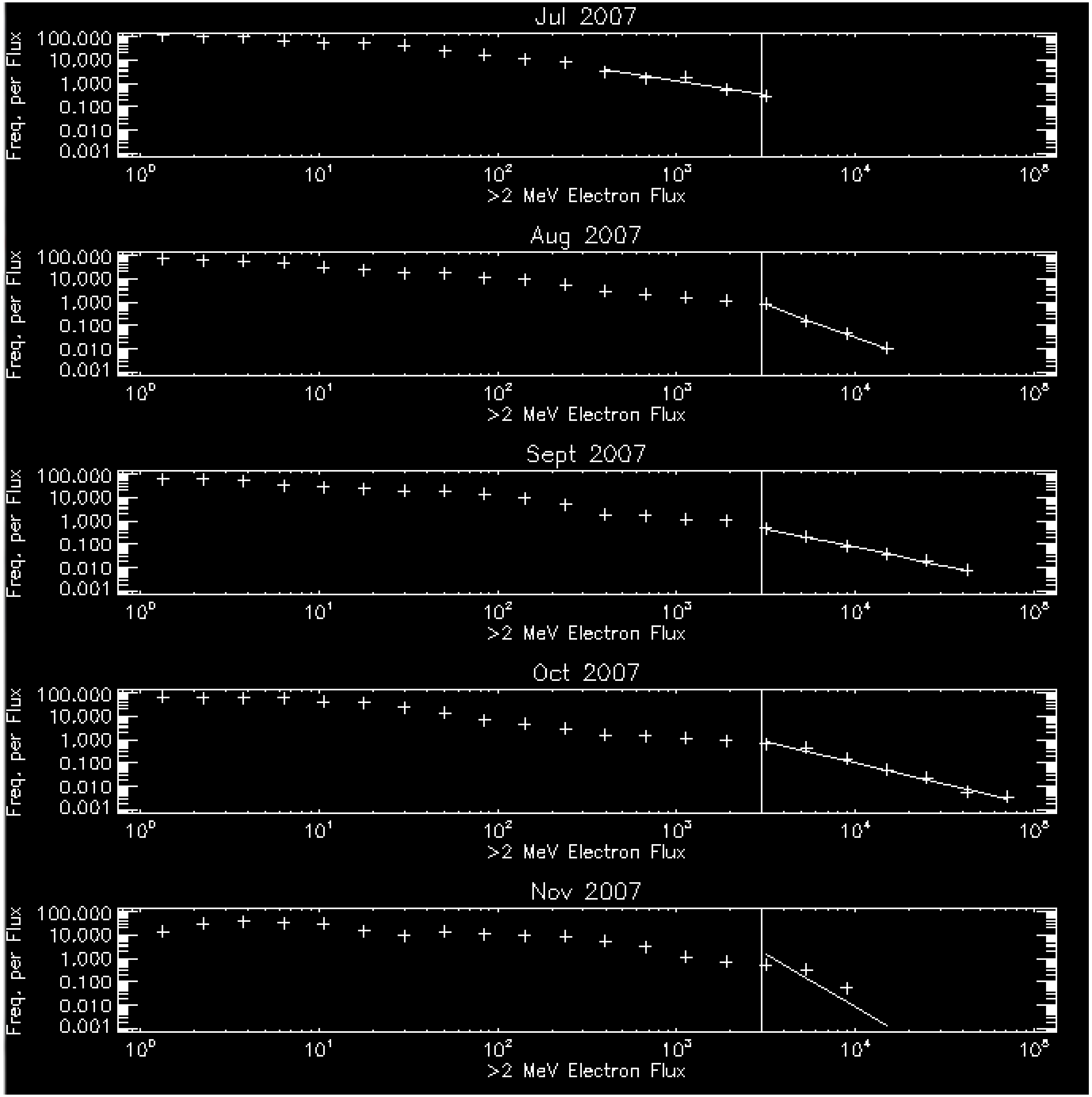
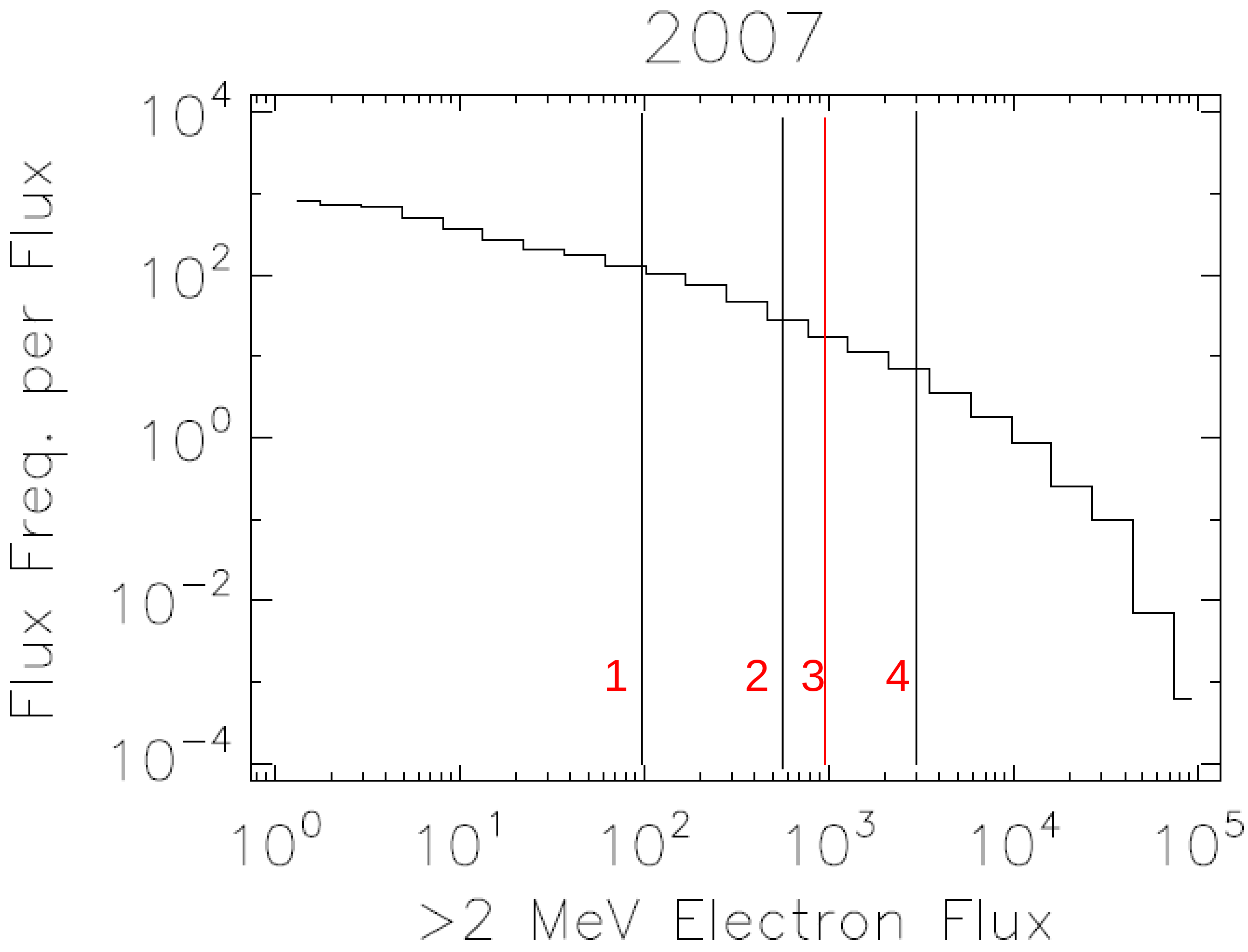
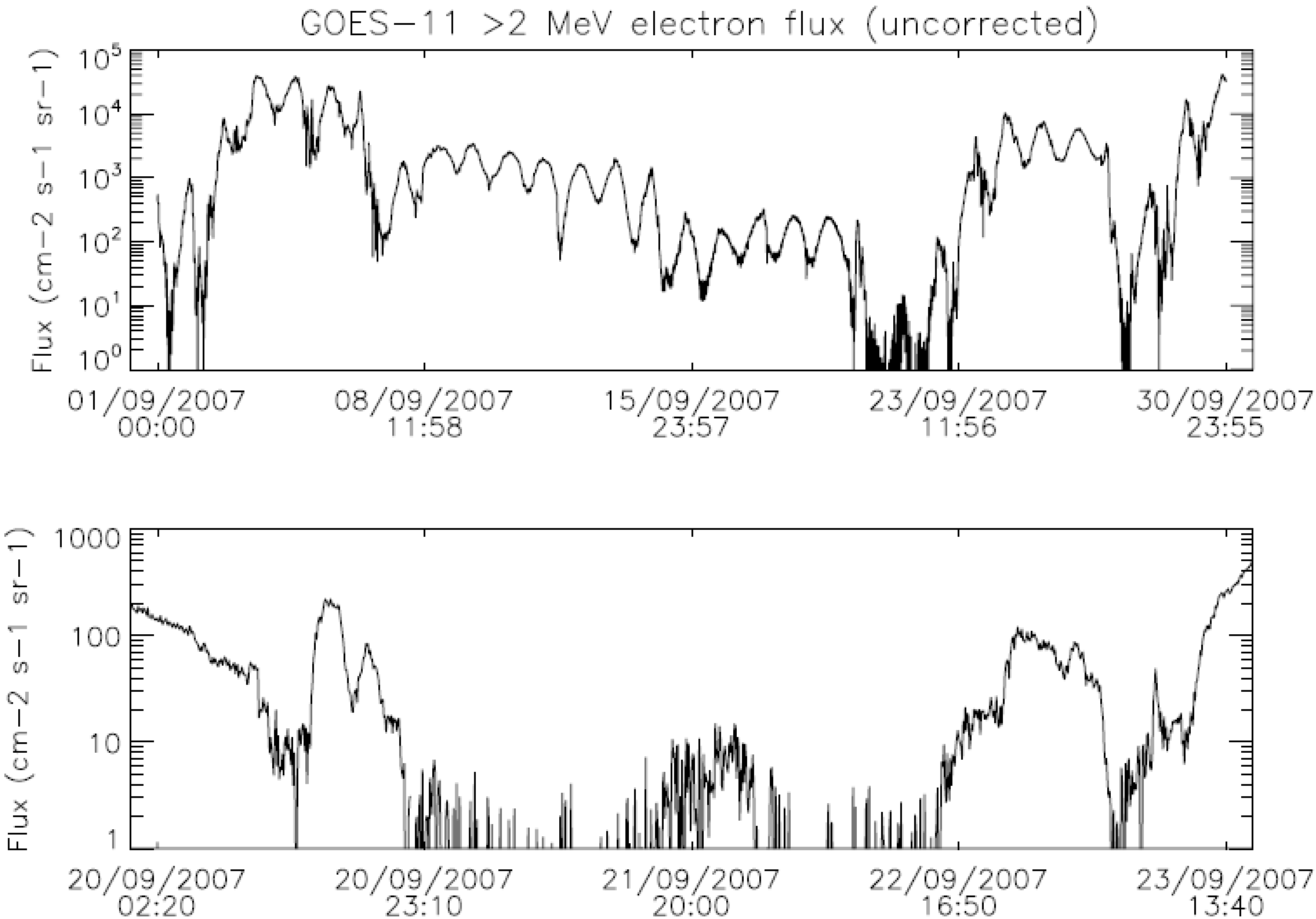
GOES-11


Jul 2007
Aug 2007
Sept 2007
Oct 2007
Nov 2007
Freq. per Flux
100.000
10.000
1.000
0.100
0.010
0.001
10^0
10^1
10^2
10^3
10^4
10^5
>2 MeV Electron Flux

GOES-11

$\alpha = -1.228 \pm 0.002$ (Line 1)
$\alpha = -1.413 \pm 0.003$ (Line 2)
$\alpha = -1.559 \pm 0.004$ (Line 3)
$\alpha = -1.894 \pm 0.008$ (Line 4)





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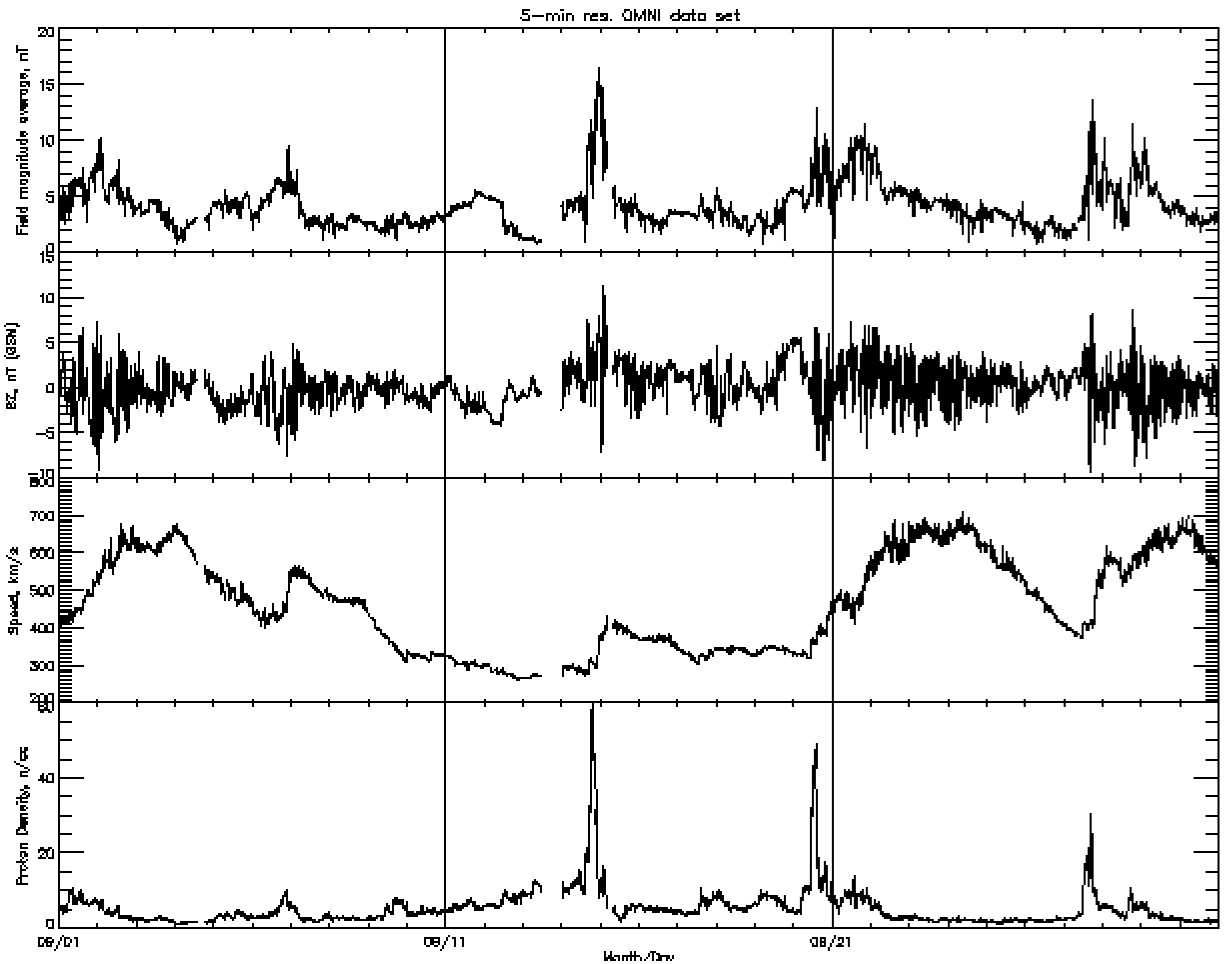
Plot omni_5min data from 20070901 to 20070930



EARTH'S OUTER ELECTRON RADIATION BELT SUMMARY

- Results suggest that the modelling of the outer electron radiation belt as a complex system in a self-organized critical state provides a good context to understand the frequency distributions of the electron parameters.
- Evidence for more dynamic control in the outer region of the outer electron radiation belt.
- Entire outer electron radiation belt appears to be affected in the same way.
- Any successful model should be able to explain [or at least to reproduce] the results of statistical studies performed on the data.