Radiation Belt Sources and Losses Driven by Solar Wind Variability

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and

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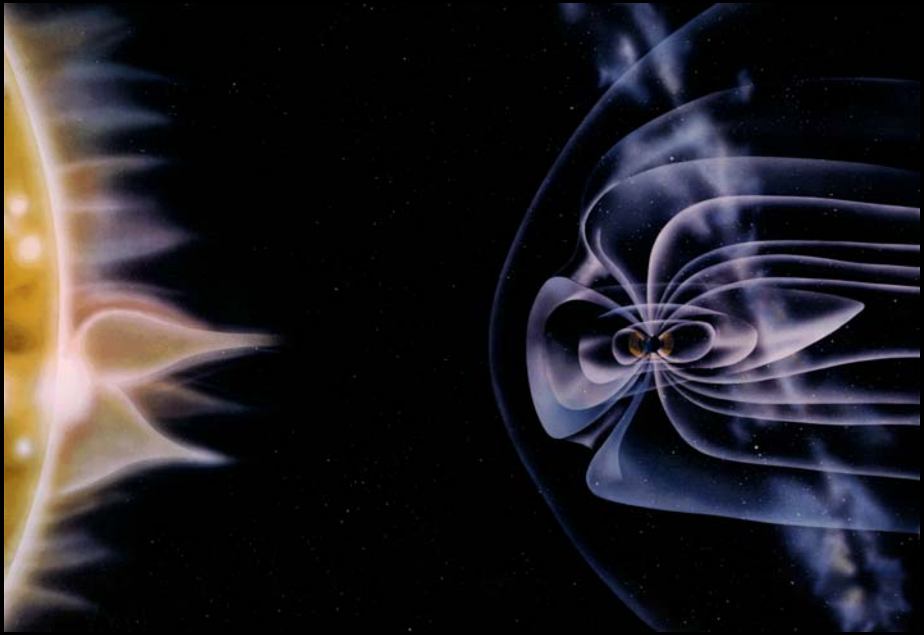
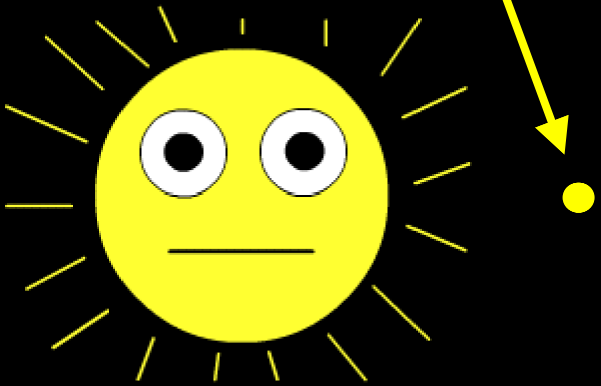
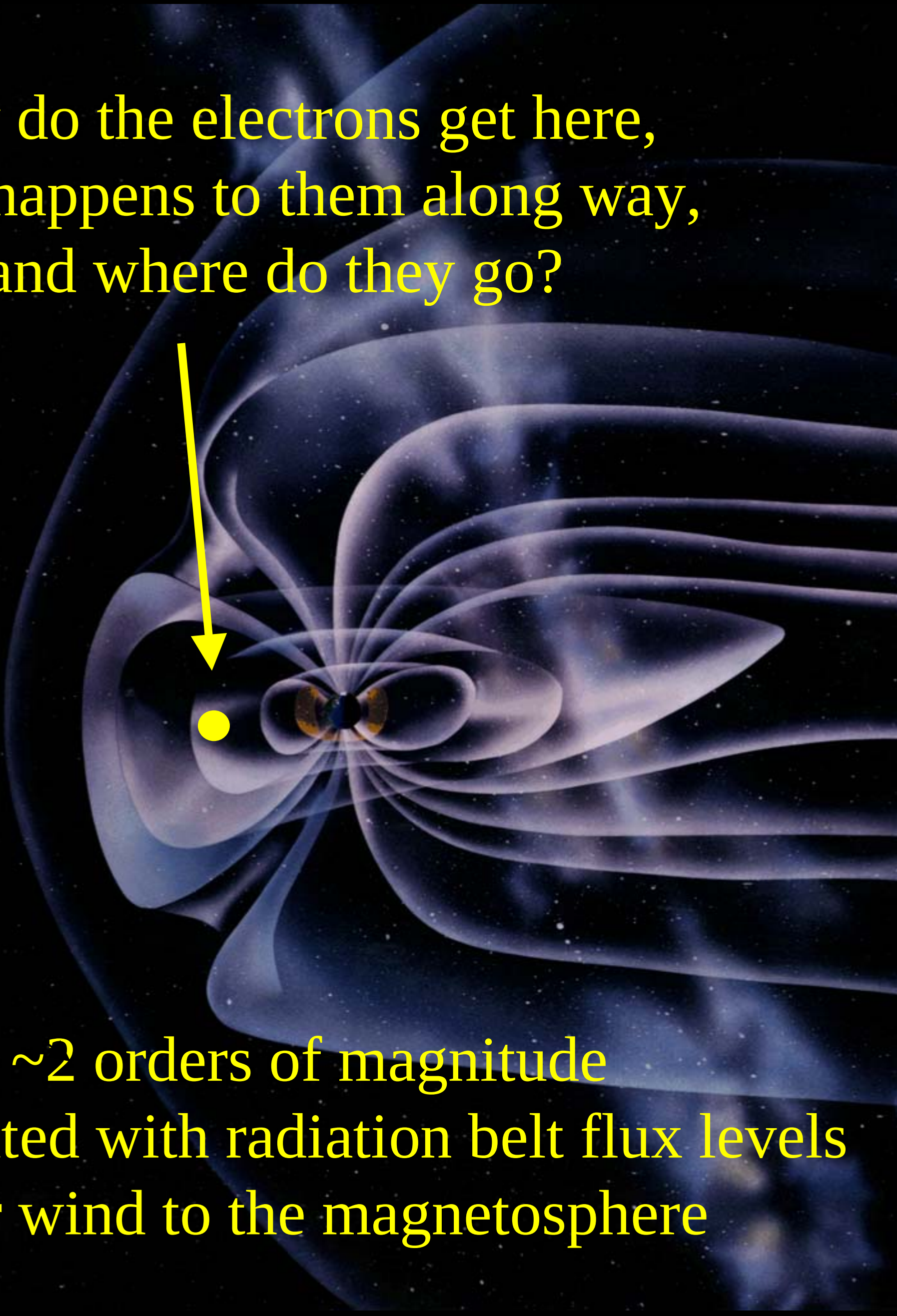


What is the electron
flux here,



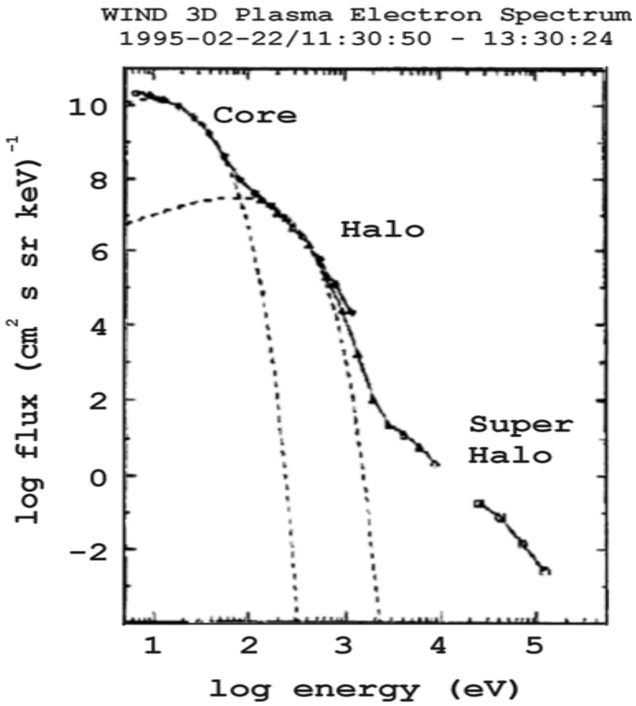
how do the electrons get here,
what happens to them along way,
and where do they go?



- Solar wind “super halo” varies by ~2 orders of magnitude
- Solar wind speed is highly correlated with radiation belt flux levels
- IMF Bz controls coupling of solar wind to the magnetosphere

Phase Space Density for Magnetic Moment: M = 2000 MeV/G

Solar Wind Electrons



$|\mathbf{B}| \cong 5\ \mathrm{nT}$

$\mathbf{E} \cong 90\ \mathbf{keV}$

$\mathbf{j} \cong 10^{-2}\ (\mathbf{cm^2 s\, sr\, keV})^{-1}$

$\mathbf{f} \cong 10^{23}\ (\mathbf{s^3 MeV^3})^{-1}$

$$f(E) = \frac{j(E)}{p^2}$$

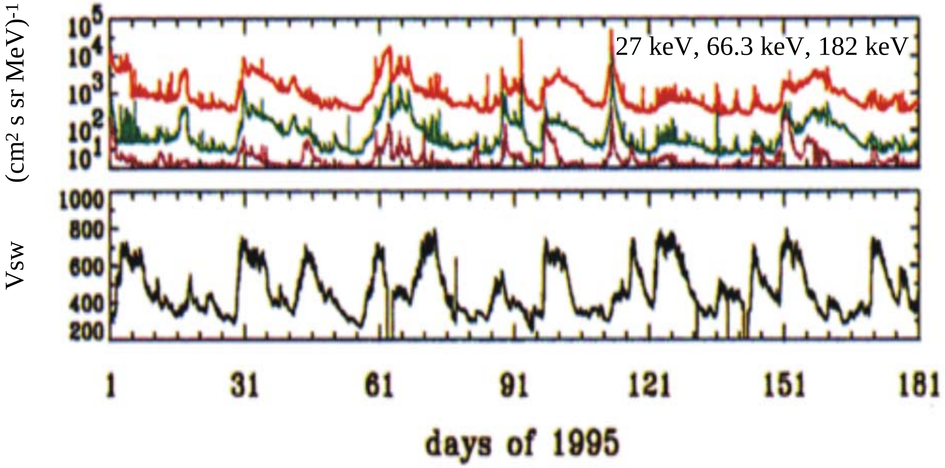
$$p^2c^2 = E^2 + 2mc^2E$$

$$M = \frac{p_\perp^2}{2mB} \approx \frac{p_\perp^2 c^2}{B}\ \frac{MeV}{G}$$

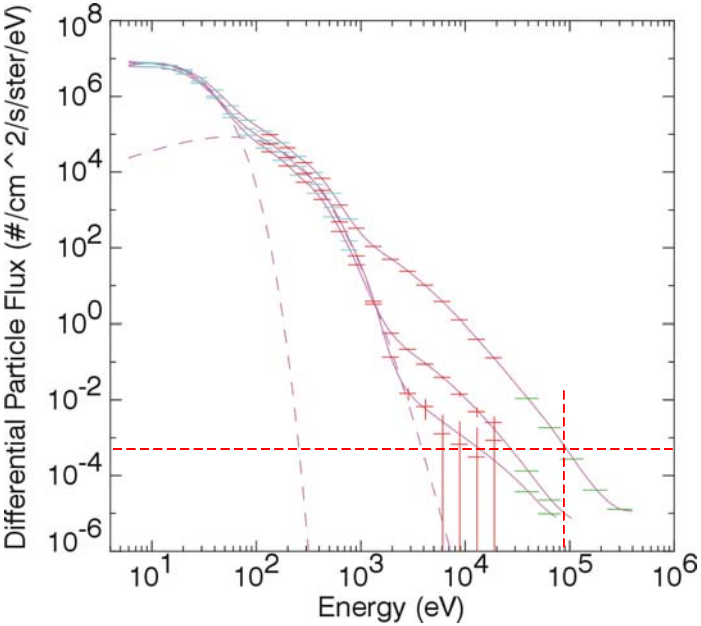
$$f = \frac{j\, 9x10^{20}}{p^2c^2}(s^3 MeV^3)^{-1}$$

Solar Wind Electron Flux is Highly Variable at High Energies

WIND Electron Flux and Solar Wind Speed [Li et al., 1997]



WIND Electron Spectra - Davin Larson



Electron flux shows some correlation with solar wind speed

Phase space density at M = 2000 MeV/G can vary by a factor of 50

$$|\mathbf{B}| \cong 5\ \mathbf{nT}$$

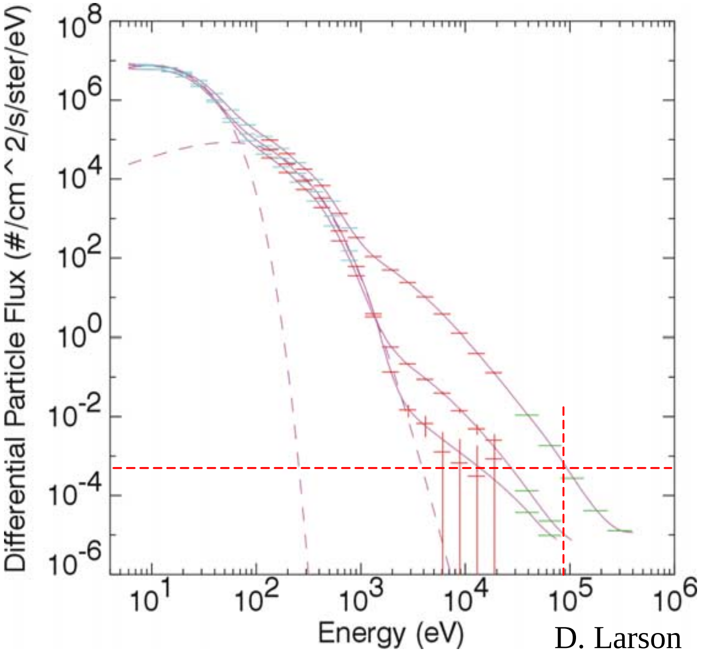
$$\mathbf{E} \cong 90\ \mathbf{keV}$$

$$\mathbf{j} \cong \mathbf{5x10^{-1}\ (cm^2 s\, sr\, keV)^{-1}}$$

$$\mathbf{f} \cong \mathbf{5x10^{24}\ (s^3 MeV^3)^{-1}}$$

Phase Space Density in the Solar Wind Versus in the Plasma Sheet

Solar Wind Electrons



D. Larson

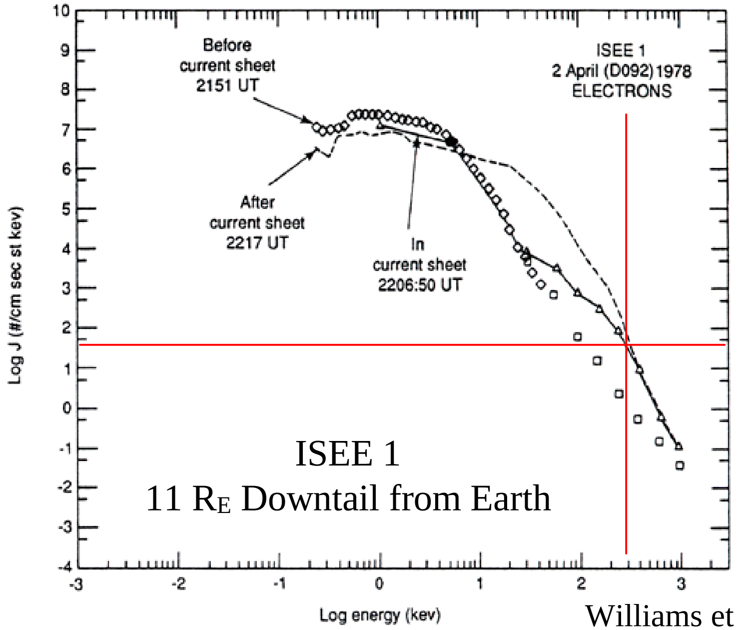
$|\mathbf{B}| \cong 5\ \mathrm{nT}$

$\mathbf{E} \cong 90\ \mathrm{keV}$

$\mathbf{j} \cong 5\mathrm{x}10^{-1}\ (\mathrm{cm}^2\mathrm{s\,sr\,keV})^{-1}$

$\mathbf{f} \cong 5\mathrm{x}10^{24}\ (\mathrm{s}^3\mathrm{MeV}^3)^{-1}$

Plasma Sheet Electrons



ISEE 1
11 R_E Downtail from Earth

Williams et al., 1990

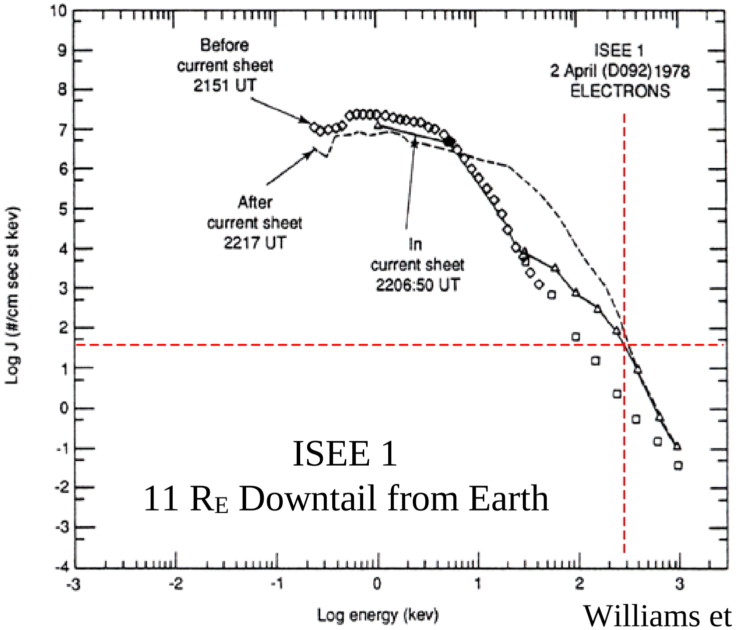
$|\mathbf{B}| \cong 20\ \mathrm{nT}$

$\mathbf{E} \cong 300\ \mathrm{keV}$

$\mathbf{j} \cong 30\ (\mathrm{cm}^2\mathrm{s\,sr\,keV})^{-1}$

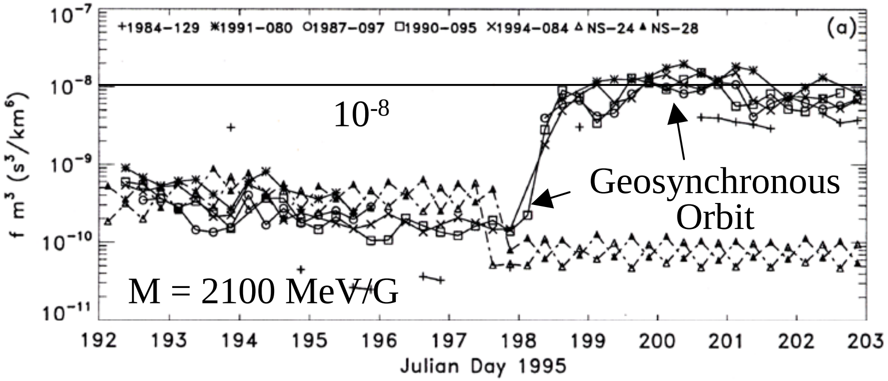
$\mathbf{f} \cong 7\mathrm{x}10^{25}\ (\mathrm{s}^3\mathrm{MeV}^3)^{-1}$

Phase Space Density in the Plasma Sheet Versus in the Radiation Belt



Williams et al., 1990

- Plasma sheet electron and ion heating was associated with current sheet disruption and field dipolarization.
- Phase space density in the near-Earth plasma sheet is comparable to phase space density at geosynchronous orbit.



Hilmer et al., 2000

- Plasma Sheet:

$$M = 2000\ MeV/G$$

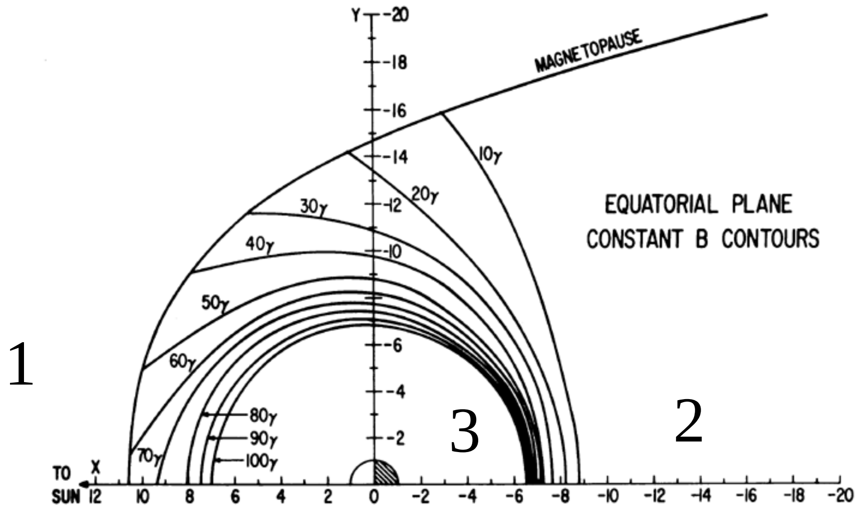
$$f\,m_e^3 = \frac{j}{p^2c^2}\left(1.66\times10^{-10}\right)\ s^3/km^6$$

$$= 10^{-8}\ \ s^3/km^6$$

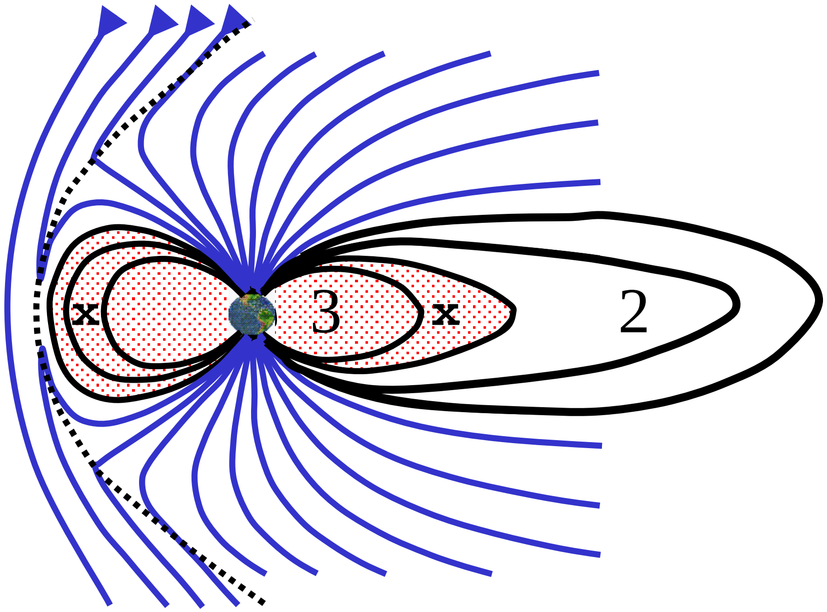
- Geosynchronous Orbit:

$$M = 2100\ MeV/G$$

$$f\,m_e^3 = 10^{-10} - \ 10^{-8}\ s^3/km^6$$



Fairfield, 1968



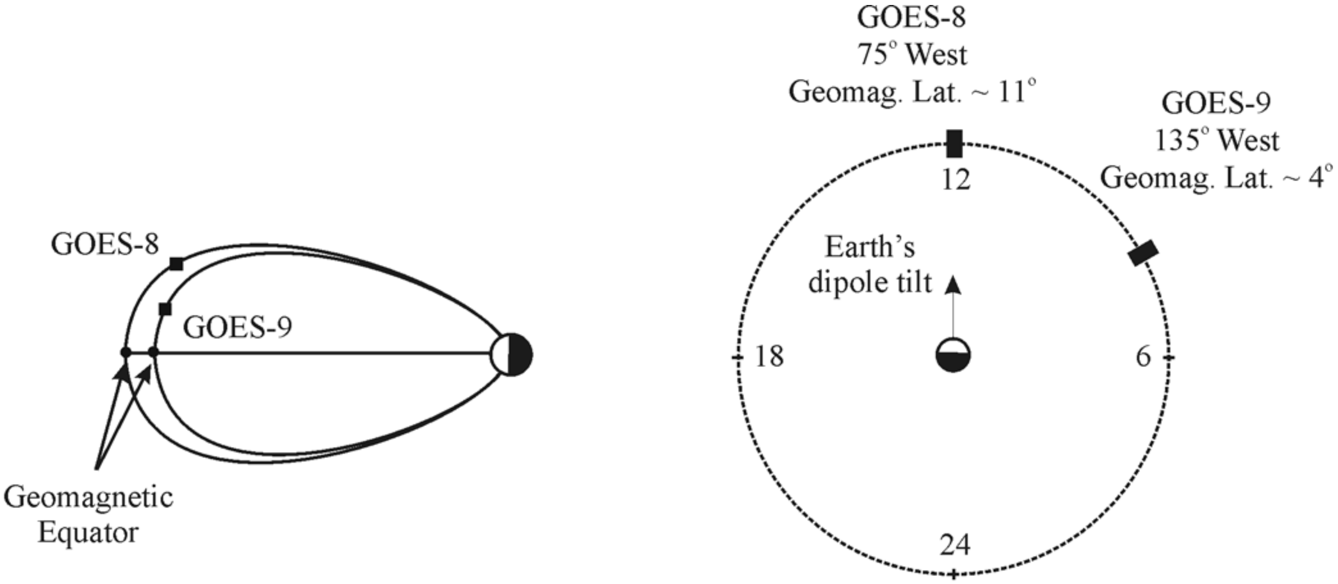
For M = 2000 MeV/G:

Solar Wind	Plasma Sheet	Radiation Belt
$f \cong 10^{22} - 10^{24}\ (s^3 MeV^3)^{-1}$	$10^{23} - 10^{26}$	$10^{24} - 10^{26}$

The plasma sheet may at times have sufficient flux to supply the radiation belt

Is the radial gradient of phase space density at geostationary orbit consistent with an electron source inside or outside of this location?

Estimating the Radial Gradient of Phase Space Density at Geostationary Orbit



Geomagnetic coordinate view from dusk

Geographic equatorial plane view

Geosynchronous Satellites Measure Electrons in Different L-shells

Convert flux to phase space density:

$$f(E) = \frac{j(E)}{p^2}$$

$$p^2c^2 = E^2 + 2mc^2E$$

Compare phase space density at fixed 1st adiabatic invariant:

$$M = \frac{p_\perp^2}{2mB} \approx \frac{p_\perp^2 c^2}{B} \frac{MeV}{G}$$

Restrict analysis to equatorially mirroring particles: 2nd invariant = 0

An assumption: $f(E) = f_o e^{-E/E_o}$

For a measured integral flux: $J(>E) = \int_E^\infty dE' \, j(E')$

$$J(>E) = \int_E^\infty dE' \, f(E') p^2$$

$$f(E) = \frac{c^2 J(>E)}{(E_0{}^2 + EE_0) 2mc^2 + 2E_0^3 + 2EE_0^2 + E^2 E_0}$$

Another assumption: $f_{equator}(E,\alpha_{eq}) = f_{eq}(E)\sin^m\alpha_{eq}$

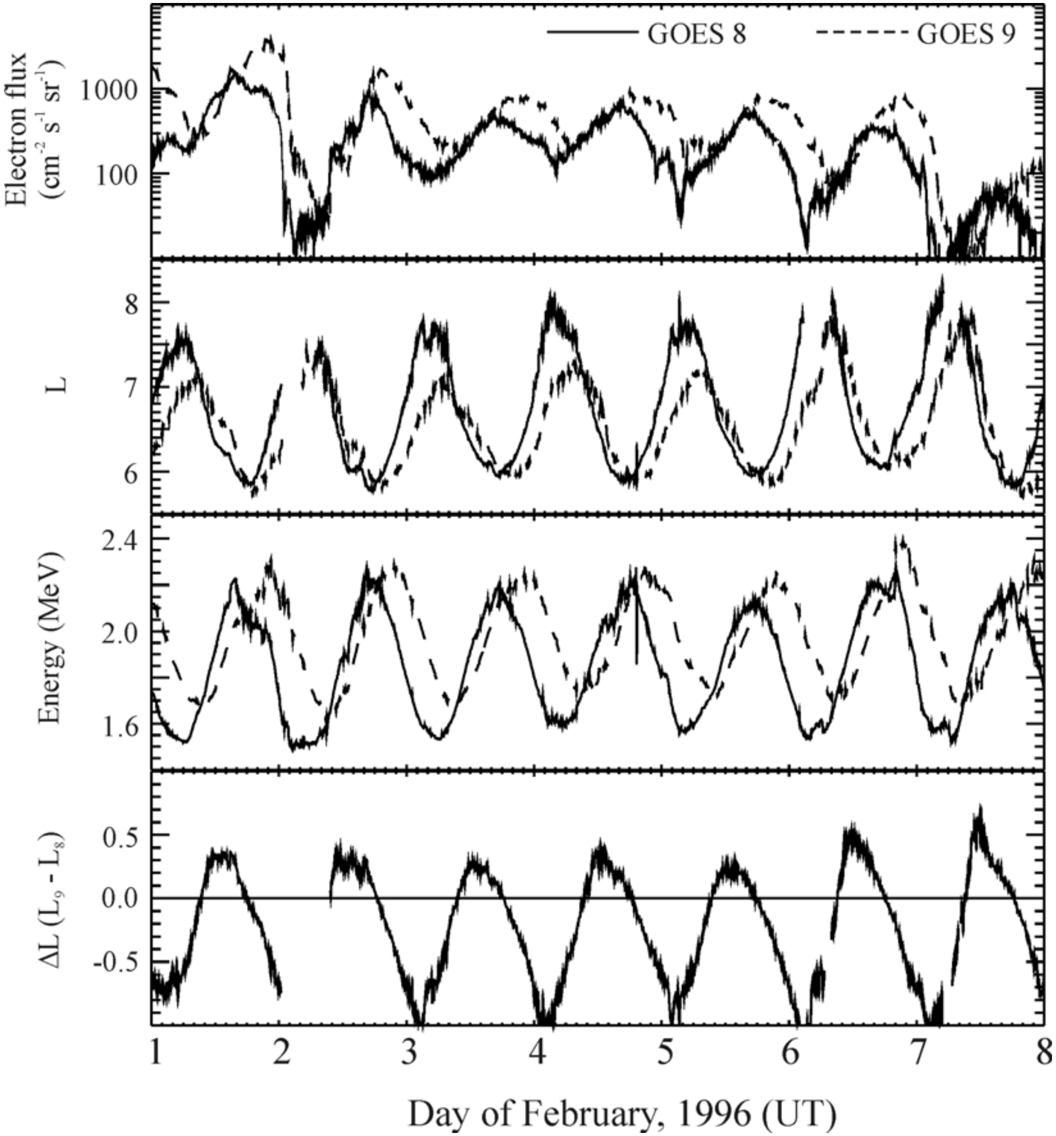
$$f_\lambda(E,\alpha_\lambda) = f_{equator}(E,\alpha_{eq}) = f_{eq}(E)\sin^m\alpha_{eq}$$

$$\sin\alpha_{eq} = \left(\frac{B_{eq}}{B_\lambda}\right)^{\frac{1}{2}} \sin\alpha_\lambda$$

$$f_\lambda(E,\alpha_\lambda) = f_{eq}(E)\left(\frac{B_{eq}}{B_\lambda}\right)^{\frac{m}{2}} \sin^m\alpha_\lambda$$

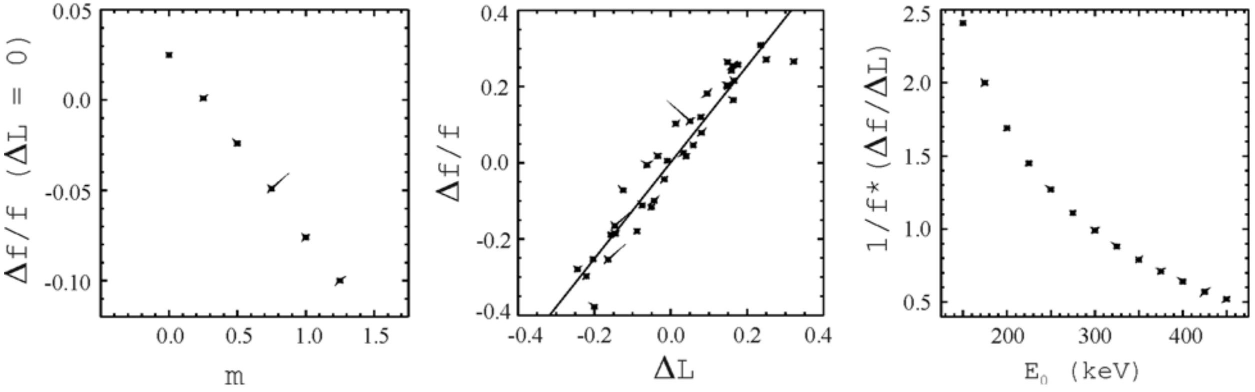
$$f_{eq}(E) = \frac{c^2 J_\lambda(>E)}{(E_0{}^2 + EE_0)\,2mc^2 + 2E_0^3 + 2EE_0^2 + E^2 E_0}\left(\frac{B_\lambda}{B_{eq}}\right)^{\frac{m}{2}}$$

Two free parameters: E_o and m



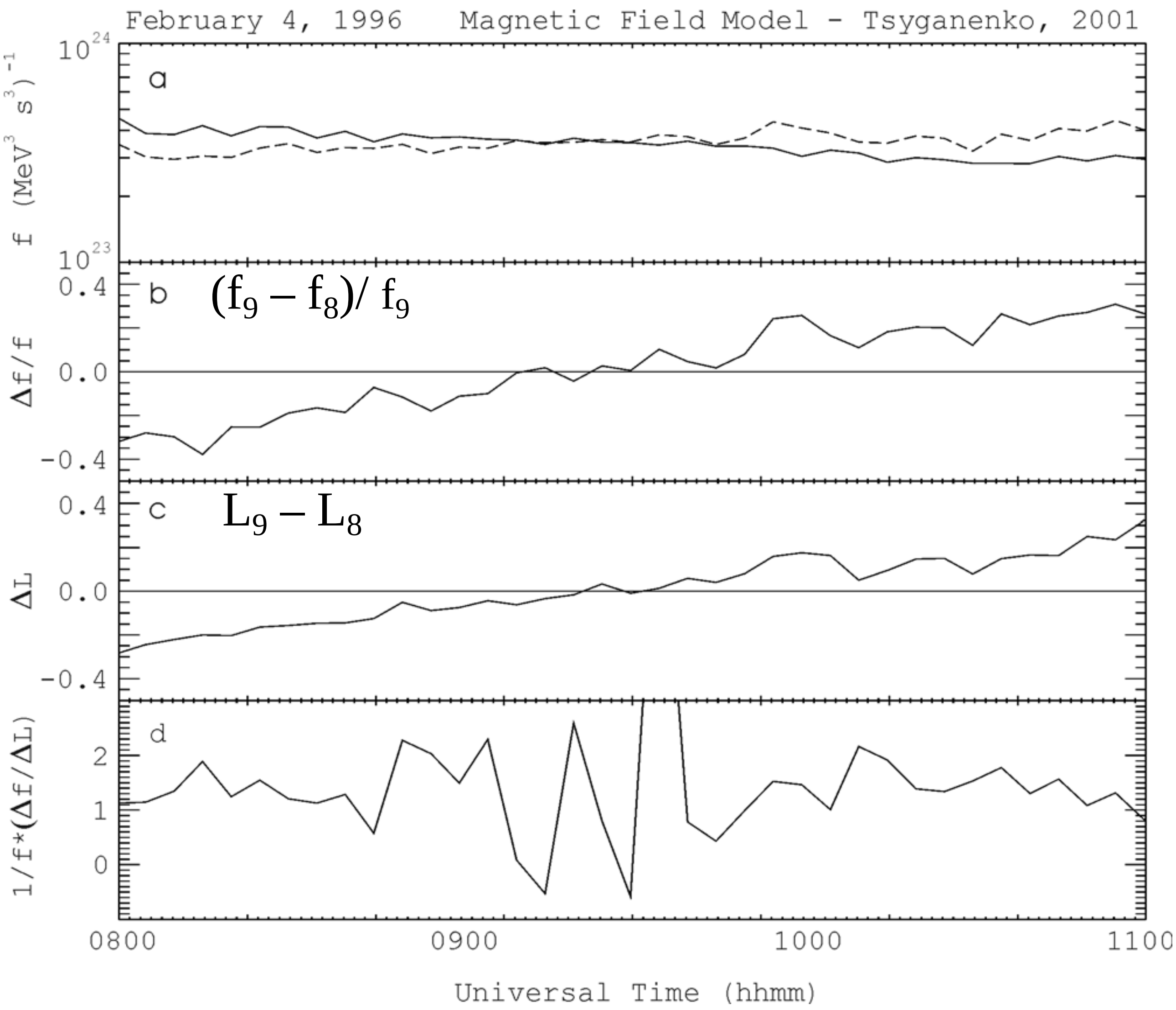
$$L = -\frac{2\pi k_0}{a\Phi}$$

February 4, 1996   08 - 11 UT



$$f_{eq}(E) = \frac{c^2 J_\lambda(>E)}{(E_0{}^2 + EE_0)\,2mc^2 + 2E_0^3 + 2EE_0^2 + E^2E_0}\left(\frac{B_\lambda}{B_{eq}}\right)^{\frac{m}{2}}$$

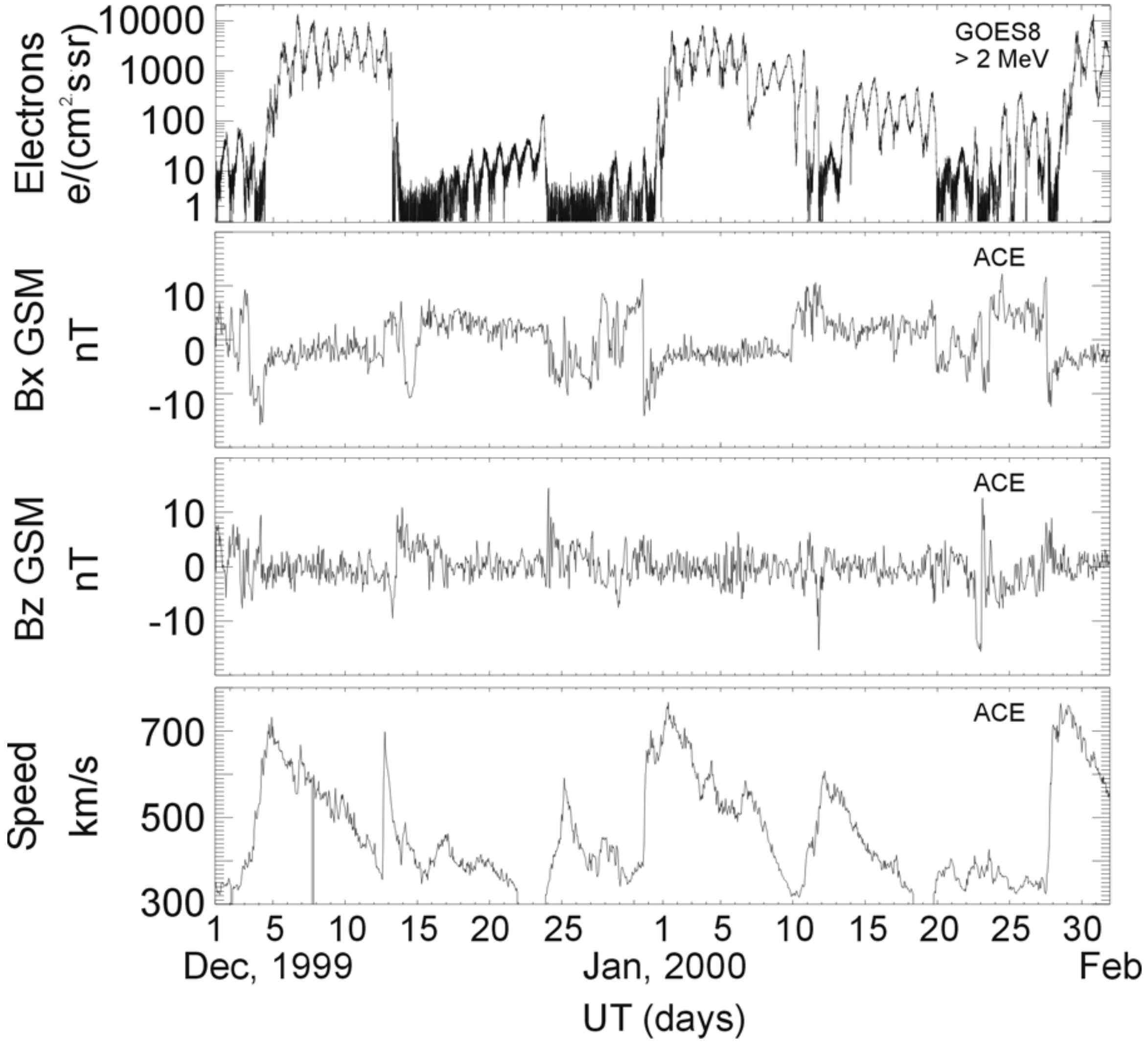
$$\frac{f_8(E)}{f_9(E)} = \frac{J_8(>2)}{J_9(>2)}\left(\frac{B_{8\lambda}}{B_{9\lambda}}\right)^{\frac{m}{2}} = 1$$



$(f_9 - f_8)/ f_9$

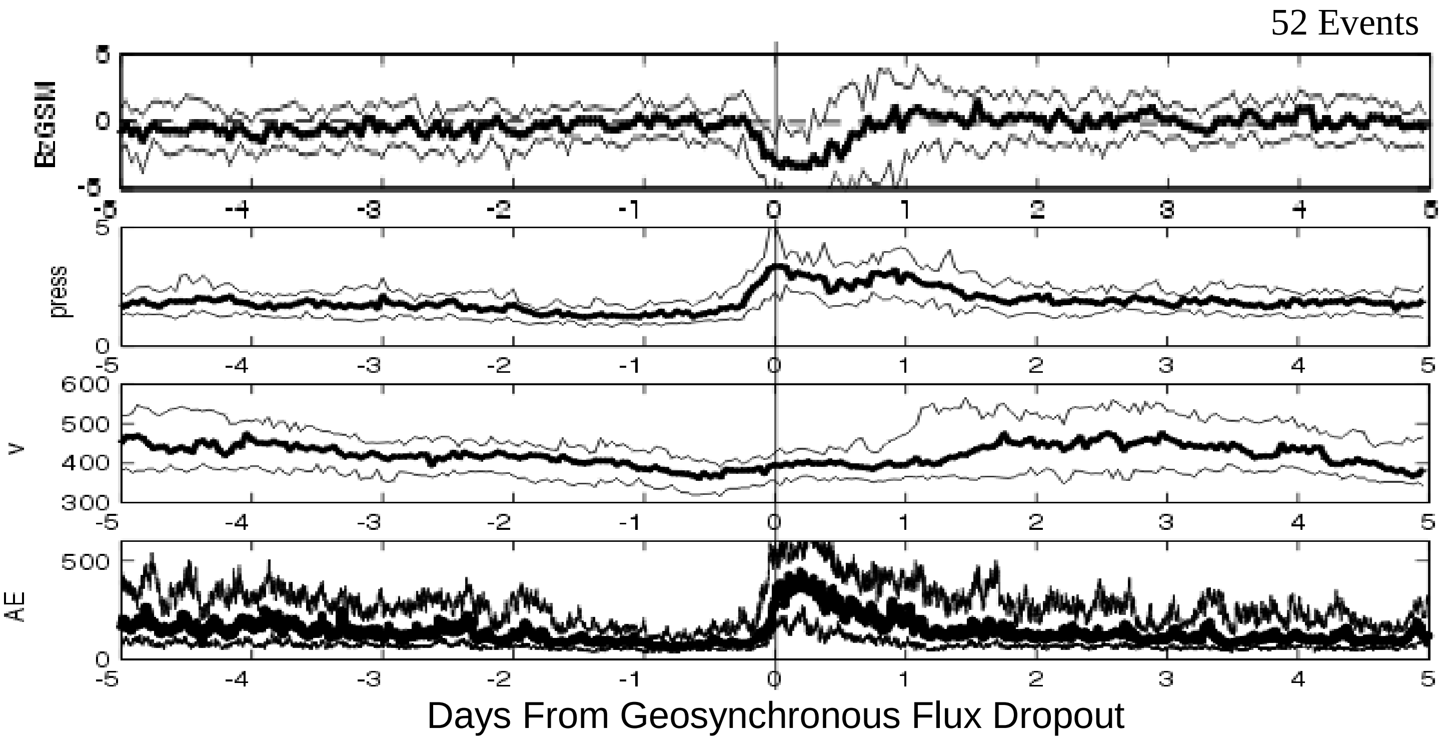
$L_9 - L_8$

$$\mathbf{f = f_o\, e^L}$$

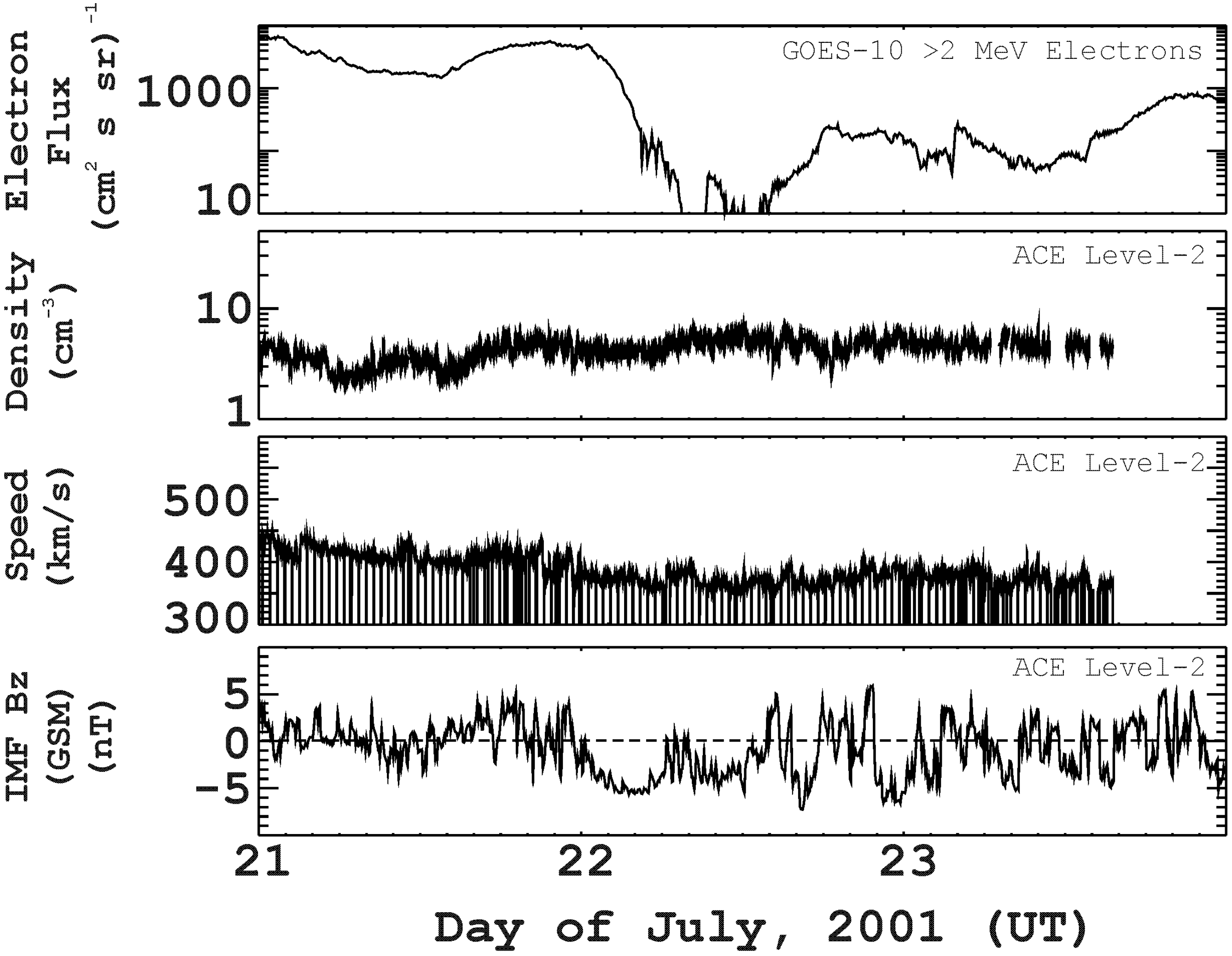

Electrons
e/(cm^2·s·sr)
10000
1000
100
10
1
GOES8
> 2 MeV
Bx GSM
nT
10
0
-10
ACE
Bz GSM
nT
10
0
-10
ACE
Speed
km/s
700
500
300
ACE
1
5
10
15
20
25
1
5
10
15
20
25
30
Dec, 1999
Jan, 2000
Feb
UT (days)

Key Factors Associated With Radiation Belt Depletion

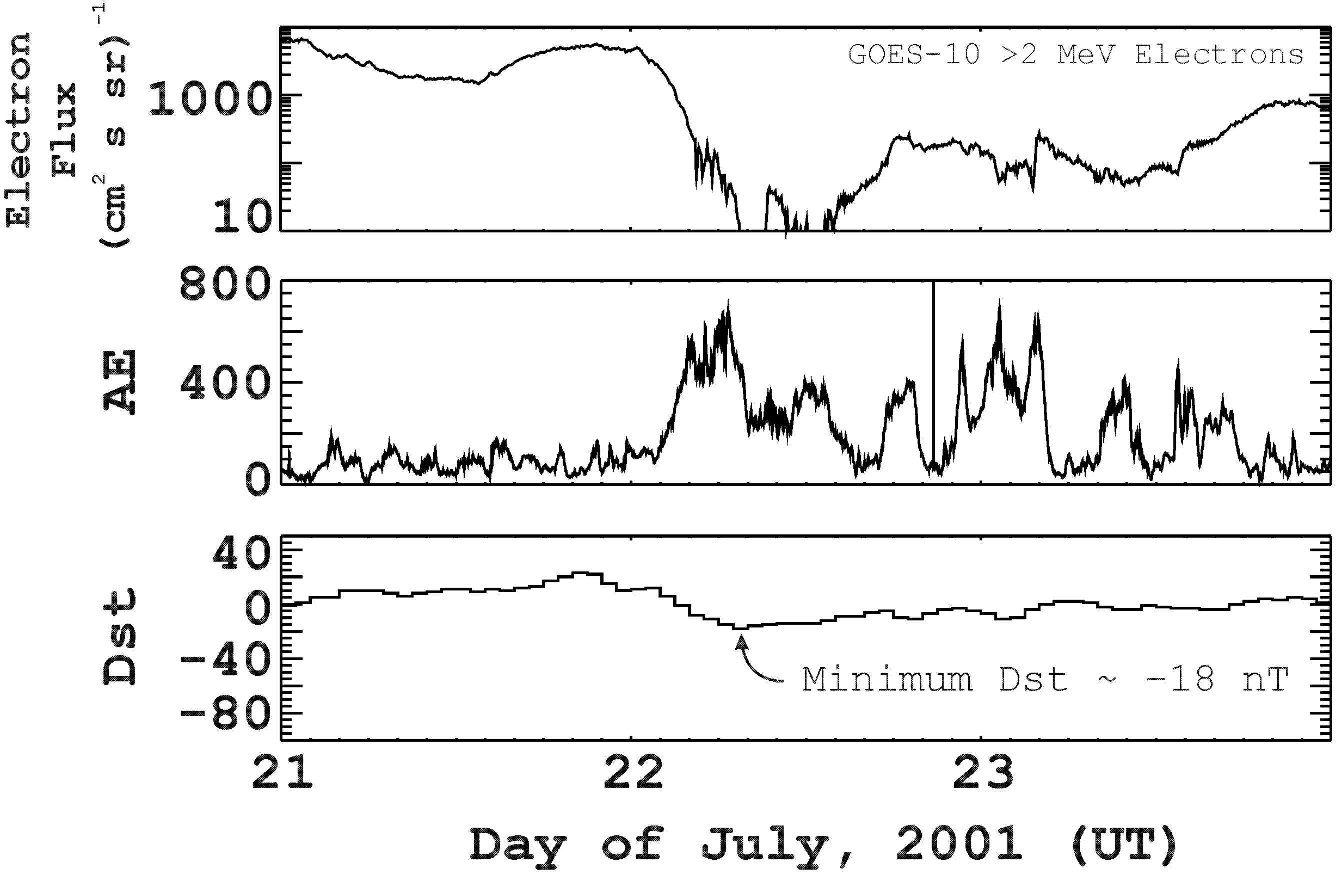
- Crossing of the heliospheric current sheet
- Southward turning and increase in total IMF
- Onset of geomagnetic activity following prolonged quiet conditions
- Increase in solar wind dynamic pressure



Solar Wind Conditions Associated with Flux Dropout



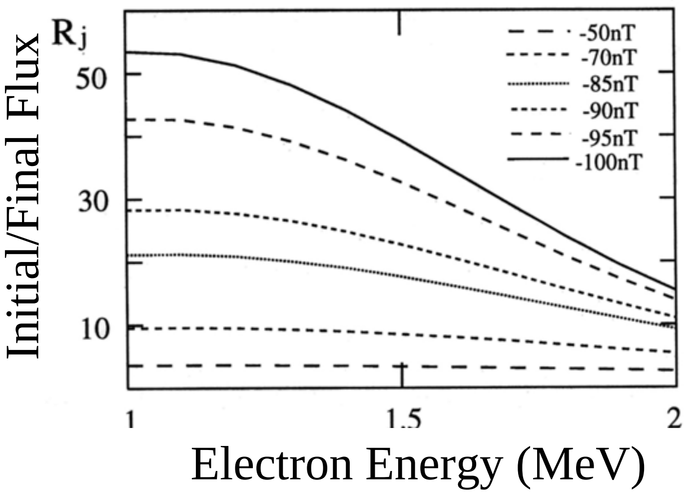
Geomagnetic Activity Associated with Flux Dropout



Estimated Magnitude of Dst Effect at Geosynchronous Orbit

Kim and Chan, 1997

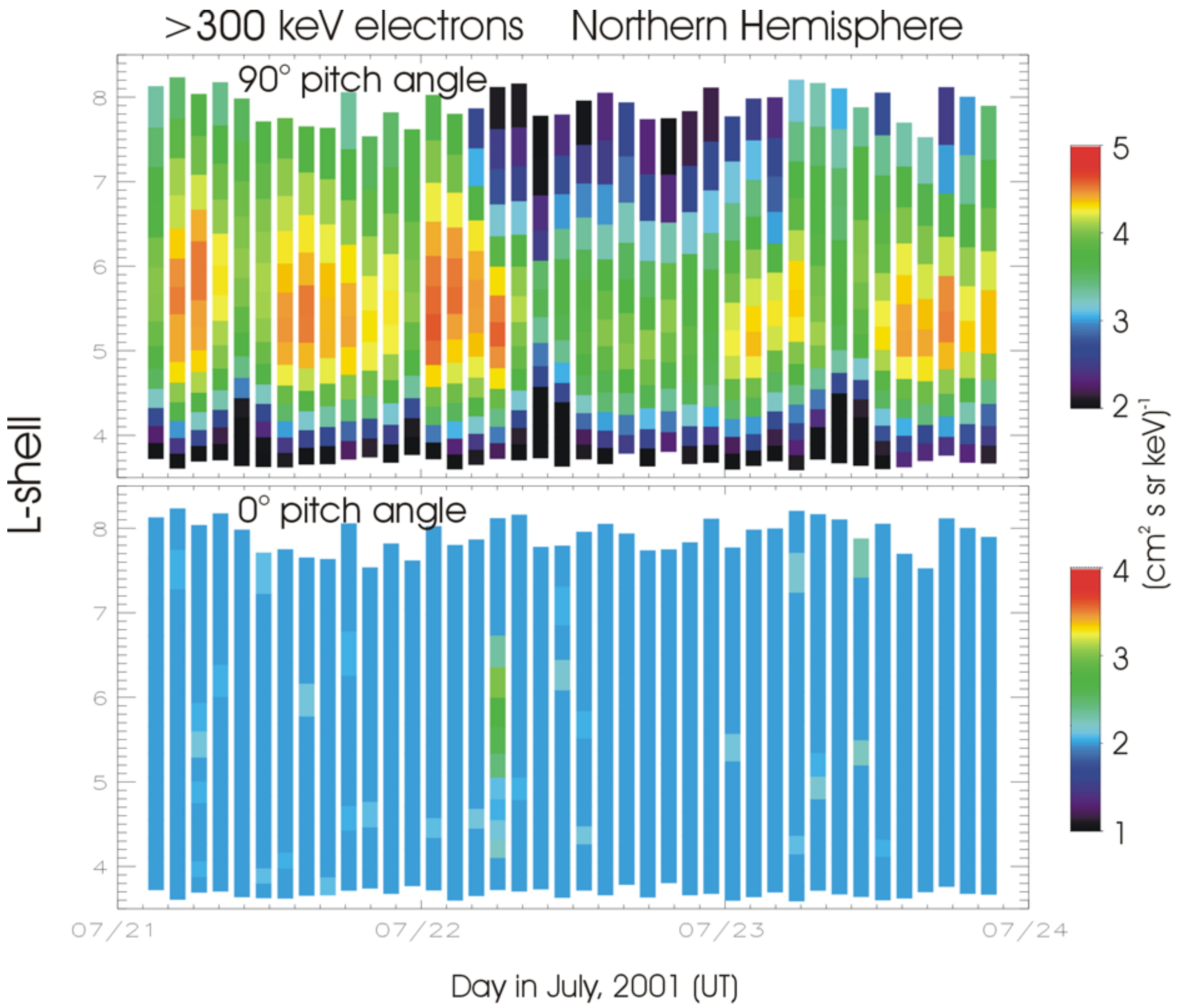
Adiabatic Effect of Dst on Geosynchronous Electron Flux



Dst	Flux Reduction Factor
-50 nT	~ 2
-100 nT	~ 15

2 MeV electron flux is expected to decrease by less than a factor of 2 for |Dst| < 50 nT

Flux Depletion Occurs Throughout the Radiation Belts



Precipitation into the atmosphere is observed at the dropout

Summary

- Energetic electron flux in the solar wind (super halo) varies by orders of magnitude, with some correlation with speed
- Considerable energization occurs in the plasma sheet – taking phase space density close to the levels in the radiation belts
- Radial gradient at geosynchronous orbit is positive (increasing outward) at times
- Radiation belt fluxes are remarkably stable and insensitive to solar wind speed under quiet geomagnetic conditions
- Following prolonged quiet conditions the radiation belts are remarkably sensitive to pressure enhancements and moderate geomagnetic activity