The Complexity of the Radiation Belts

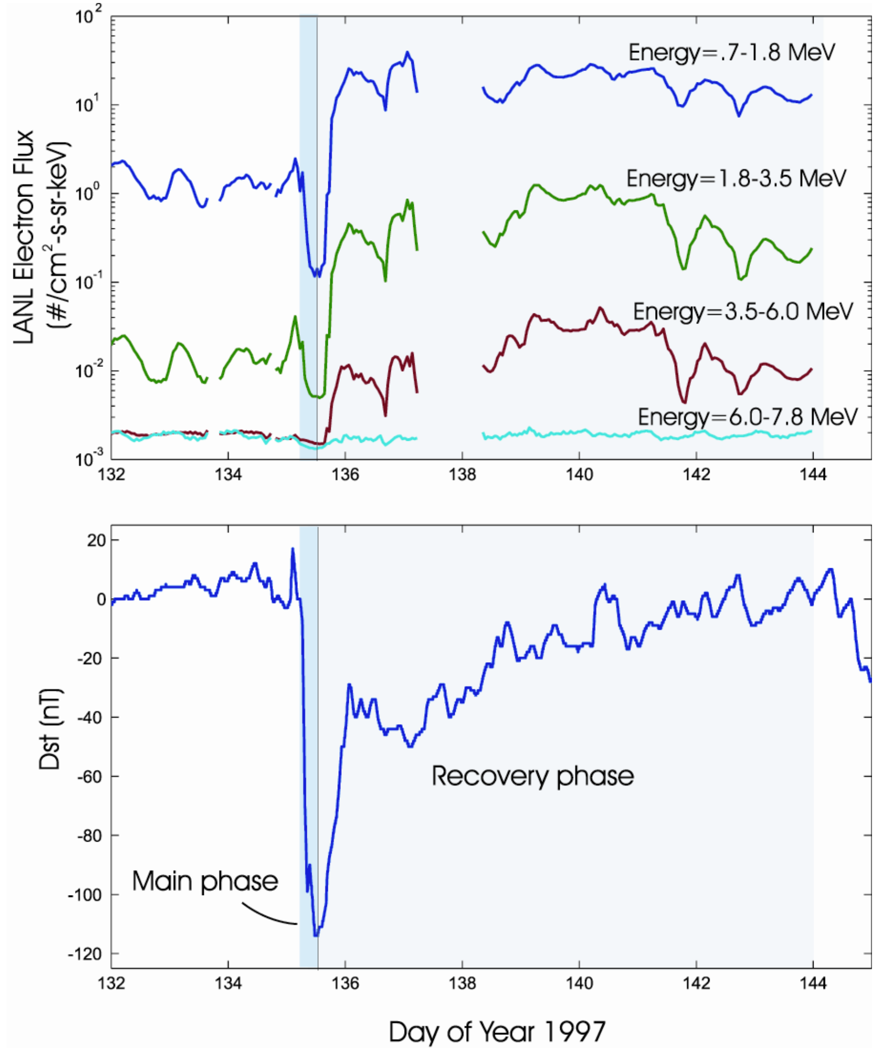
J.C. Green

Outline

- The adiabatic effect
  - What is it?
  - What does it look like?
- Phase space density
  - Errors in calculation and effect on interpretation

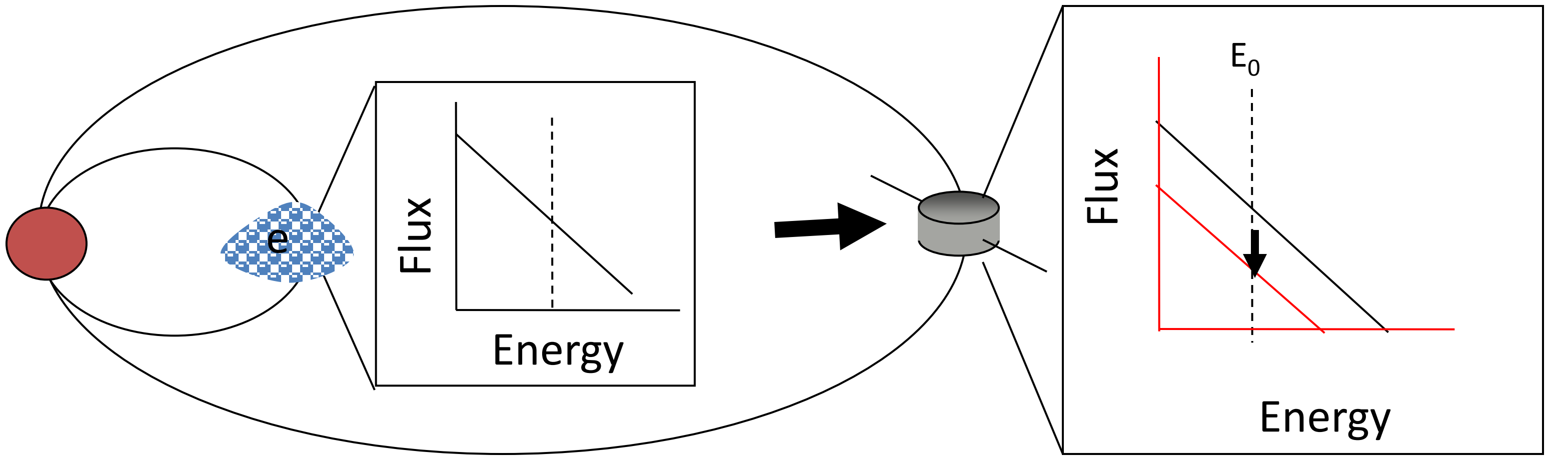
Adiabatic Motion

- Electrons move due to changing magnetic fields and induced electric fields.
- If the field changes slowly compared to the gyro, bounce and drift period then the motion can be described by assuming all 3 adiabatic invariants are conserved.
- Example: Dst effect [Dessler and Karplus, 1961; Kim and Chan, 1997…]



Dst Effect/Adiabatic Flux Decrease

1) During the main phase the inner magnetospheric field decreases. Relativistic electrons move outward to conserve the flux invariant.
2) Electrons move out to a lower magnetic field region. Their energy drops to conserve μ.



3) A spacecraft at fixed radial distance sampling fixed energy measures the flux of electrons previously at smaller radial distance shifted to lower energy resulting in a flux decrease.
4) **Adiabatic flux changes are only apparent loss. When the field relaxes back to the prior conditions the electrons return.**

Examples

- Kim and Chan [1997]
  - Showed how decreases at geosynchronous can be explained by adiabatic changes in the magnetic field

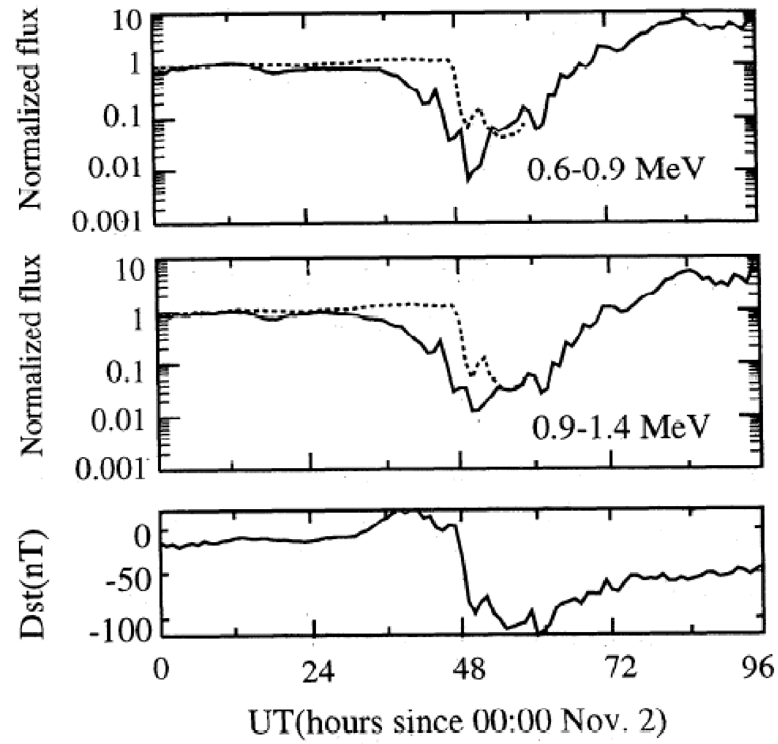
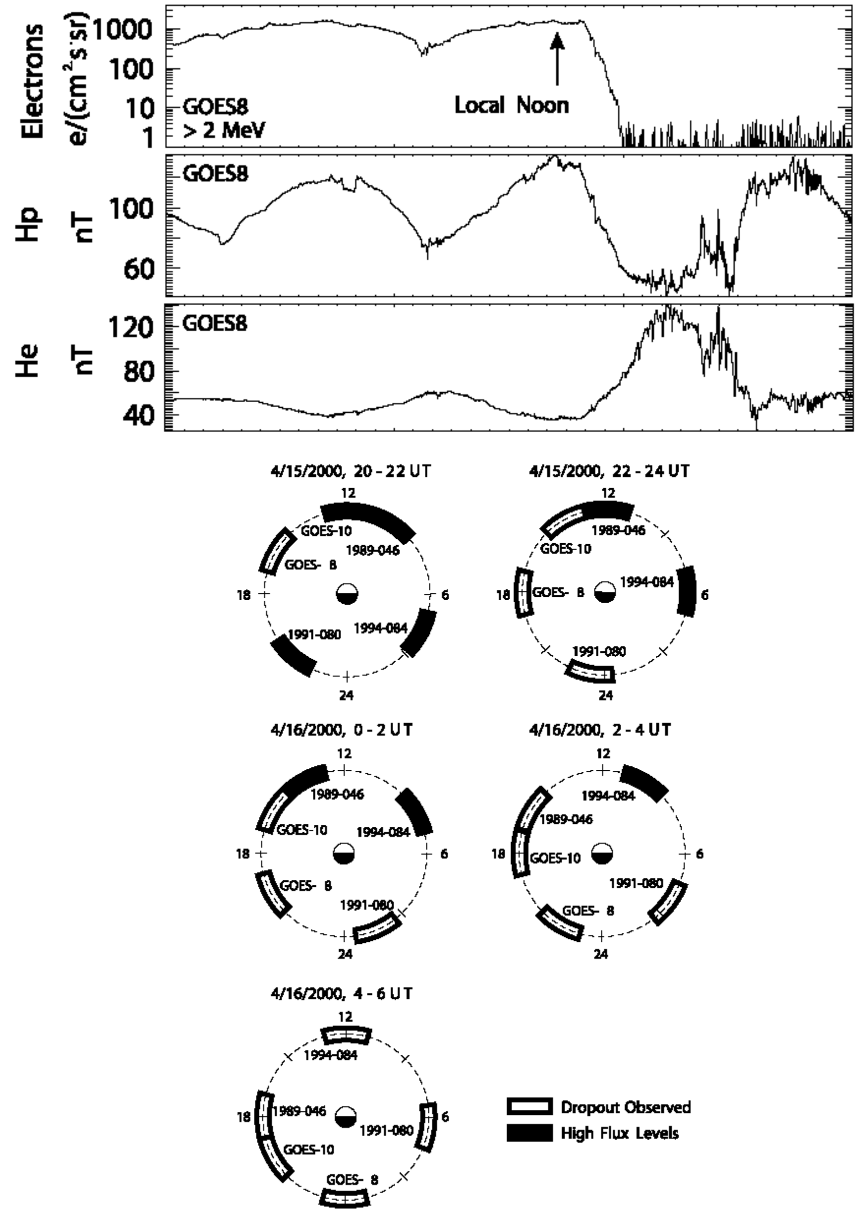


Figure 8. Comparison of the LANL CPA electron flux data for the storm of November 2–5, 1993 (solid curve), and the calculated fluxes for the Ding-Toffoletto-Hill field model (dotted curve). The fluxes are normalized by the value at UT=6.

Example: Electron Flux Drop-Outs

- Onsager [2002] showed electron an electron flux drop-out that began near dusk but took 10 hours to progress to all local times
- Adiabatic effect explains initial flux decrease but not permanent loss



Example

- Green et al. [2004] used a superposed epoch analysis to show a common sequence of events
  - Quiet solar wind and geomagnetic conditions produces a super dense plasma sheet. With the onset of activity the dense material moves earthward to form a partial ring current.
  - The magnetic field stretches first at dusk.
  - The electron flux decreases at dusk in response to the changing magnetic field topology. After ~8 hours, low fluxes are observed at all local times.
  - After ~1-2 days the field returns to its dipolar configuration but the electron flux remains low for >4 days.
- Electron flux decreases are observed at all L but protons remain unchanged.

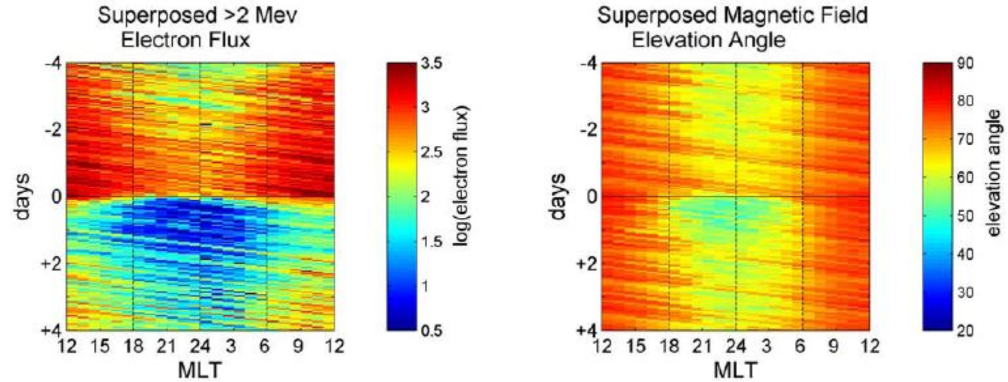


Figure 4. Superposed epoch plot of electron flux and magnetic field as a function of local time and time. (a) The median >2 MeV (#/cm^2 s) electron flux measured by GOES and LANL satellites at geosynchronous for all 52 decrease events in 1-hour time and local time bins. (b) The median elevation angle (degrees) of the magnetic field at geosynchronous measured by the GOES satellites in the same

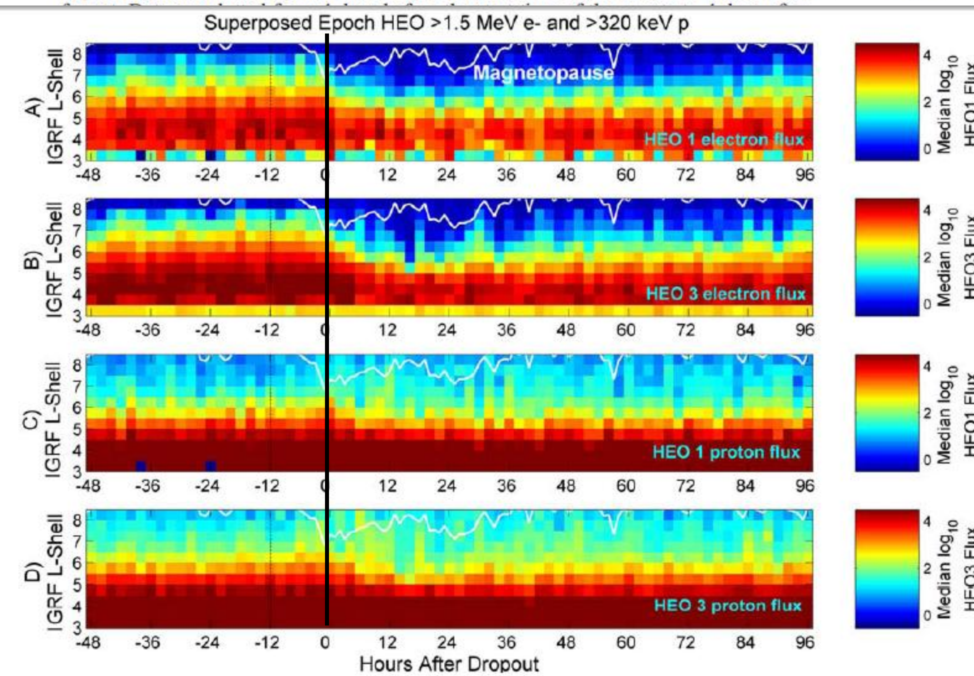


Figure 7. Superposed epoch plot of HEO1 and HEO3 electron and proton flux as a function of L and time. (a) The median value of the HEO1 >1.5 MeV electron flux (#/cm^2 s). (b) The median value of the HEO3 >1.5 MeV electron flux (#/cm^2 s). (c) The median value of the HEO1 >0.3 MeV proton flux (#/cm^2 s). (d) The median value of the HEO3 >0.3 MeV proton flux (#/cm^2 s). The white trace in all panels shows the minimum magnetopause standoff distance calculated from the *Shue et al.* [1997]

Examples

- Kim et al [2002]
  - Showed storm main phase equatorial flux decreases from L=2.5-6.5 using CRESSELE and Ding-Toffeletto-Hill field model
  - An order of magnitude flux decrease at low L=3 is possible during the moderate storms

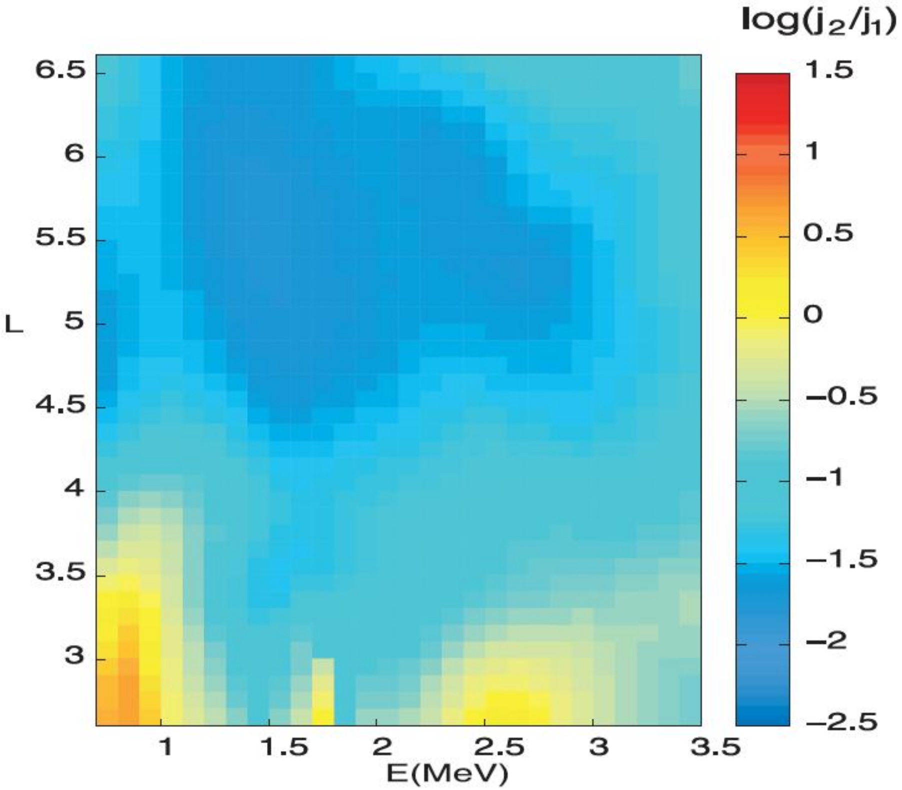
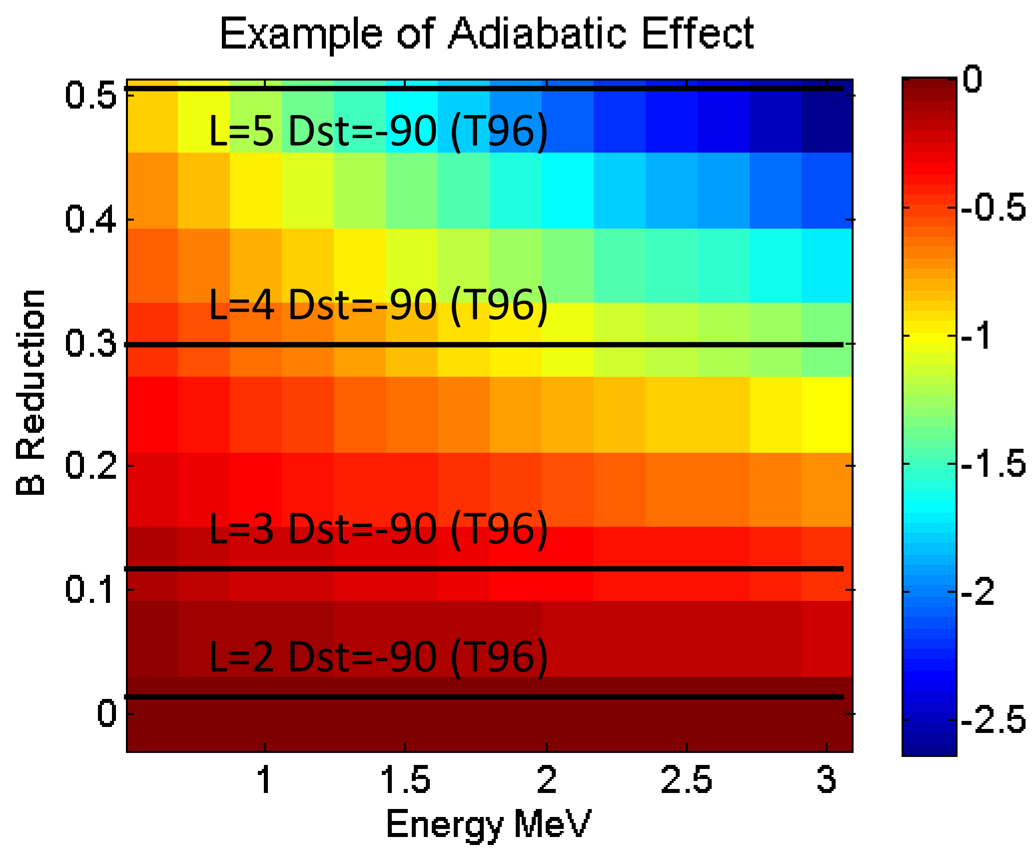


Figure 6. A color map of the logarithm of electron flux ratios, $j_2(E_2, L_2)/j_1(E_2, L_2)$, for $Dst = -120$ nT in the $E - L$ plane.

Example

- Flat radial gradient and 90 degree equatorial pitch angles
  - The flux decrease is related to the field decrease
  - A 30% reduction of the field reduces the 2 MeV flux by an order of magnitude
  - A 50% reduction of the field reduces the 2 MeV flux by 2 orders of magnitude



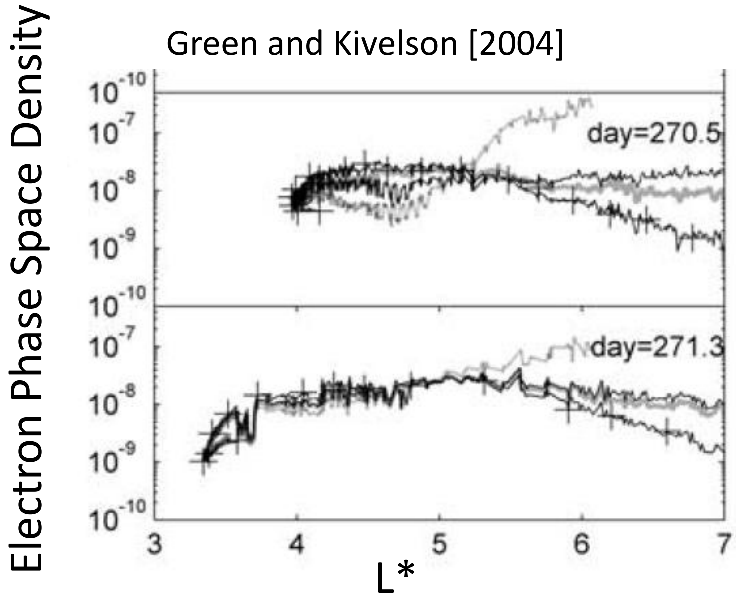
Phase Space Density

- What is it?
  - $f(\mu,K,L^*)=J(\mu,K,L^*)/p^2$
- How does it help?
  - The phase space density as a function of the adiabatic invariants does not change as long as the field changes slowly enough that the invariants are conserved

Phase Space Density

- How can you possibly go wrong?

Green and Kivelson [2004]

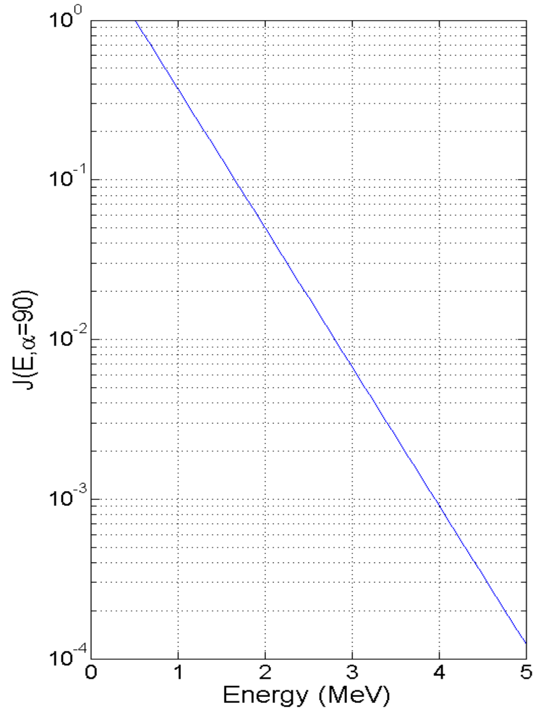


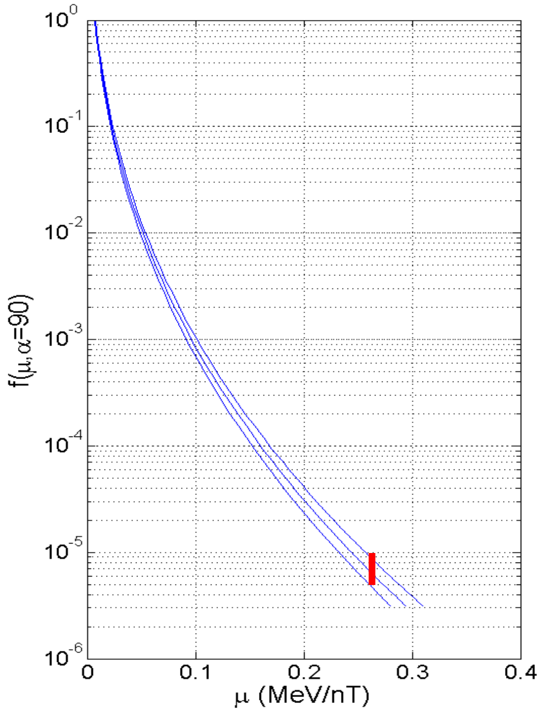
A more stretched magnetic field model over estimated K and PSD. The less stretched model underestimated K and PSD.

- Errors in calculating f(u,K,L*)
  - Errors in μ
  - Errors in K
  - Errors in L*

Errors in μ

- Start with instruments output $J(E,\alpha)$
- Calculate $J(\mu,\alpha)$->$f(\mu,\alpha)$
  - $\mu=(p_{perp})^2/2m_0B$ and $f=J/p^2$
- Error in B gives error in μ and a range of $f(\mu,\alpha)$
  - 5% error in B

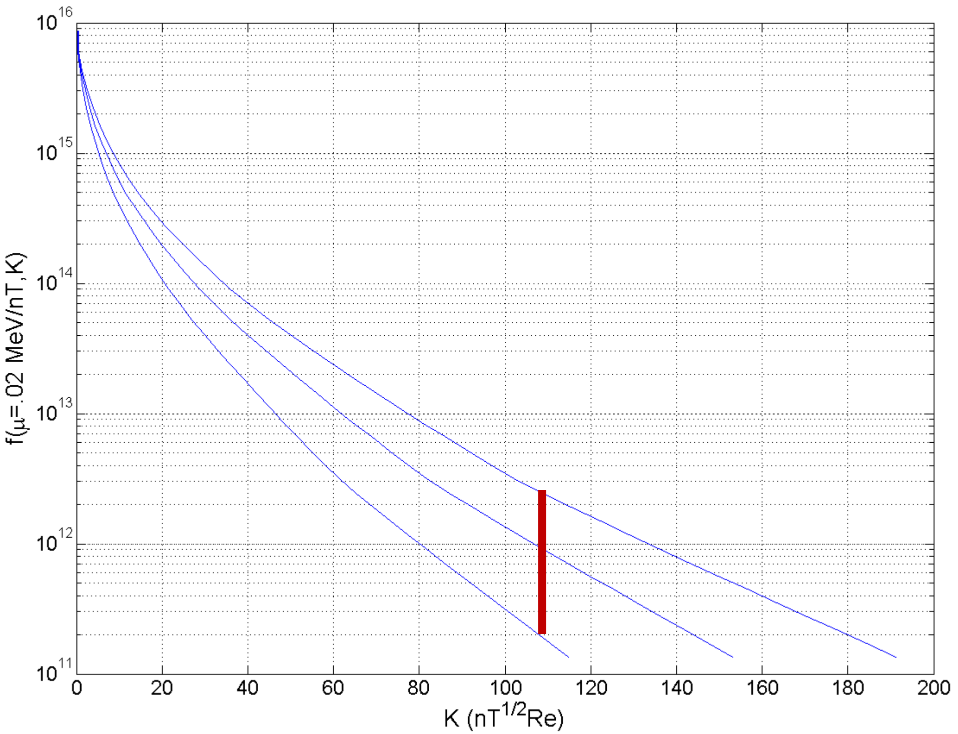




Errors in K

$$K = \int_{sm}^{sm'} sqrt(B_{mirror} - B(s))ds \;= I(B_{mirror})^{1/2}$$

+/- 25% error in K gives factor of 10 difference in PSD estimate



What to do for RBSP?

- Numerically calculate K error assuming that the error in the model magnetic field is the same everywhere

$$\sigma_K^2 = \sigma_B^2 \left(\frac{\partial K}{\partial B_{mirror}} \right)^2 + \sigma_B^2 \left(\frac{\partial K}{\partial Bs} \right)^2$$

$$\sigma_K^2 = \frac{\sigma_B^2}{2} \left(\oint (B_m - B(s))^{-1/2}) ds \right)^2$$

Summary

- Adiabatic effect can cause large flux changes even at low L
- Unknown errors in magnetic field models can result in order of magnitude PSD errors that may obscure interpretation
- RBSP scientists will have to consider both the adiabatic effect and errors in PSD when comparing data from multiple satellites to theoretical predictions