Inner Radiation Belt Data / Model Comparisons

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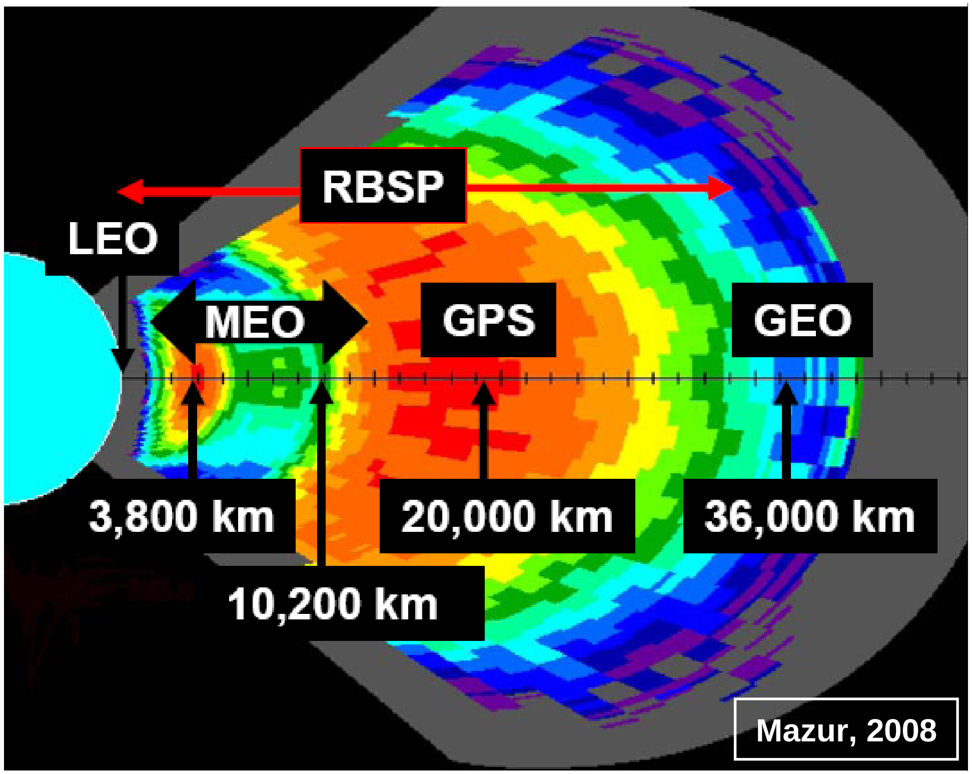
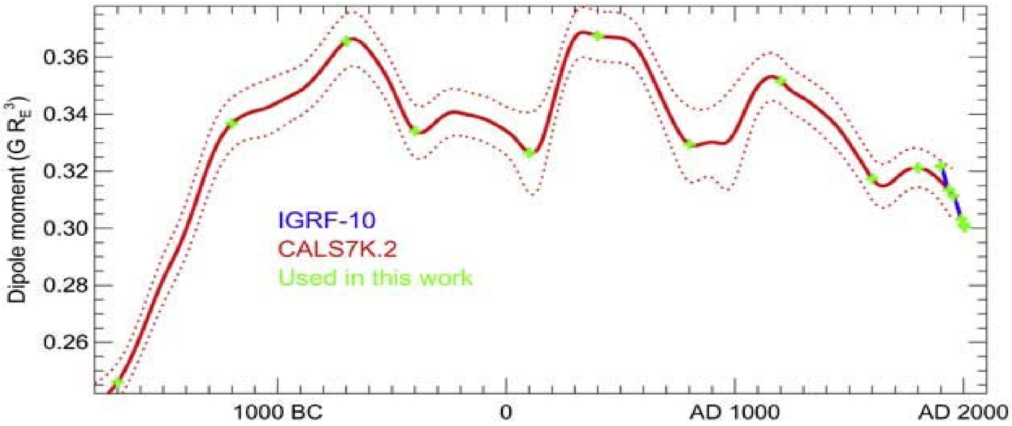
Motivation

- Spacecraft designers can benefit from environmental specifications which are as realistic as possible.
- One specific objective of the Space Radiation Climatology GEM Focus Group will be to run data-assimilative models of magnetospheric dynamics over solar-cycle time-scales, providing this best-guess specification.
- This data / model comparison will lead to running the Selesnick et. al., 2007 inner belt model in a data-assimilative fashion.



This paper presents preliminary comparisons of a physics-based inner-belt proton model (Selesnick et. al., 2007) with trapped proton observations at LEO (SAMPEX/PET).

Inner Belt Proton Model (Selesnick et. al., 2007)

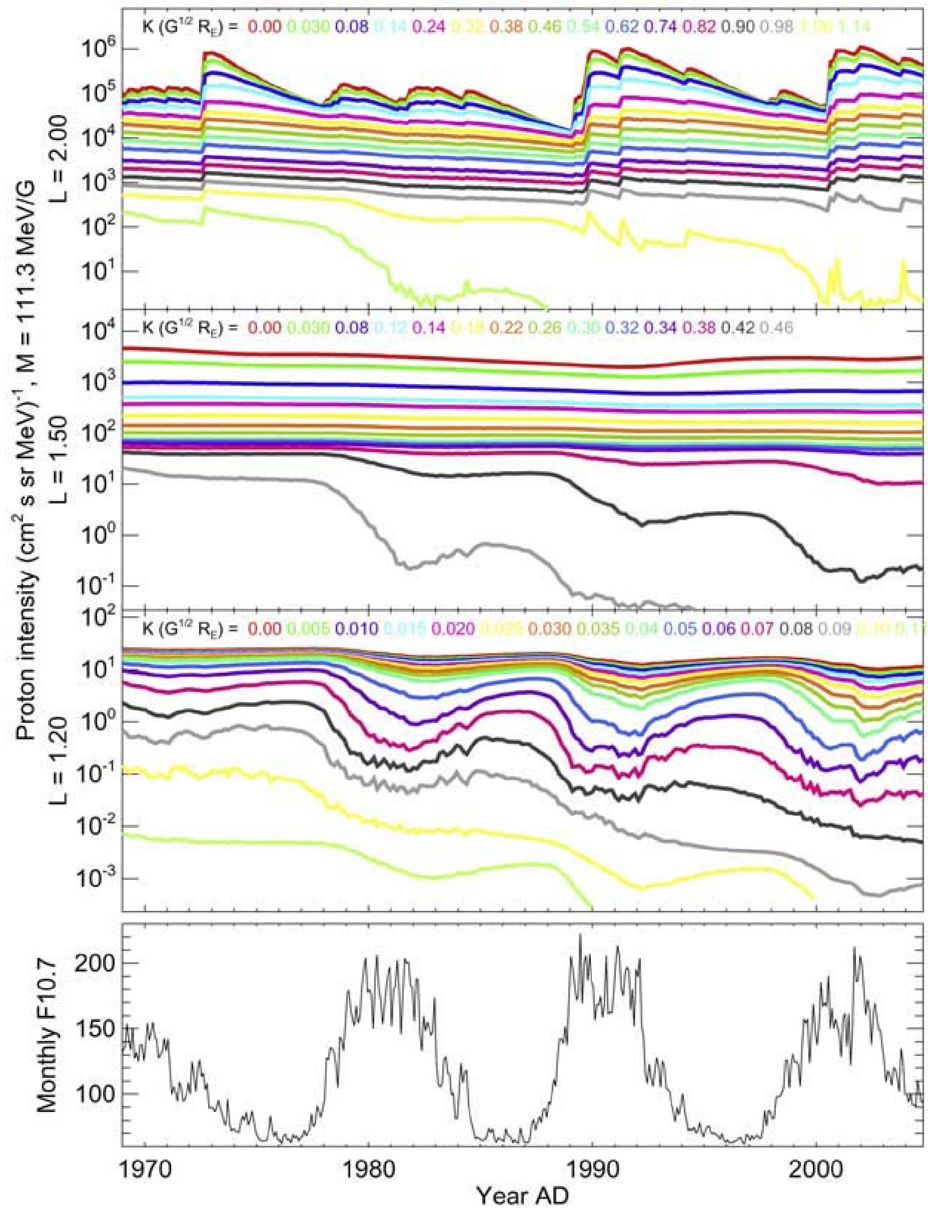


Sources	Losses
•CRAND (Cosmic Ray Albedo Neutron Decay) •Solar Protons •Radial Diffusion	•Ionization energy loss •Free electron energy loss •Adiabatic energy change •Radial diffusion

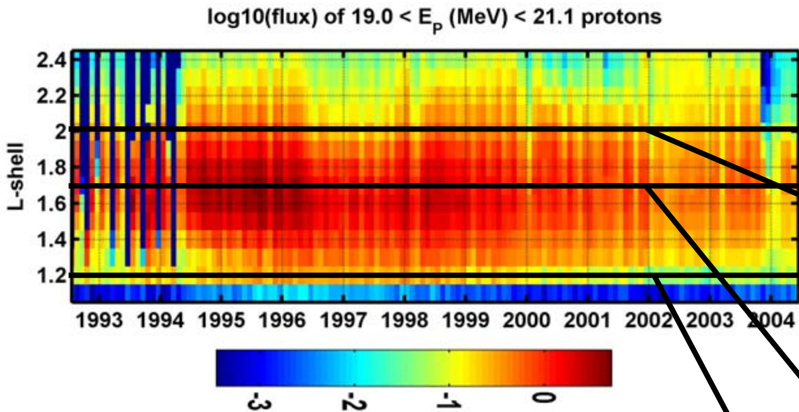
- The Selesnick et al., 2007 model computes the proton intensity of trapped protons as a function of time and the three adiabatic invariants (M, K, and L) from ~10 MeV to ~4 GeV and from 1.1 < L < 2.4.
- They found that the long-term secular change of the geomagnetic field has a significant effect on the long-lived inner belt population.
  - Factor of 10 in the intensities.

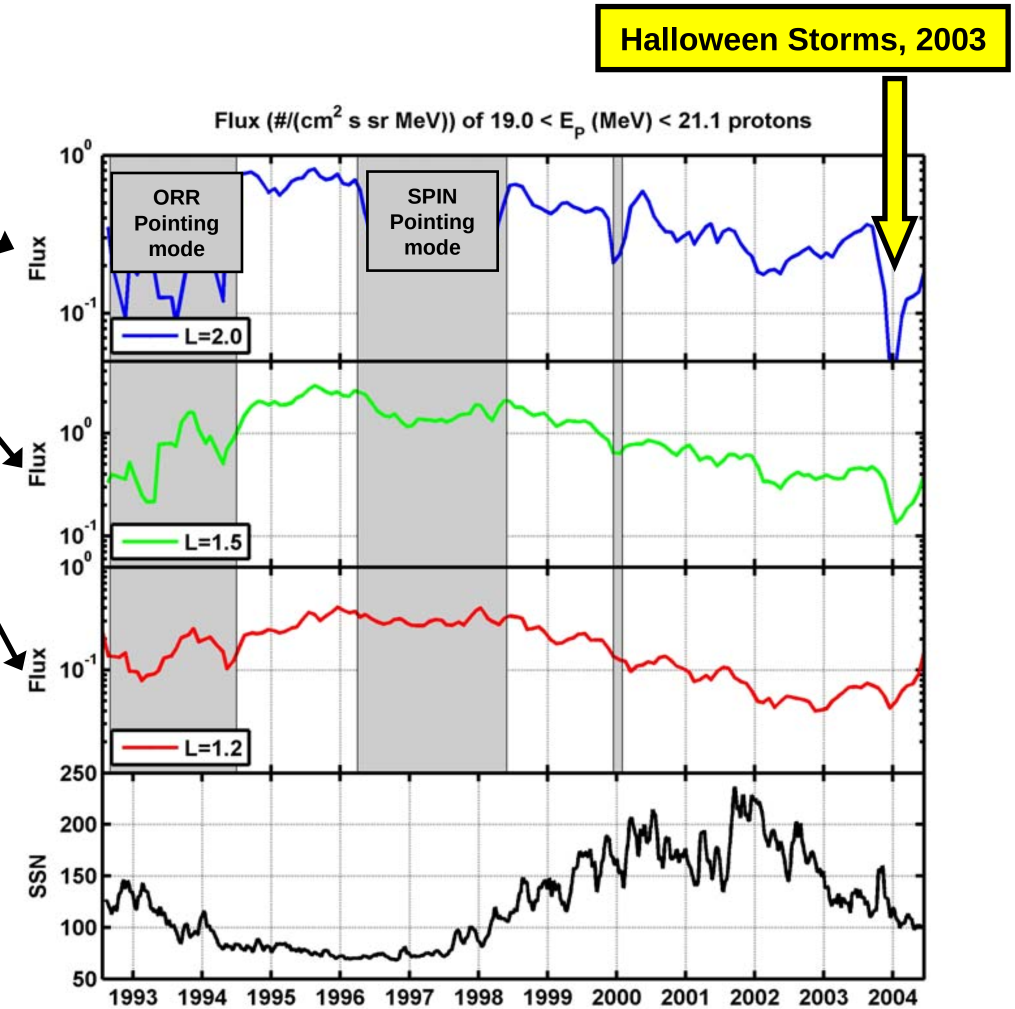
Inner Belt Model Results

- **3 ½ solar cycles of inner belt proton fluxes at a constant energy at**
  - **L=2 (top panel)**
  - **L=1.5 (2nd panel)**
  - **L=1.2 (3rd panel)**
- **The outer portion of the inner belt (top panel) is dominated by external dynamics (SEPs)**
- **The inner portion of the inner belt (3rd panel) is dominated by the CRAND process, varying inversely with the solar cycle.**



SAMPEX/PET observations





- Above plot shows the 1-month average flux as a function of L (IGRF) and time throughout the SAMPEX mission
- Extract timeseries at 3 L-shells (2.0, 1.5, 1.2), plotted at right.
  - L=1.2 fluxes strongly anti-correlated with the solar cycle
  - L=2.0 fluxes dominated by impulsive solar particle events, such as the Halloween, 2003 storms.

Qualitative agreement with Selesnick et al., 2007 model

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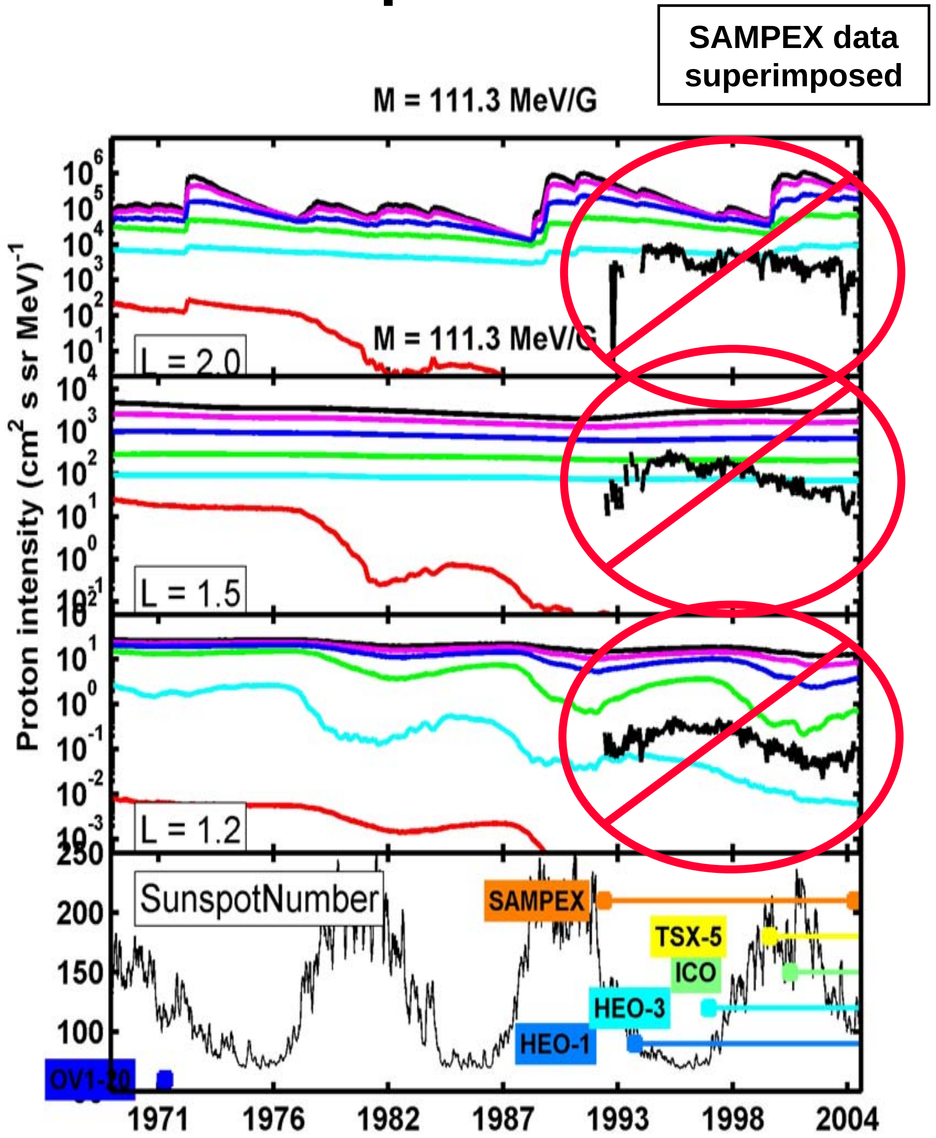
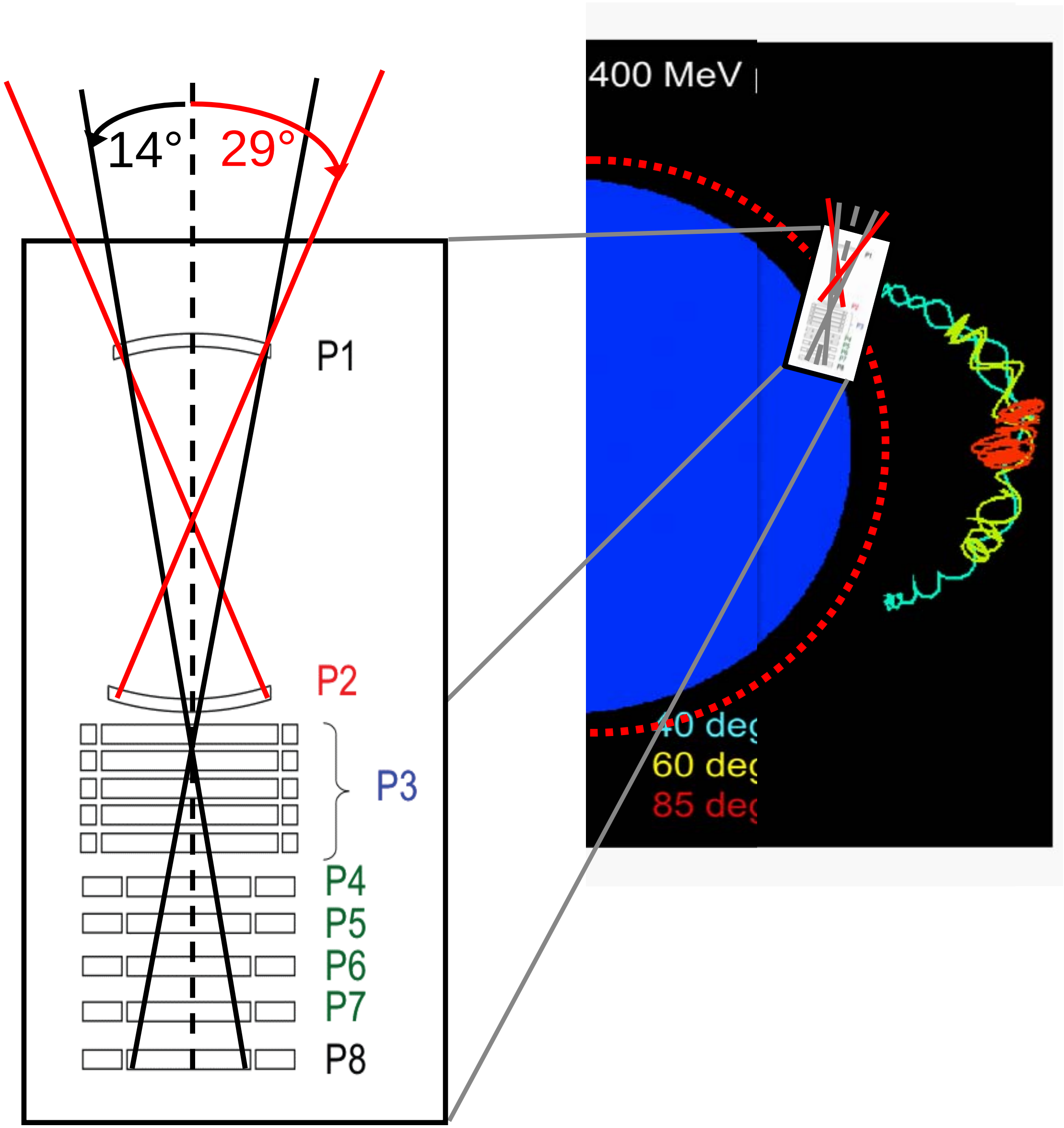
Making a valid data / model comparison

- **Although the "first-order" behavior of the observations and simulation are similar, we don't know which K's to compare our SAMPEX timeseries to.**
  - **PET has a fairly wide field-of-view (~60°), so many different pitch angles (and their associated K's) have access to the detector.**

We need a more careful approach when comparing observations and the model



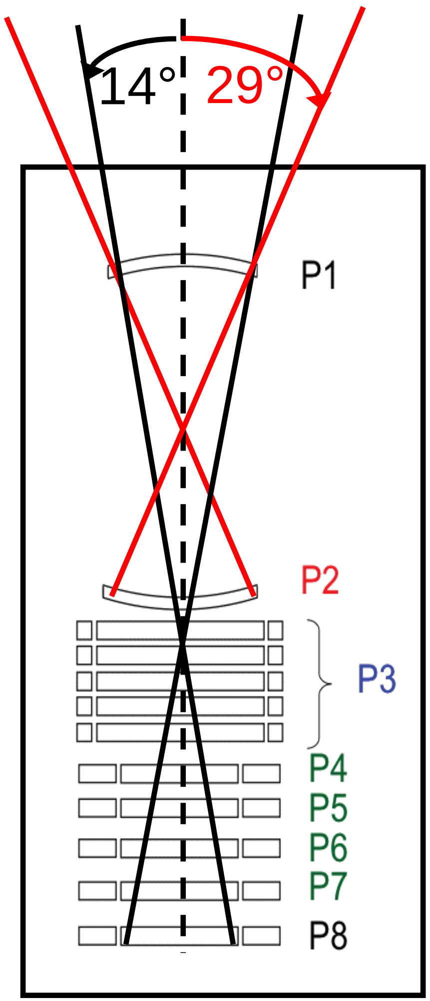
Simulating the PET response within the proton model

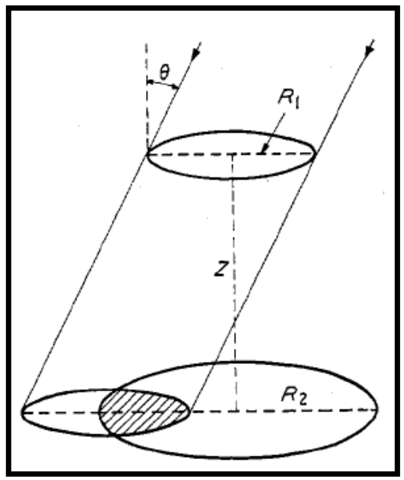


- The PET instrument consists of 8 silicon detectors arranged in a stack.
- Coincidence logic and pulse-height analysis enables determination of 15 energy channels.
- Acceptance angle decreases with energy channel
  - 29° FOV for a proton triggering only P1 and P2 (red lines)
  - 14° FOV for a proton triggering all detectors. (black lines)
- Only select times when the PET telescope axis is within <u>10° of perpendicular</u> to the local field line.

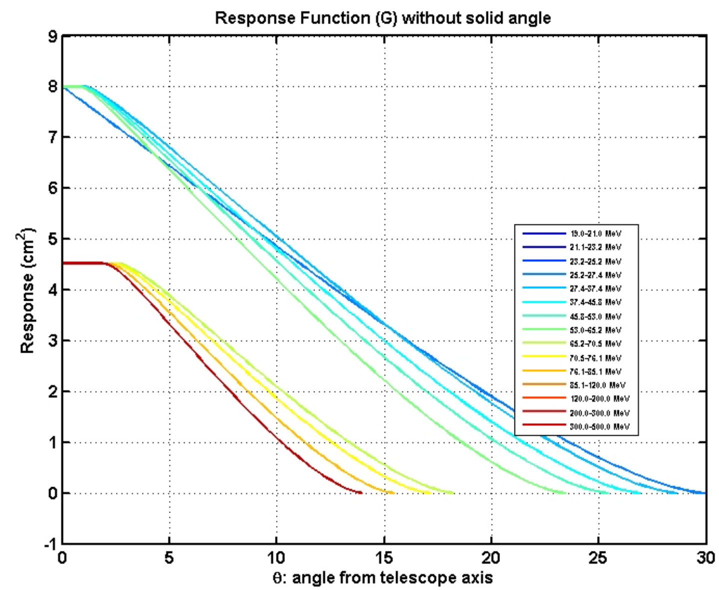
PET Response

Starting from the detector geometry, derive detector response as a function of angle from telescope axis



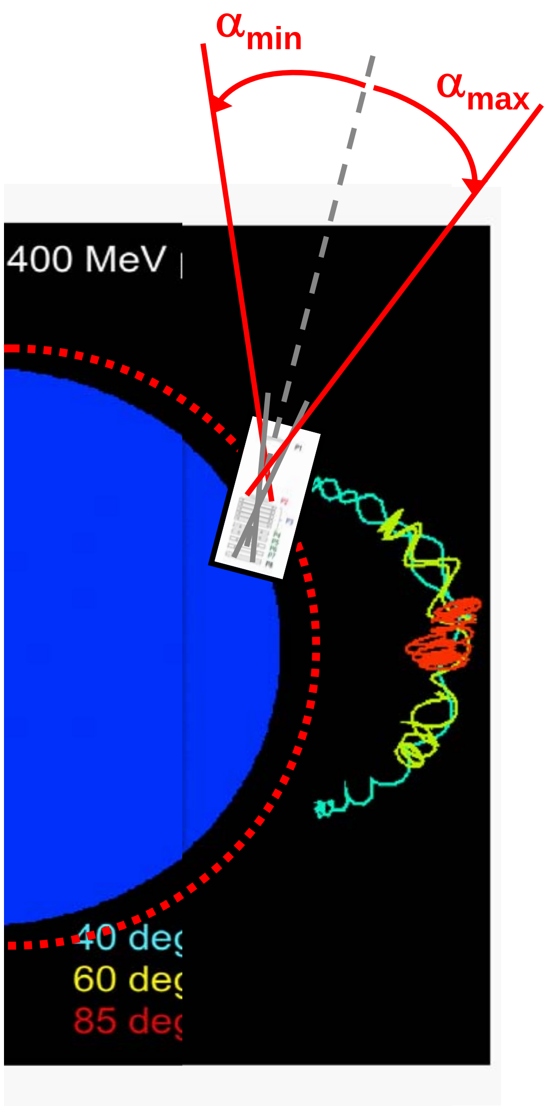


Compute shadow area as a function of angle from telescope axis…



And energy, to get a response function, $R(E, \theta_t)$.

Simulate a “virtual PET” inside the model



- **For $\alpha_{min} < \alpha < \alpha_{max}$, calculate model coordinates accessible to the detectors.**

$$M = \frac{p^2}{2mB_m}$$

$$K = \int_{s_m}^{s'_m} \left[B_m - B(s)\right]^{1/2} ds$$

$$L = \frac{2\pi\mu_E^{2000}}{R_E \Phi}$$

- **Where p is momentum, B_m is the mirror magnetic field, s_m and s'_m are the mirror point locations, μ_E^{2000} is the Earth’s dipole moment in 2000, and Φ is the magnetic flux inside a drift shell.**

- **Interpolate into model to determine the model intensity at each observed M, K, and L.**

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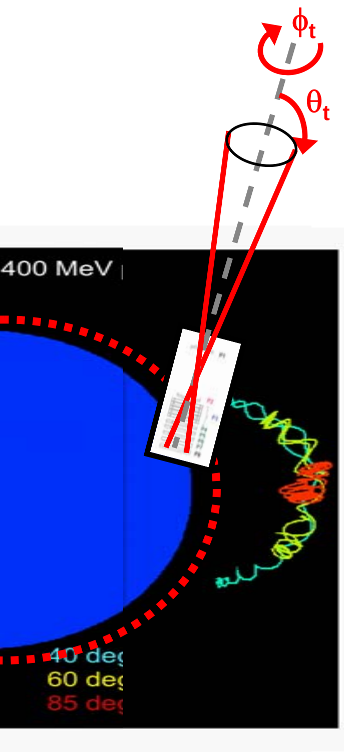
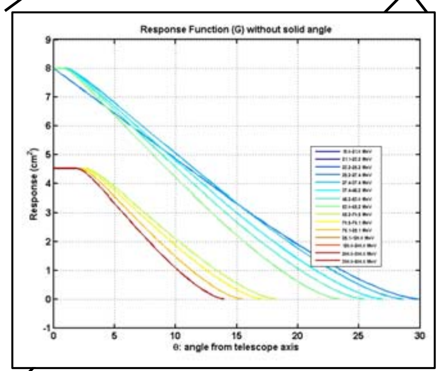
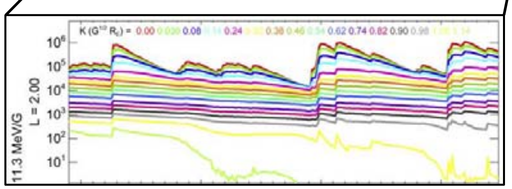
Calculate detector count rates

$$r = \int_0^{2\pi} \int_0^{\theta_{\max}} \int_{E_1}^{E_2} R(E,\theta_t)\, j(E,\alpha)\, dE \, \sin\theta_t \, d\theta_t \, d\phi_t$$



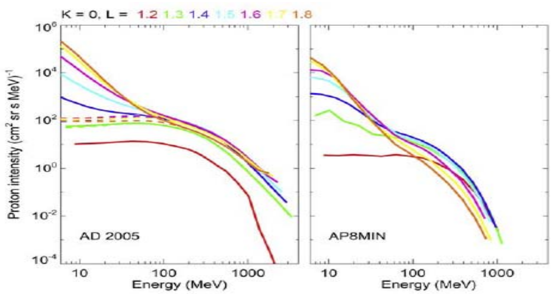




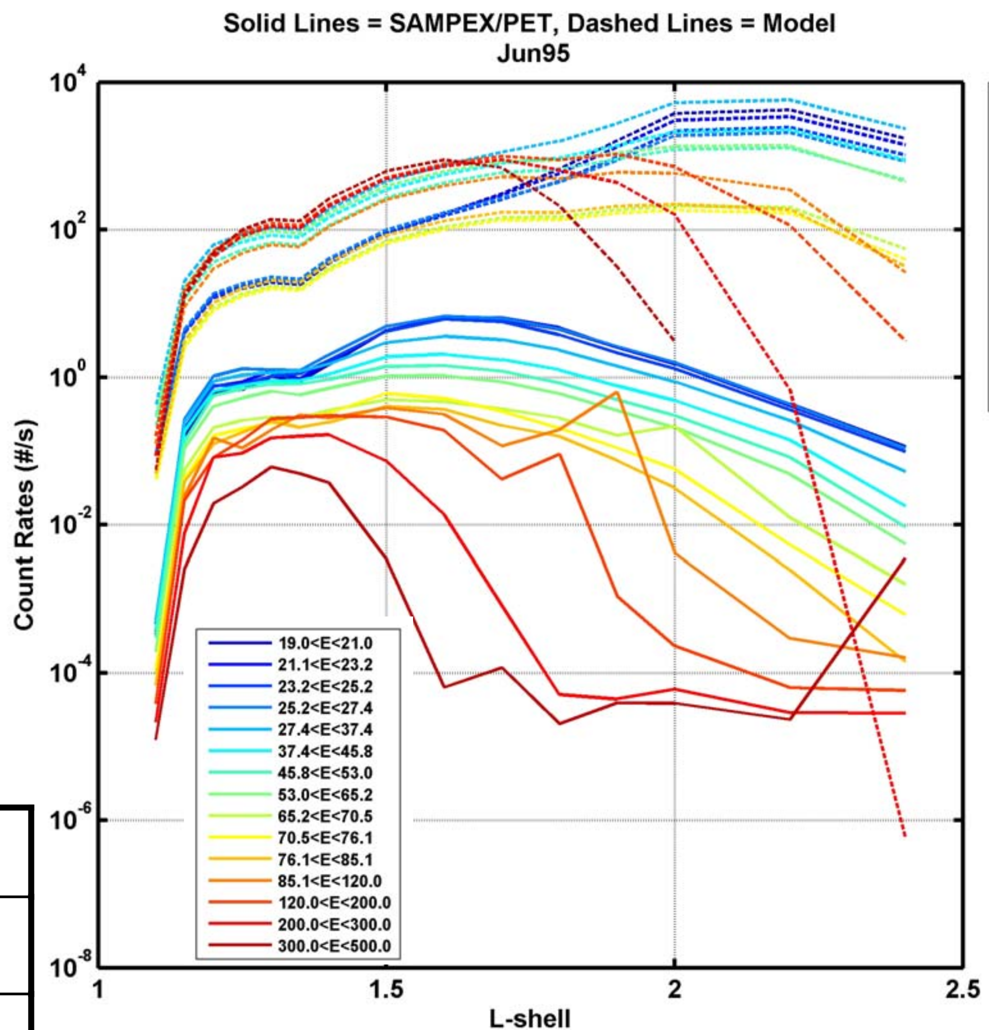
- We reproduce what the detector would have seen in the Selesnick et al., 2007 model by:
  - Specifying the energy and angular response of the detector, $R(E,\theta_t)$.
  - Determining which M, K, and L values have access to the detector for every inner belt data point.
  - Interpolating into the model at those M, K, and L values, $j(E,\alpha)$.
  - Integrating from the lower (E_1) to the upper energy bound (E_2) of each detector channel, from the telescope axis to the upper end of the acceptance cone, and around the telescope axis.

Preliminary Results

- One month of L-binned data/model at the SAMPEX location.
- Count rate offset is not correct – due to averaging in the L-binning.
- The model count rates seem "stretched" in L
  - Observed ~20 MeV fluxes peak at L~1.6
  - Simulated ~20 MeV fluxes peak at L~2.1.
- Revisit Selesnick et al., 2007, Figure 17, to estimate how different in fluxes the model should be from observations.



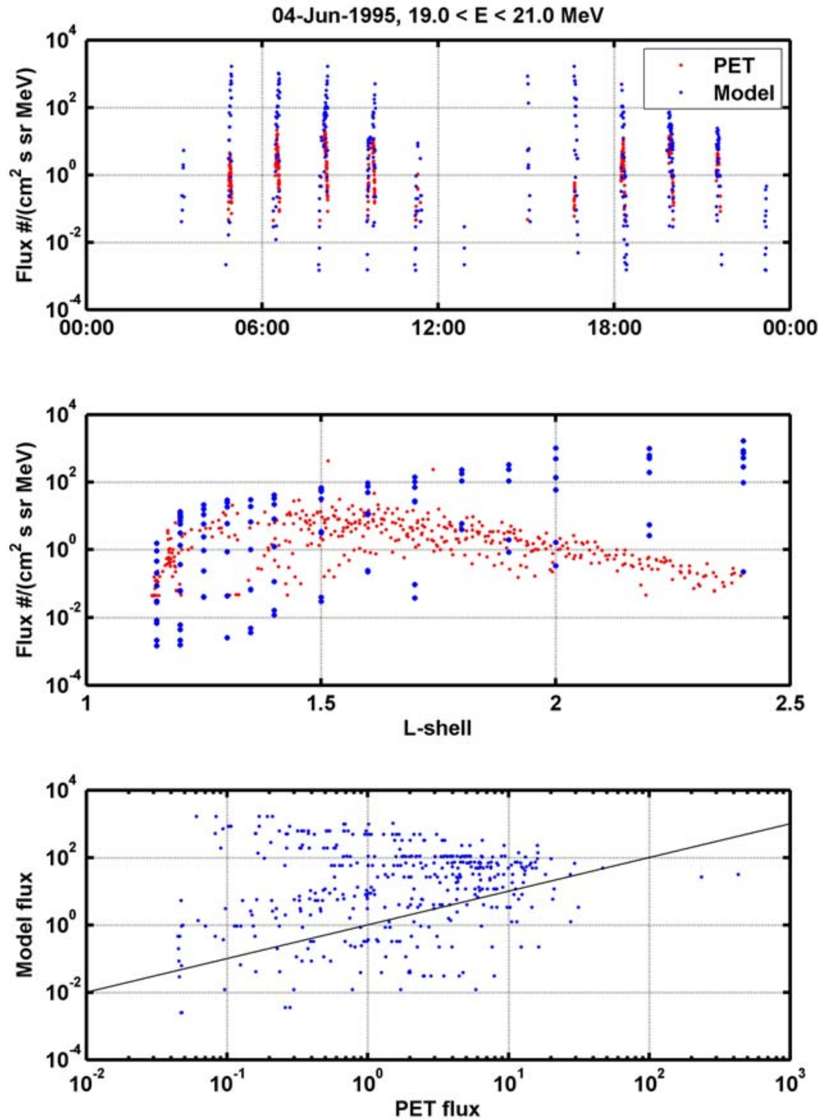
	j @ 20 MeV		j @ 100 MeV	
L-shell	Selesnick	AP8	Selesnick	AP8
1.2	~10	~3	~10	~3
1.5	~1000	~600	~100	~10
1.8	~3000	~600	~100	~3



10x difference common, 100x not

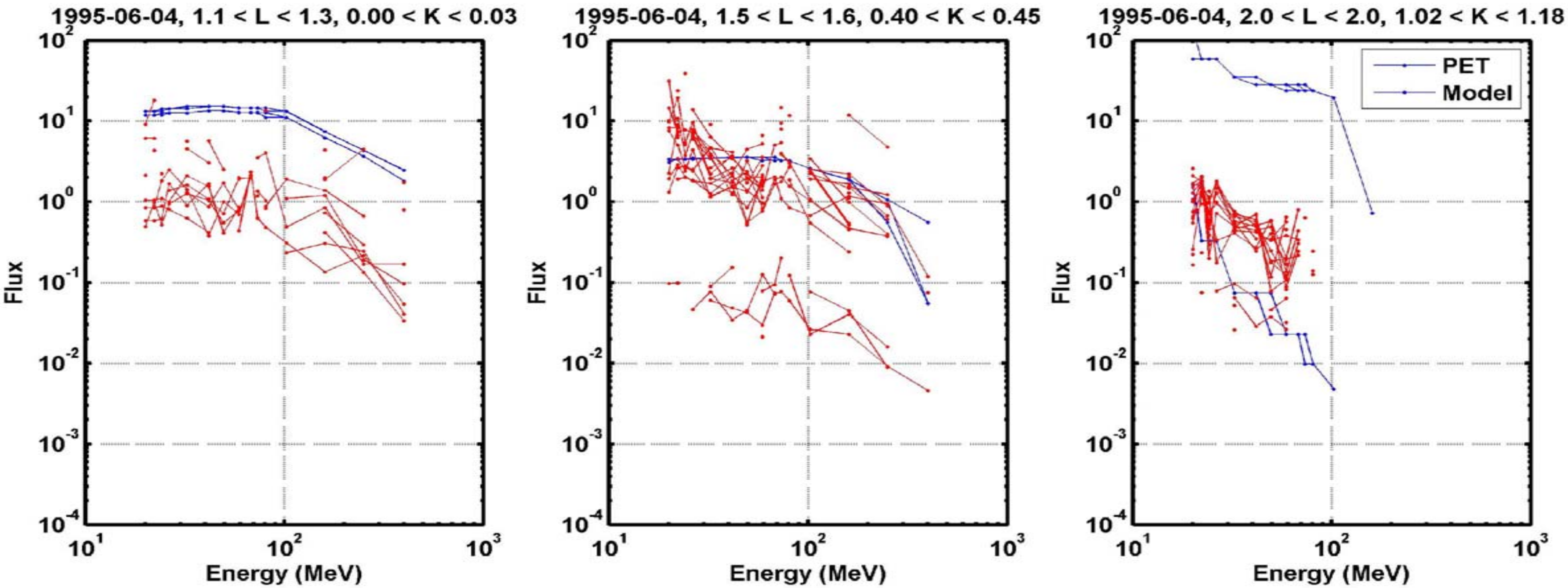
A Simpler Experiment

- Only looking at one day, June 4^{th}, 1995.
- Only looking at the M, K, and L of a particle going down the PET telescope axis (i.e. not using the angular response function)
- Just using the closest model M, K, and L grid point to that observed, i.e. no interpolation into the model.
- No integrating over response functions.
- Just comparing the fluxes given by the PET dataset with the fluxes given by the Selesnick model, in the closest model M, K, and L bin to the observed M, K, and L.
- Figure to right plots the model and data fluxes vs time (top), vs L-shell (middle), and vs. each other (bottom).
- Note large discrepancies in each diagnostic.



Data / Model Spectra Comparison

- By limiting our comparison to only times when PET is looking within certain ranges of L and K, we find that the model spectra are closer to the "ensemble" observational spectra.
- This result should improve with interpolation into the model, not just picking the fluxes at the closest model grid points.
- L-binning (averaging) the data as performed on slide 11 artificially increases the data / model discrepancy, because the observations have more "zero-count" measurements than the model-sampling.

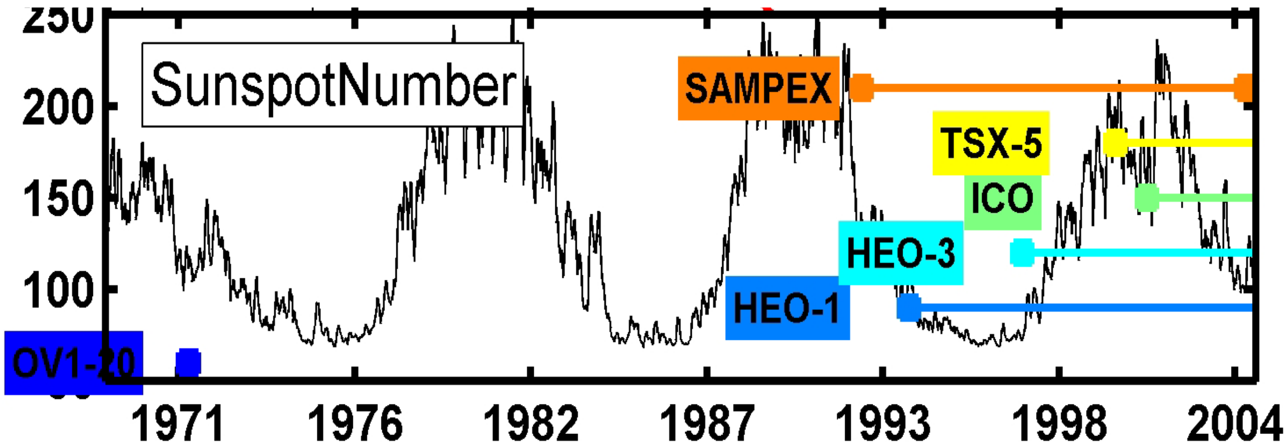


Summary

- We perform a first-cut data / model comparison between the Selesnick et al., 2007 theoretical model of the inner belt proton fluxes and SAMPEX/PET observations.
- Doing the comparison correctly involves calculation of magnetic coordinates and integration of the model over the PET response functions.
  - Hard.
- Preliminary comparison show that the Selesnick et al., 2007 model is at least in the ballpark (within 10x) of LEO observations, but sparse and highly variable observations complicate the analysis.

Future Work

- Revisit comparison of the count rates, interpolating within model and integrating the response functions.
- Include additional observations to test the model in various orbital regimes (HEO, MEO, elliptical LEO).



- Augment the Selesnick et al., 2007 model with a data-assimilation capability, and drive the model with these observations for a climatological interval.

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