Relativistic Electron Loss Timescales in the Slot Region

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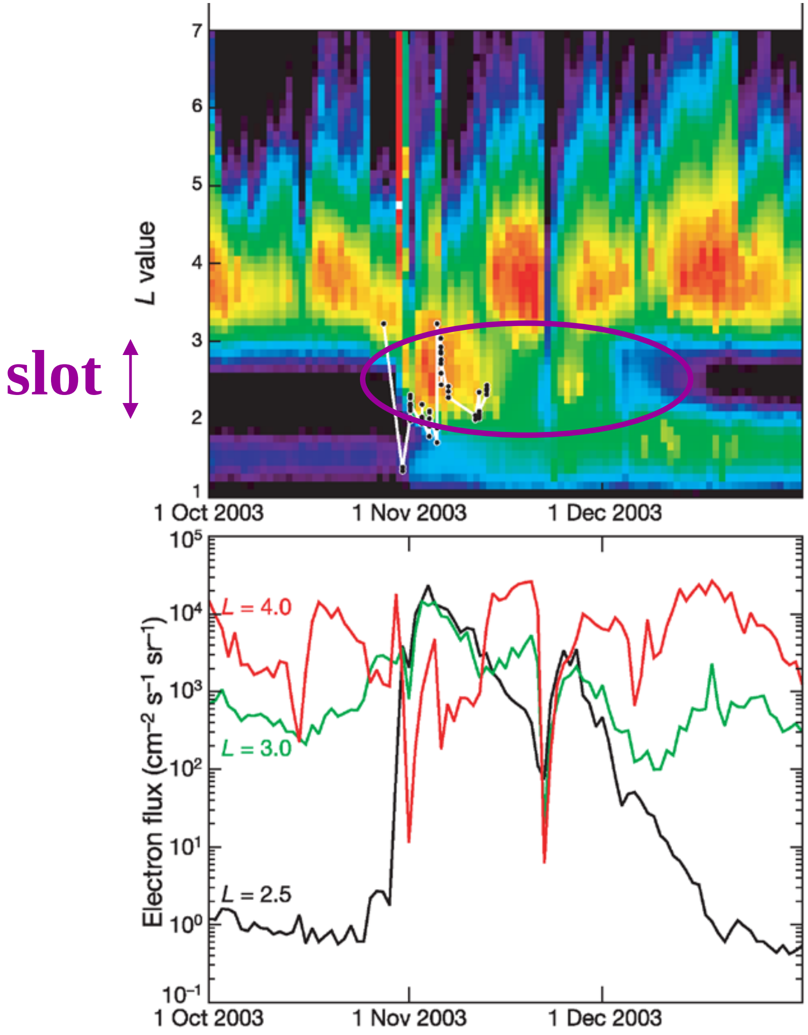
Slot Region Dynamics

- Slot region
  - is not always empty.
  - can become filled during exceptionally large storms such as the Halloween Storms of 2003.
  - subsequently reforms over the following weeks to months.

SAMPEX 2-6 MeV Electrons



Baker *et al*., Nature, 2004

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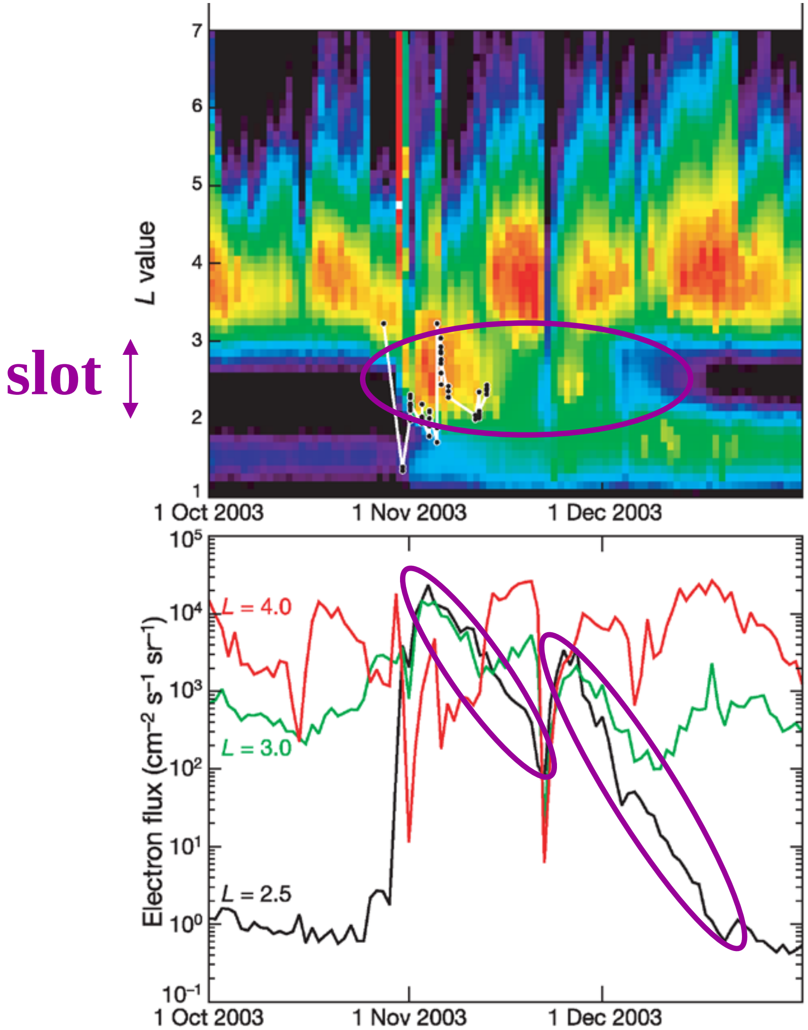
Slot Region Loss Timescales

- Loss timescales for 2-6 MeV electrons in the centre of the slot at L = 2.5 are estimated to be of the order of 2.9 – 4.6 days.

- This is consistent with theoretical expectations based on losses due to plasmaspheric hiss **[Meredith *et al*., 2007]**.

SAMPEX 2-6 MeV Electrons



Baker *et al*., Nature, 2004

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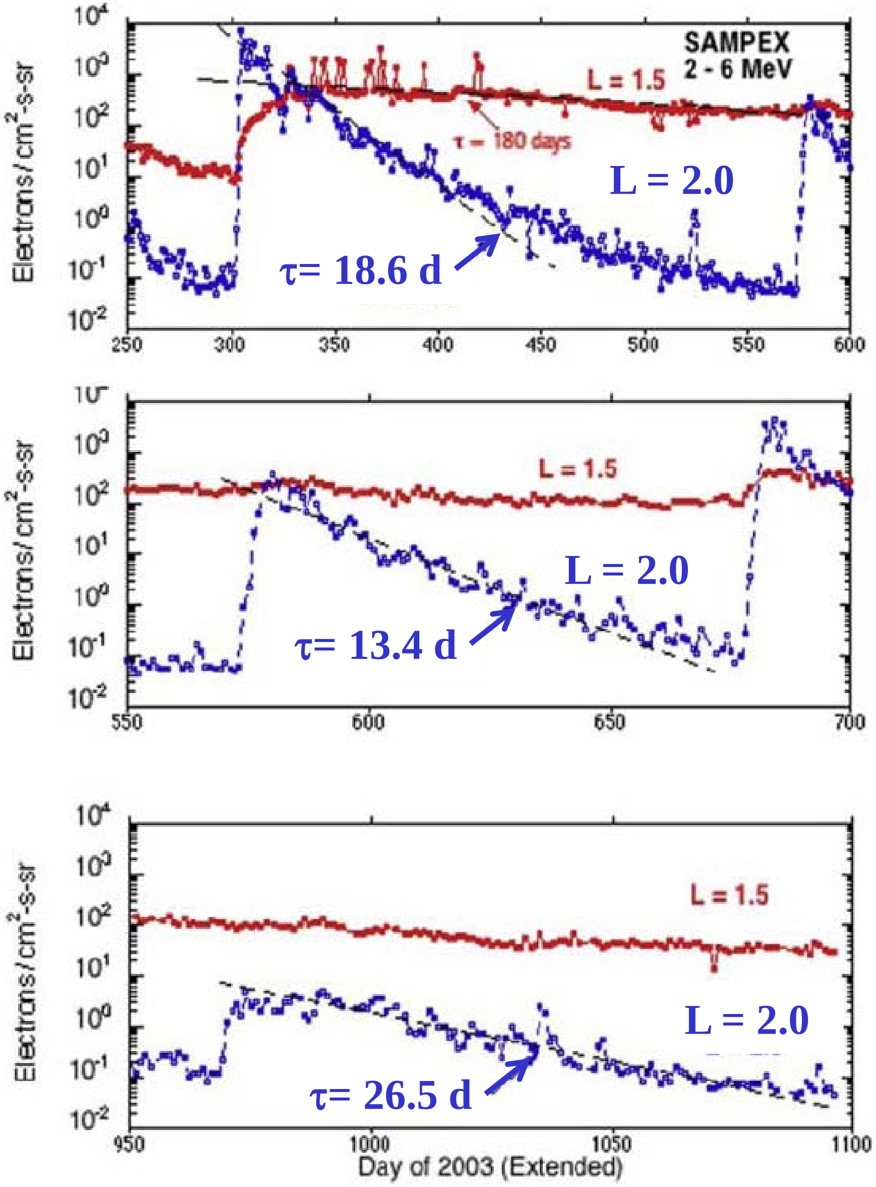
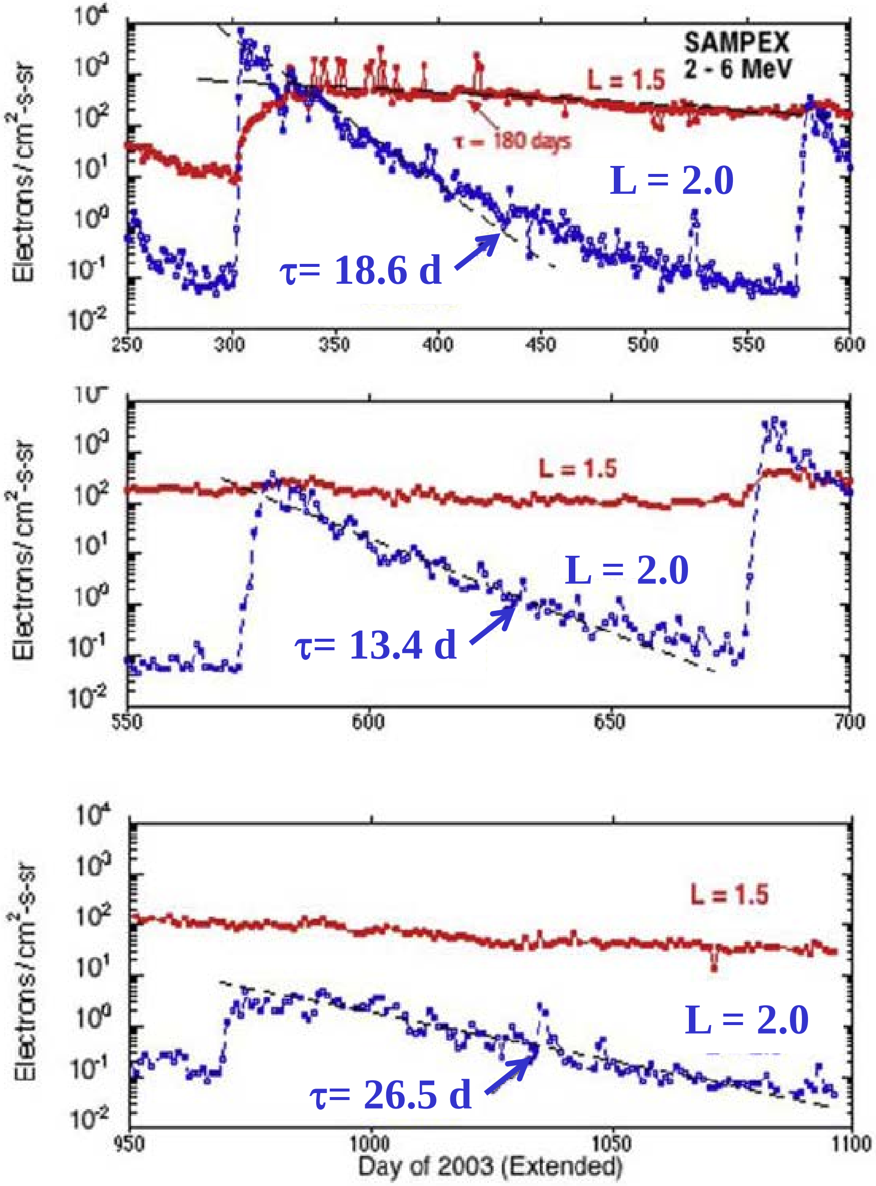
Slot Region Loss Timescales

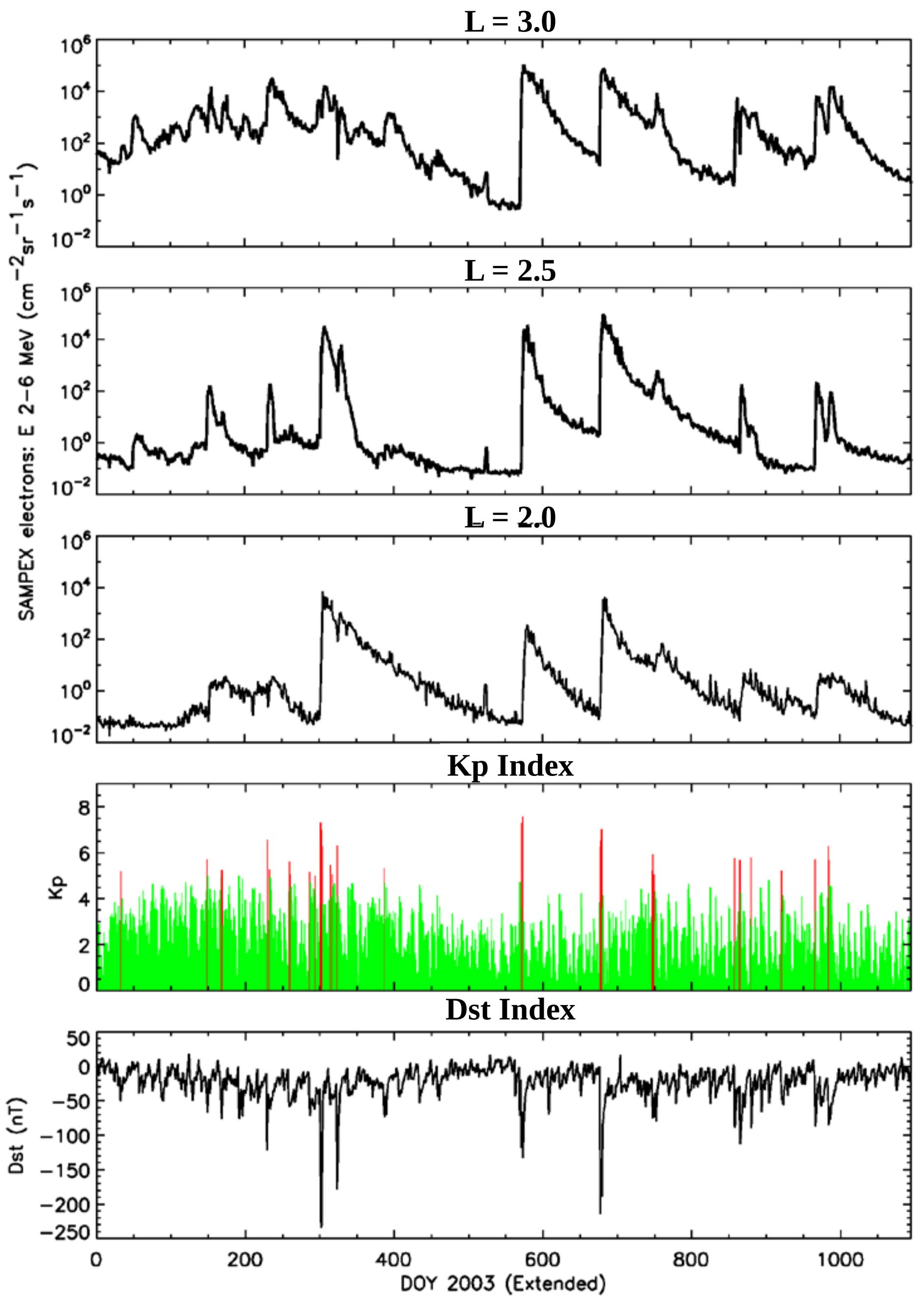


- The experimental lifetime at L = 2.0 is ~20 days **[Baker *et al*., 2007]**.
- This lifetime is much shorter than the theoretical estimates of a few hundred days as a result of losses due to plasmaspheric hiss alone. **[Meredith *et al*., 2007]**.

Slot Region Loss Timescales



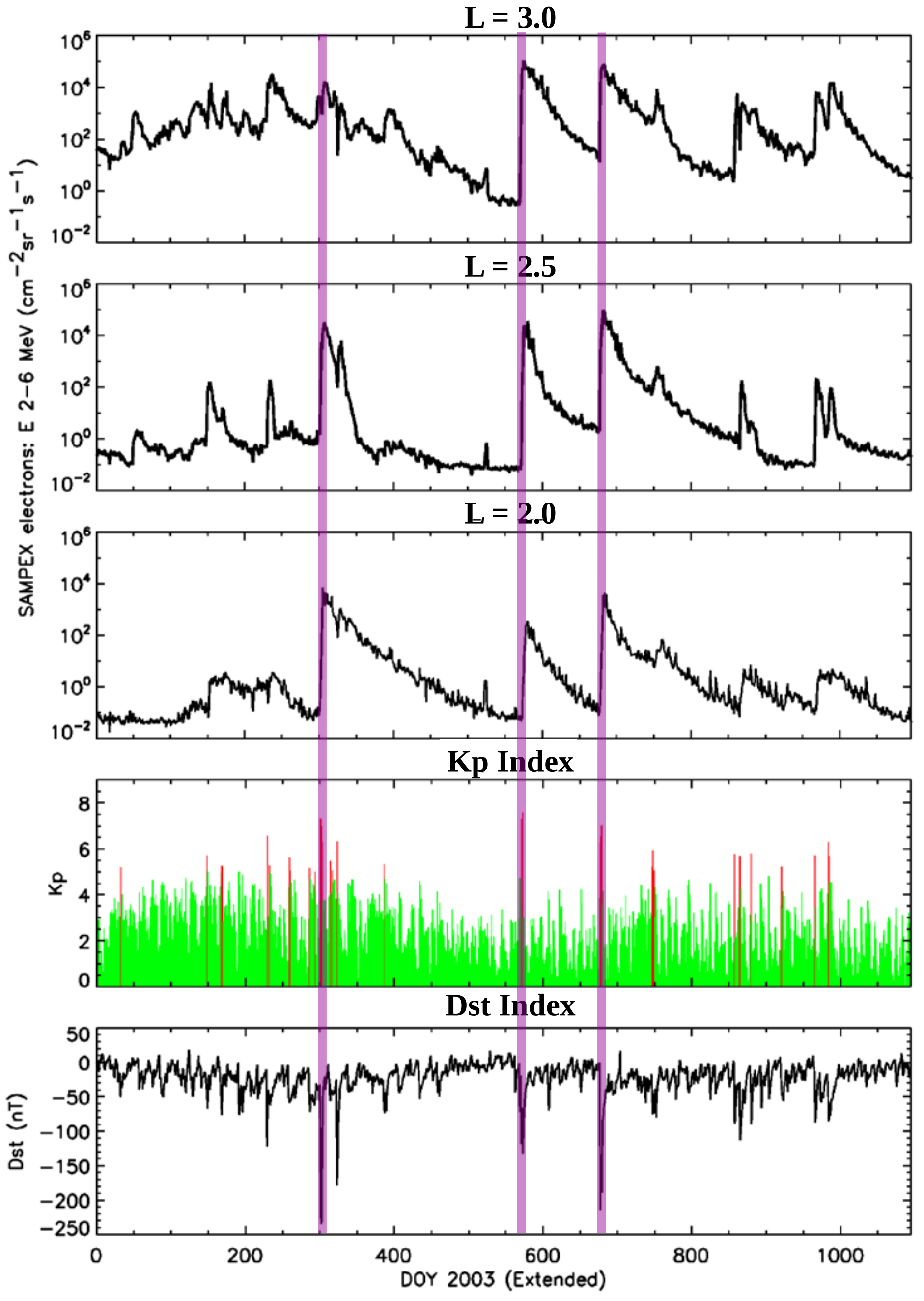
- In this study we perform a comprehensive survey of relativistic electron loss timescales in the slot region.
- We compare SAMPEX observations with theoretical predictions derived from wave models based on CRRES observations.



Slot Region Dynamics

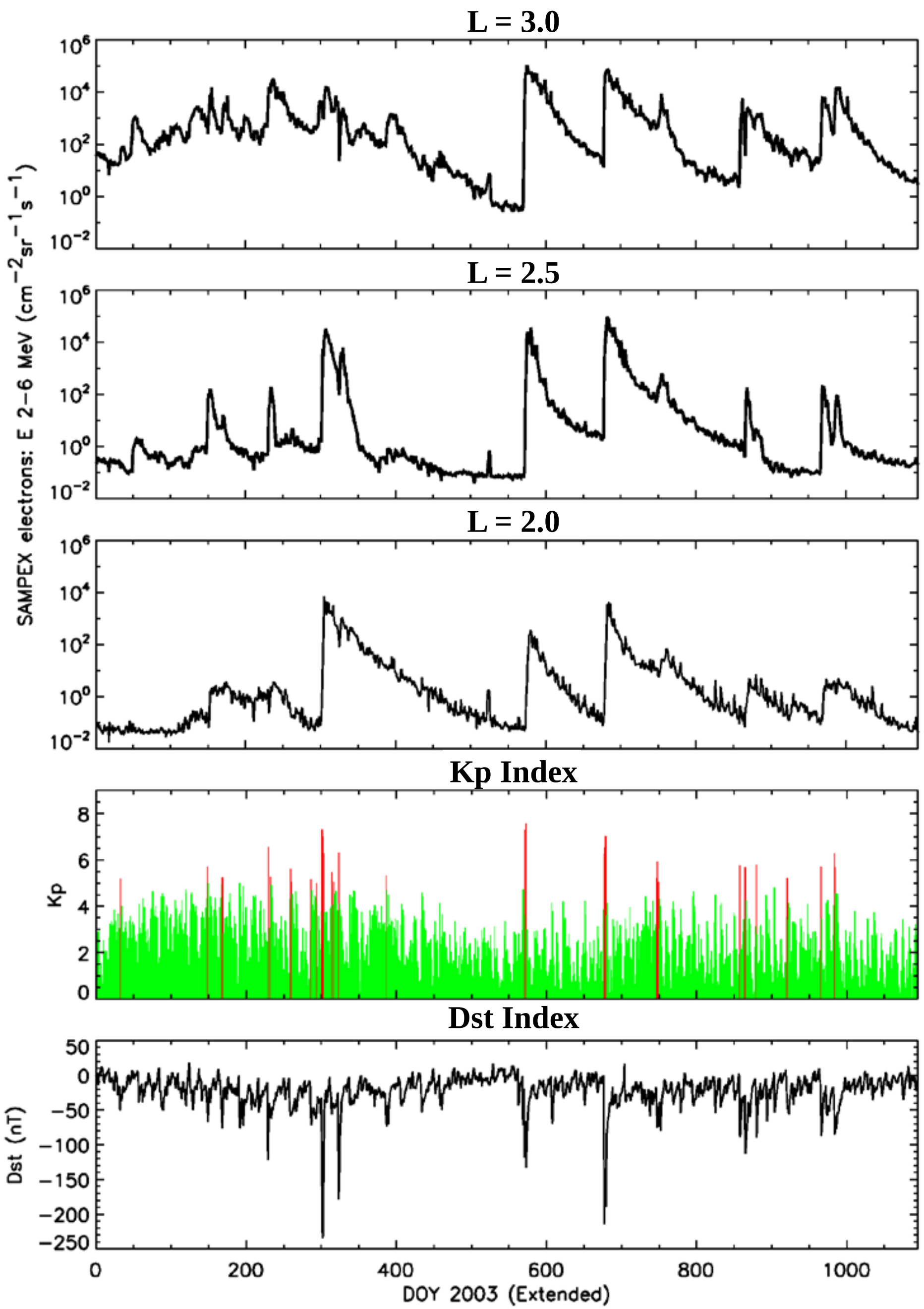
- The flux at each location is characterised by a number of abrupt rises followed by gradual exponential decay.
- The abrupt increases
  - can be as large as 5 orders of magnitude.

Slot Region Dynamics



- The flux at each location is characterised by a number of abrupt rises followed by gradual exponential decay.

- The abrupt increases
  - can be as large as 5 orders of magnitude.
  - are associated with strong storms and enhanced magnetic activity.

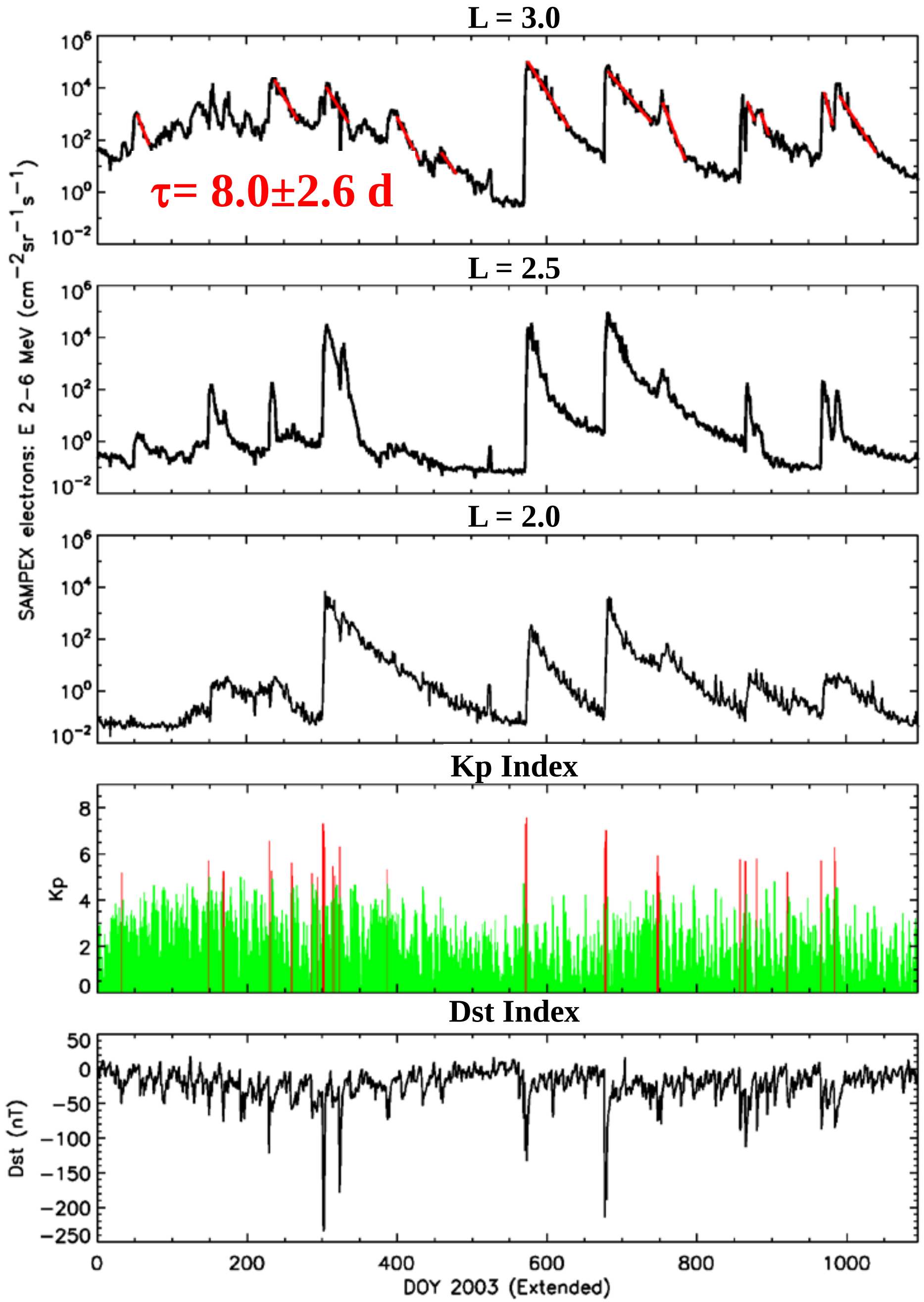


Loss Timescales

- To quantify the decay rates we fit an exponential function of the form:

$$J = J_0 \exp(-t/\tau)$$

- where τ is the loss timescale



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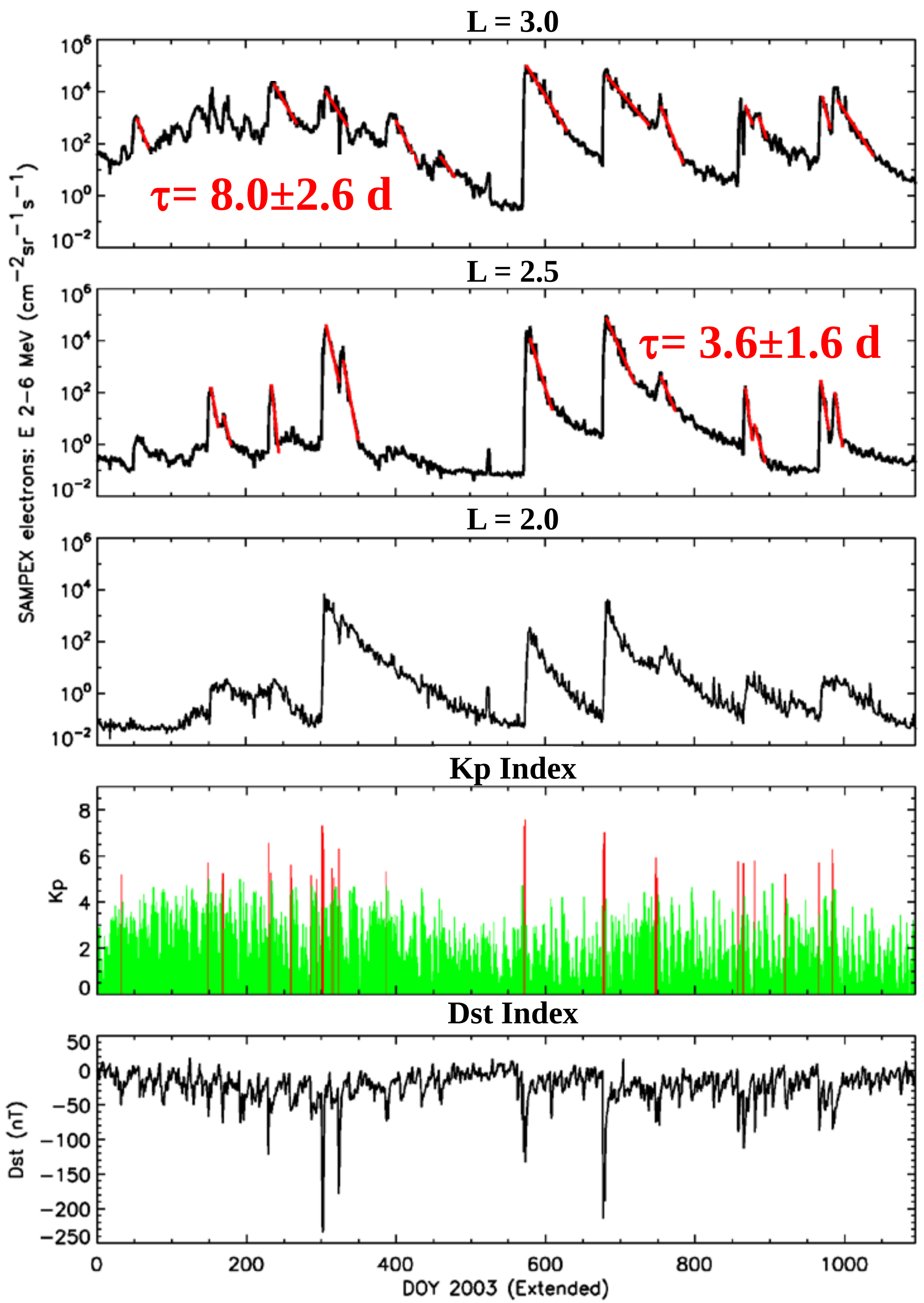
L	τ (days)
3.0	8.0 ± 2.6



Loss Timescales

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3.0	8.0 ± 2.6
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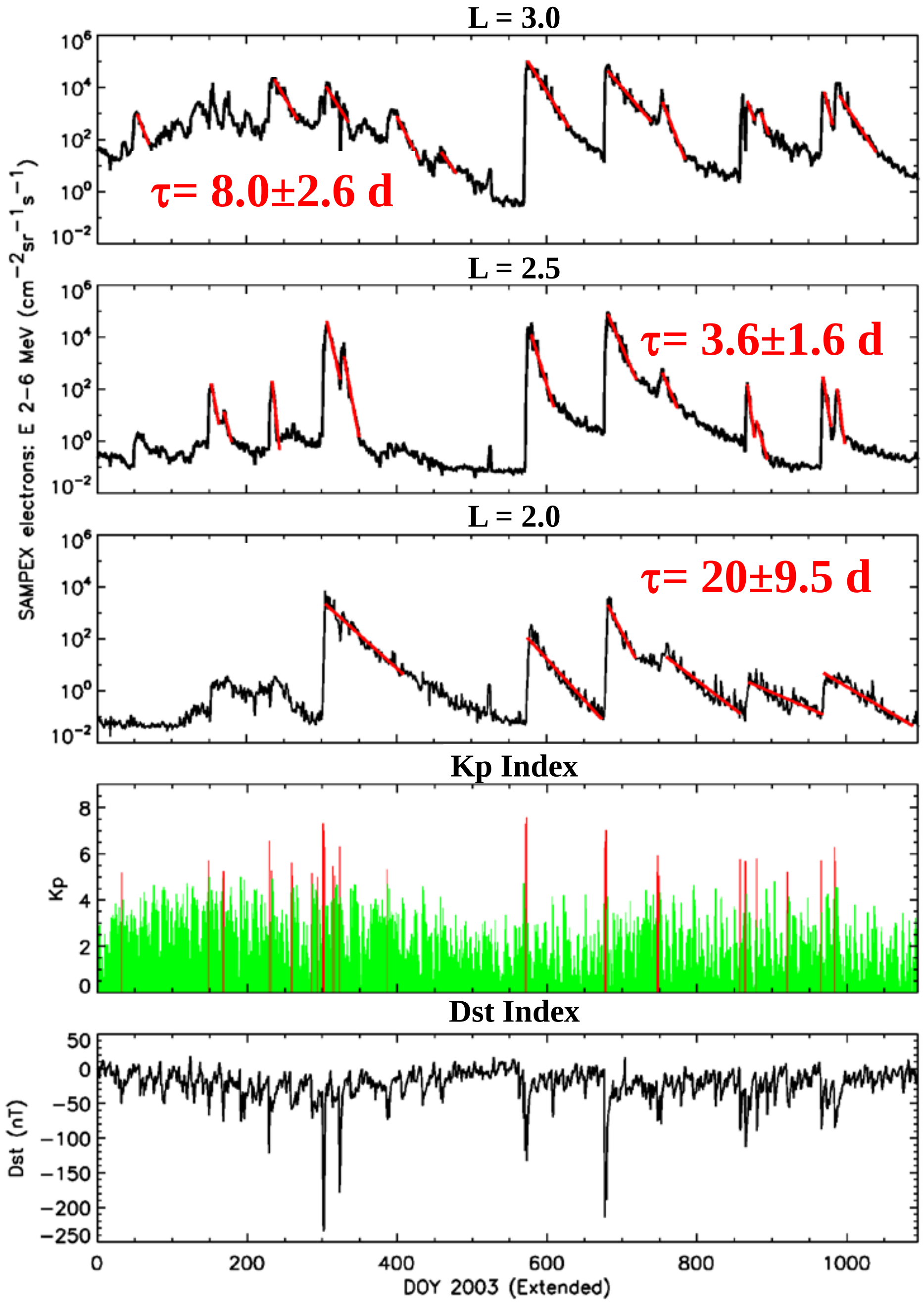


Loss Timescales

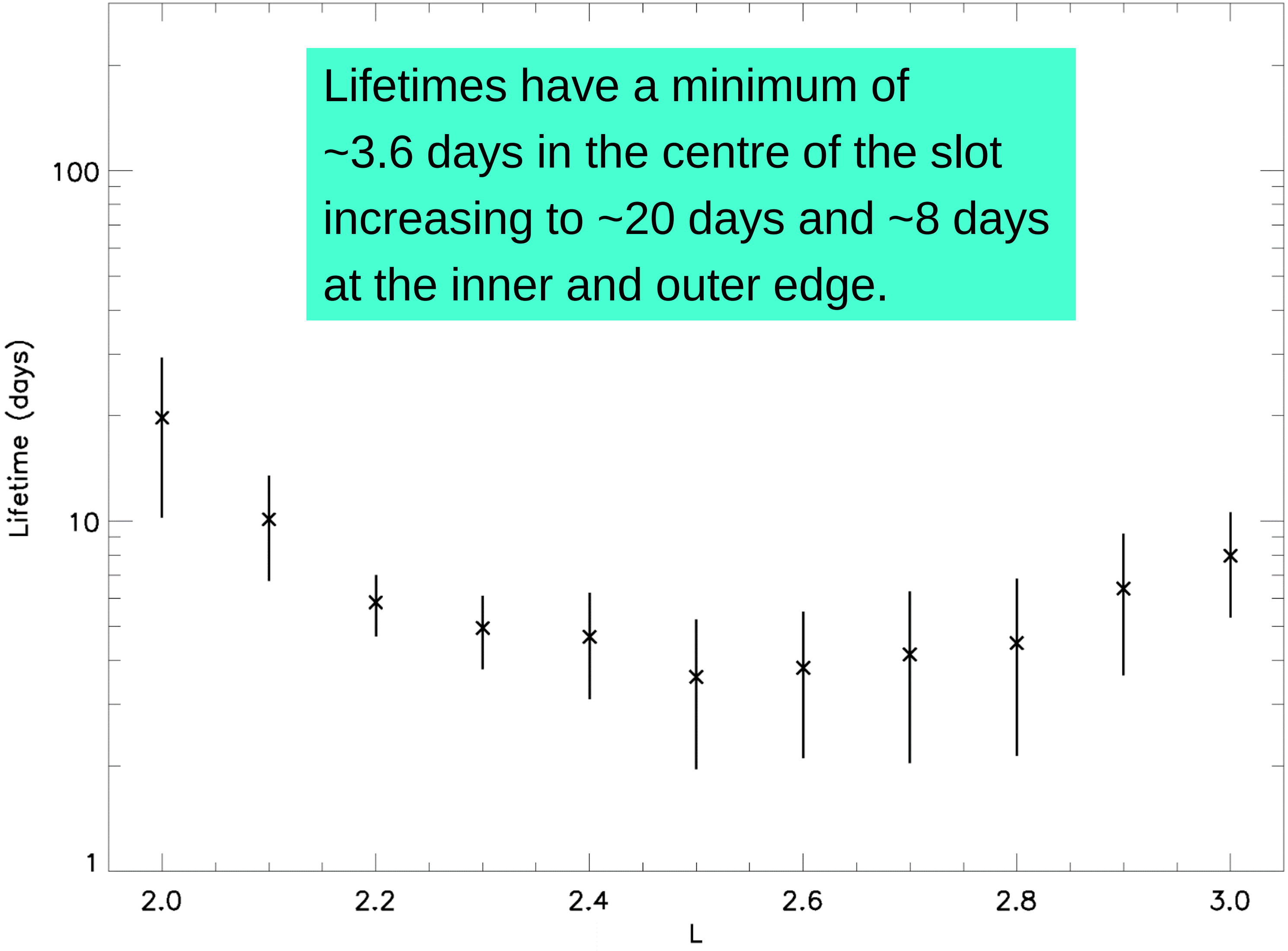
- To quantify the decay rates we fit an exponential function of the form:

$$J = J_0 \exp(-t/\tau)$$

- where τ is the loss timescale

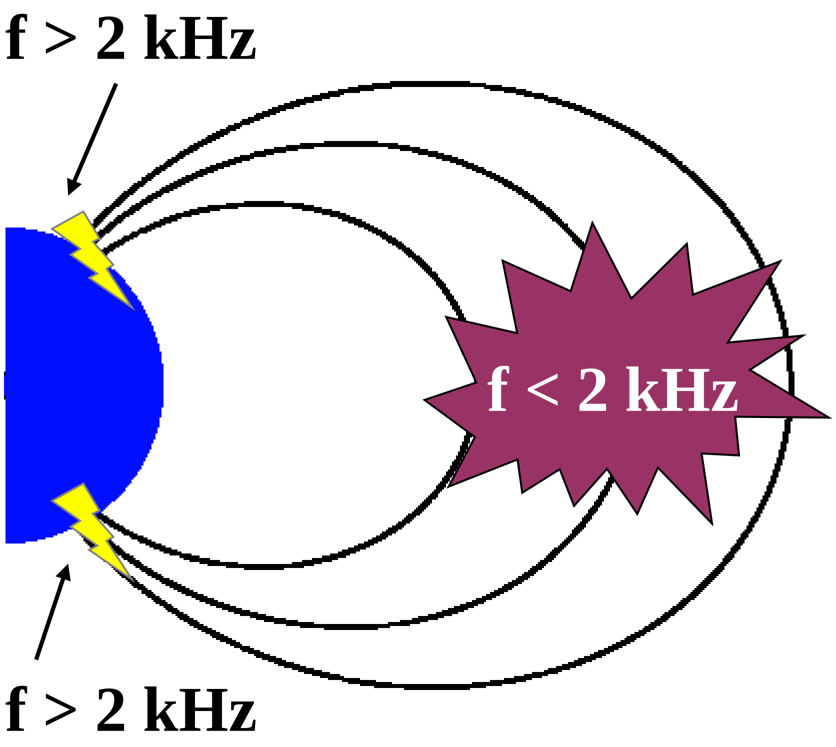
L	τ (days)
3.0	8.0 ± 2.6
2.5	3.6 ± 1.6
2.0	20 ± 9.5

Lifetime of 2 MeV Electrons



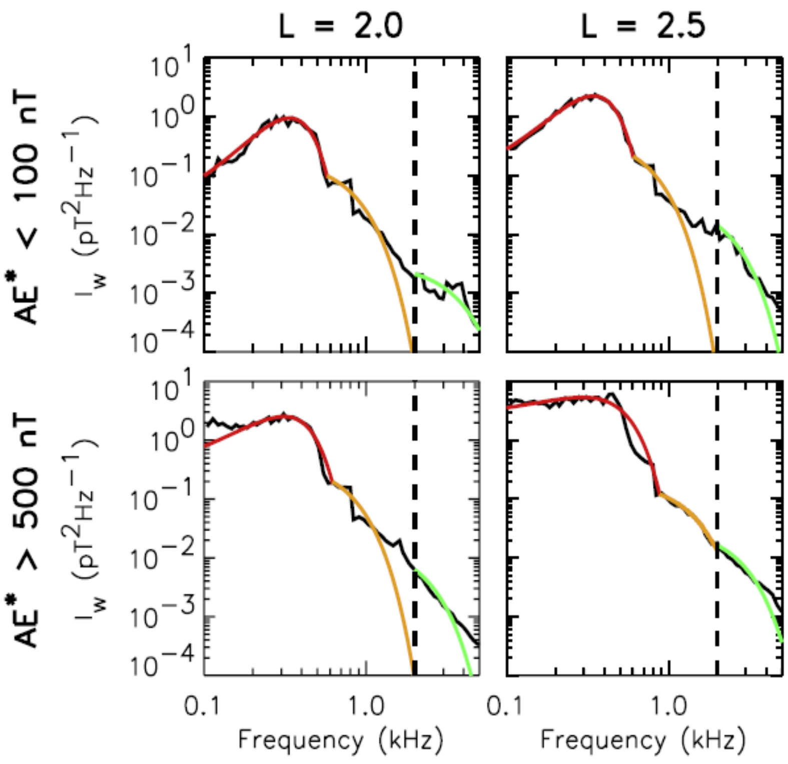
Broadband Plasmaspheric Emissions

- Broadband plasmaspheric emissions can be split into two categories **[Meredith *et al*., 2006]**:
  - Plamaspheric hiss
    - 100 Hz < f < 2 kHz
    - generated by whistler mode chorus
  - Lightning-generated whistlers
    - 2 kHz < f < 5 kHz
    - produced by thunderstorms on Earth



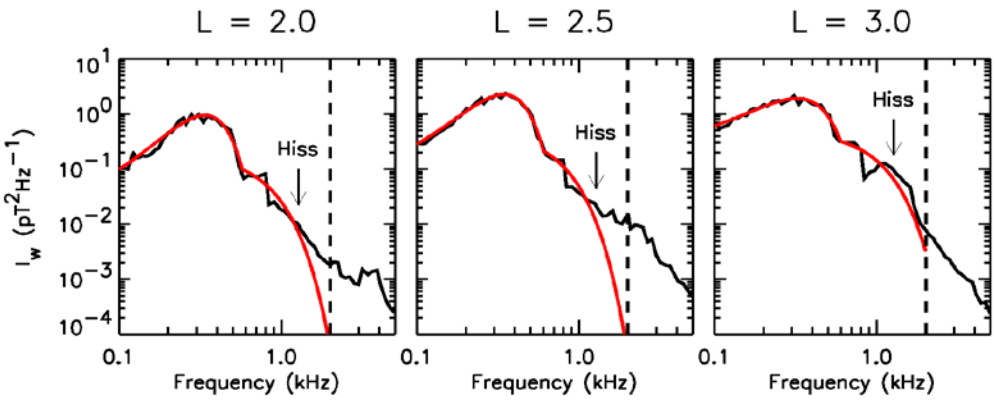
Calculation of Loss Timescales from Waves

- Use global models of the wave spectral intensity based on CRRES observations.
- Calculate bounce-averaged pitch angle diffusion rates using the PADIE code **[Glauert and Horne, 2005]**.
- Determine the loss timescale and the evolution of the pitch angle distribution using the 1D pitch angle diffusion equation following **Lyons et al., [1972]**.



Meredith et al., JGR, 2007

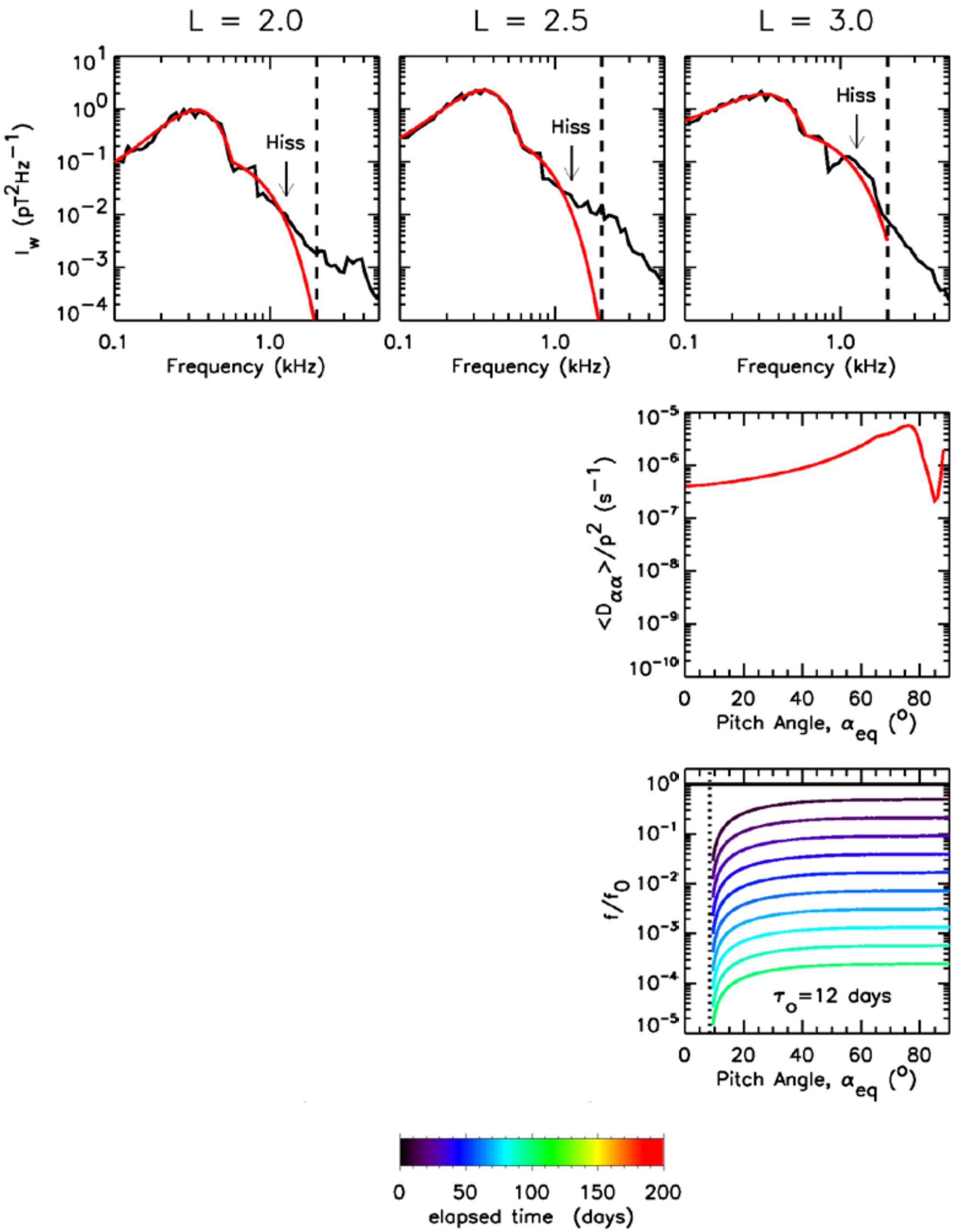
Lifetimes due to Hiss



- Wave power in the frequency range 100 Hz – 5 kHz is dominated by plasmaspheric hiss.

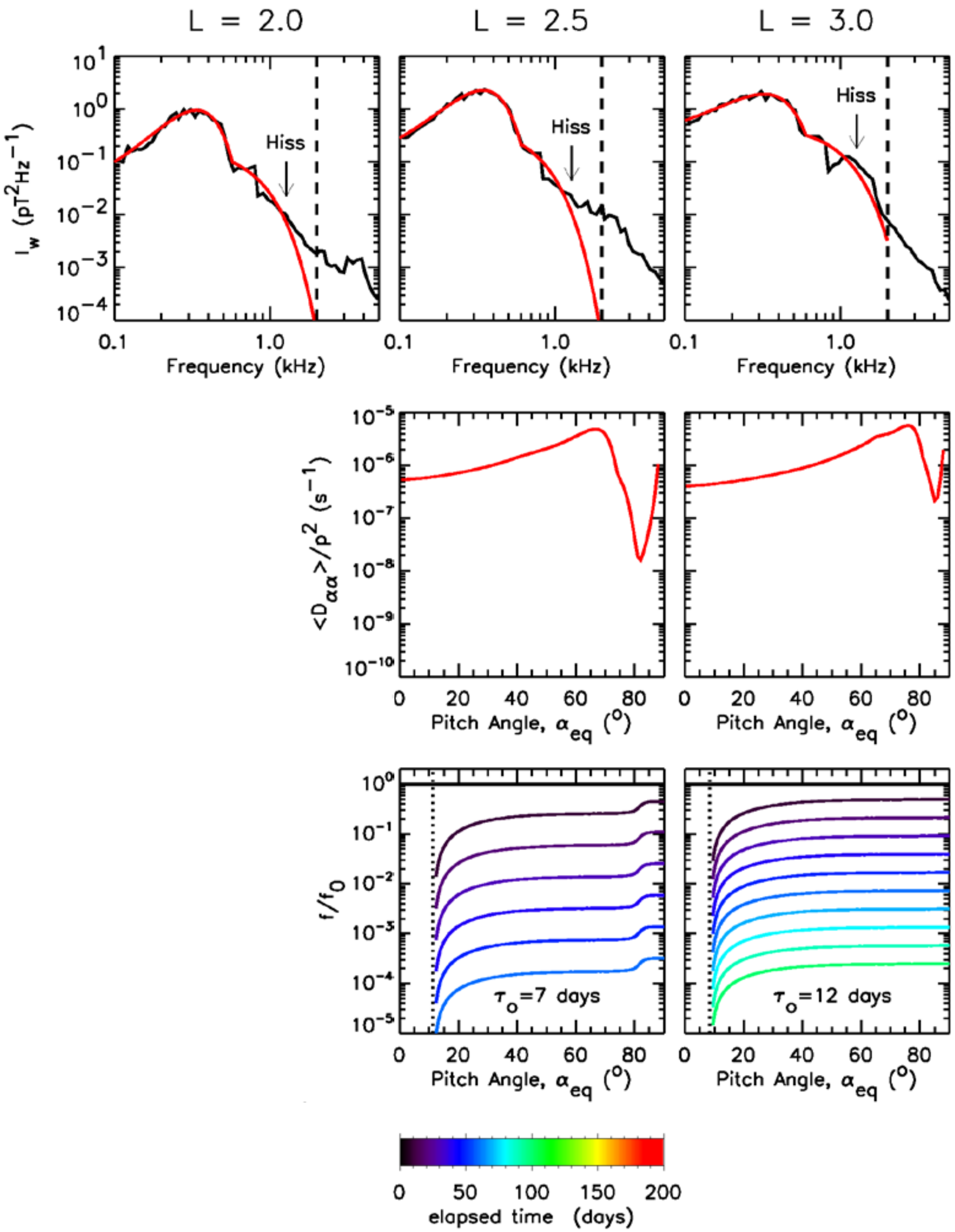
- We begin by considering the effect of hiss during quiet conditions (AE* < 100 nT).

Lifetimes due to Hiss



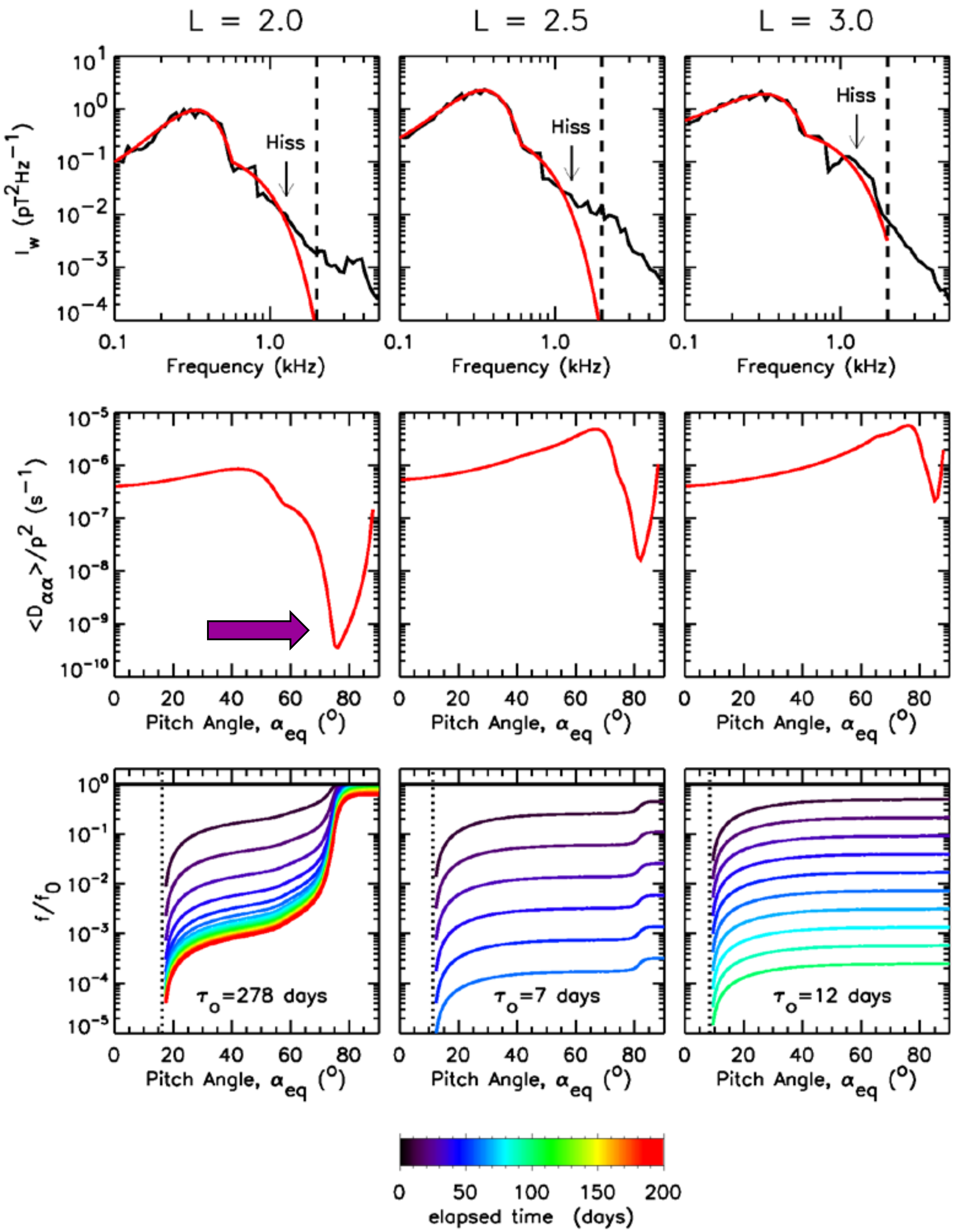
- At L = 3.0 there is a minimum in the diffusion rates at large pitch angles, but the diffusion rate does not fall by more than a factor of 2 compared to the edge of the loss cone.
- The pitch angle distribution quickly reaches an equilibrium state and decays exponentially at all pitch angles on a timescale of 12 days.

Lifetimes due to Hiss



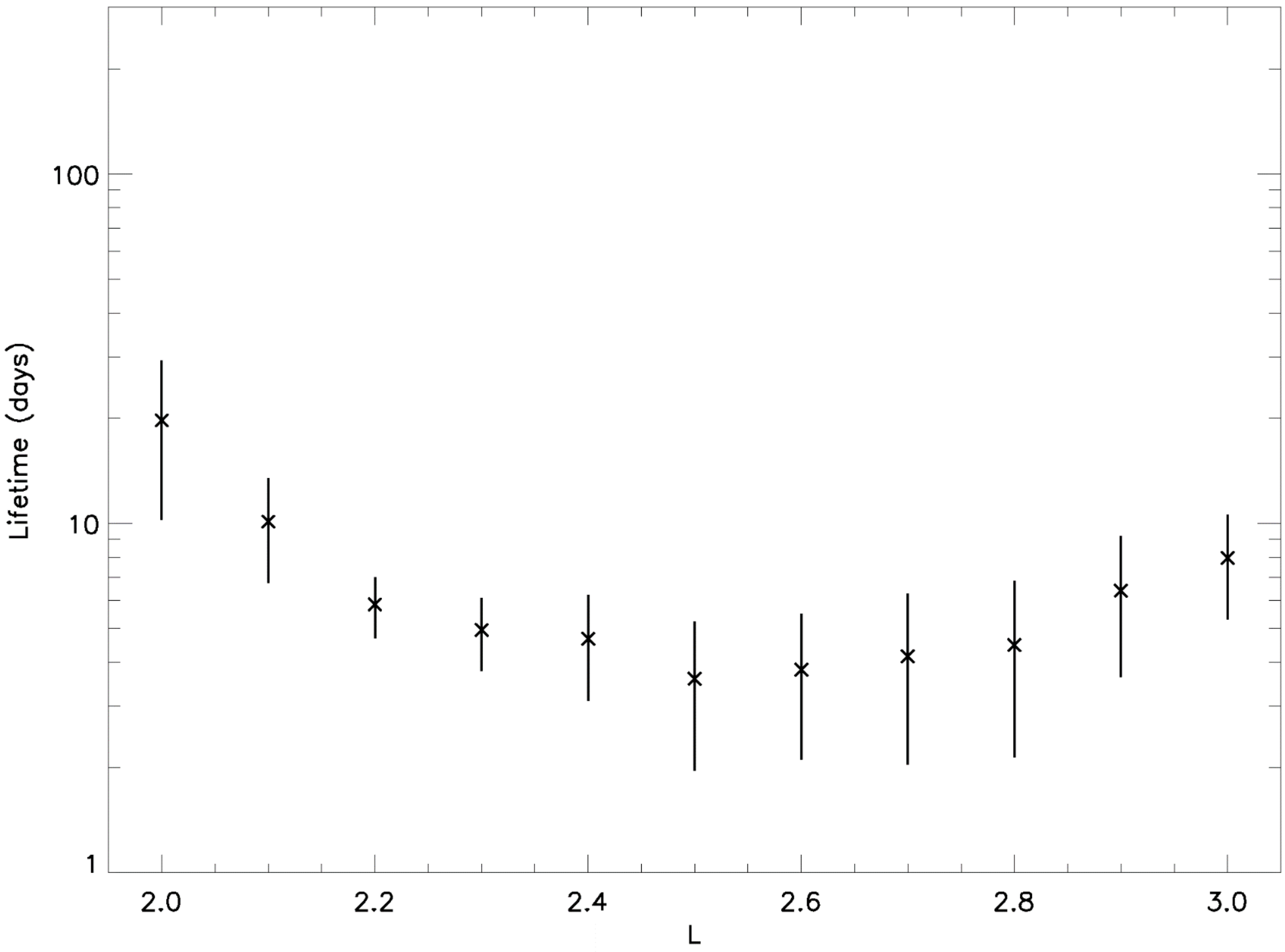
- At L = 2.5 there is a larger minimum in the diffusion rate.
- The pitch angle distribution quickly reaches an equilibrium state and decays exponentially at all pitch angles on a timescale of 7 days.

Lifetimes due to Hiss

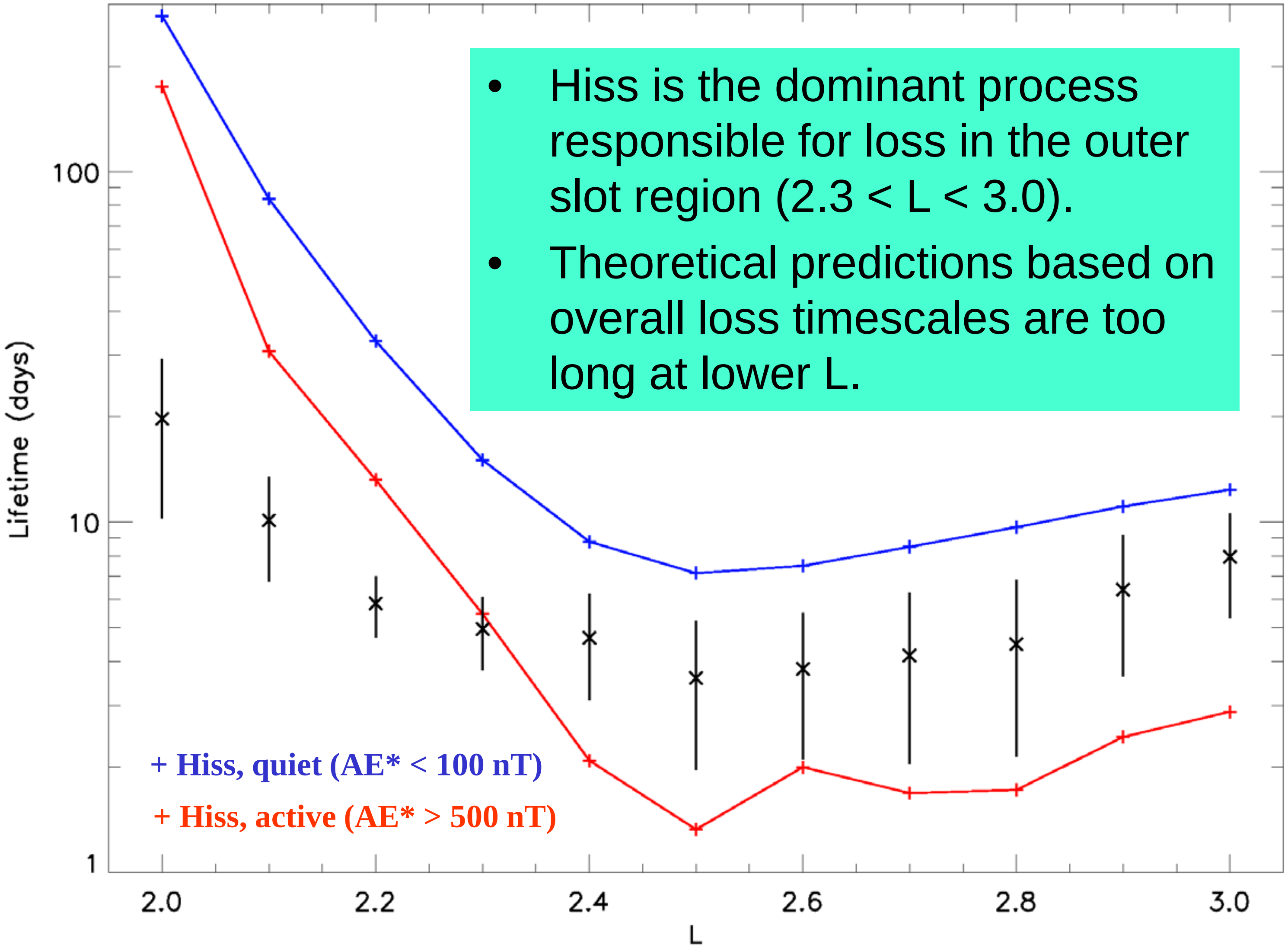


- At L = 2.0 there is a very deep minimum in the diffusion rate.
- This dramatically effects the evolution of the PAD:
  - The decay is pitch angle dependent.
  - The distribution initially decays more rapidly at smaller pitch angles.
- Once an equilibrium shape is reached the entire distribution decays with a timescale of 278 days.

Lifetime of 2-6 MeV Electrons

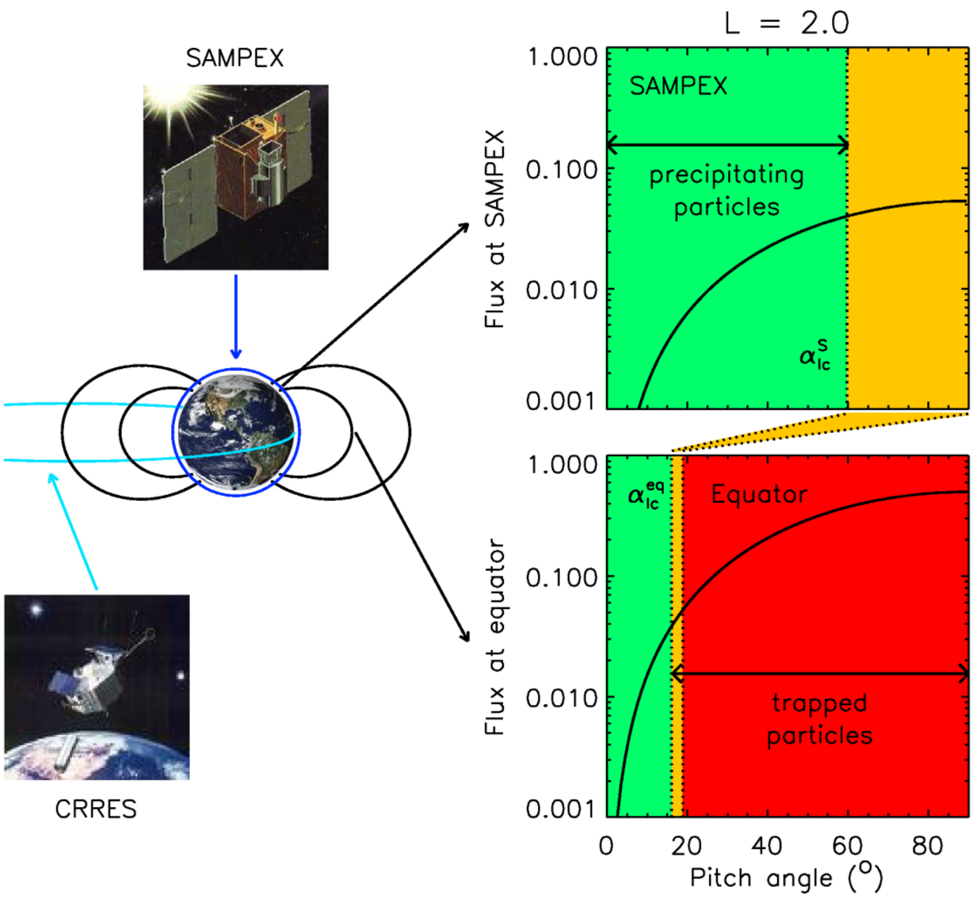


Lifetimes due to Plasmaspheric Hiss



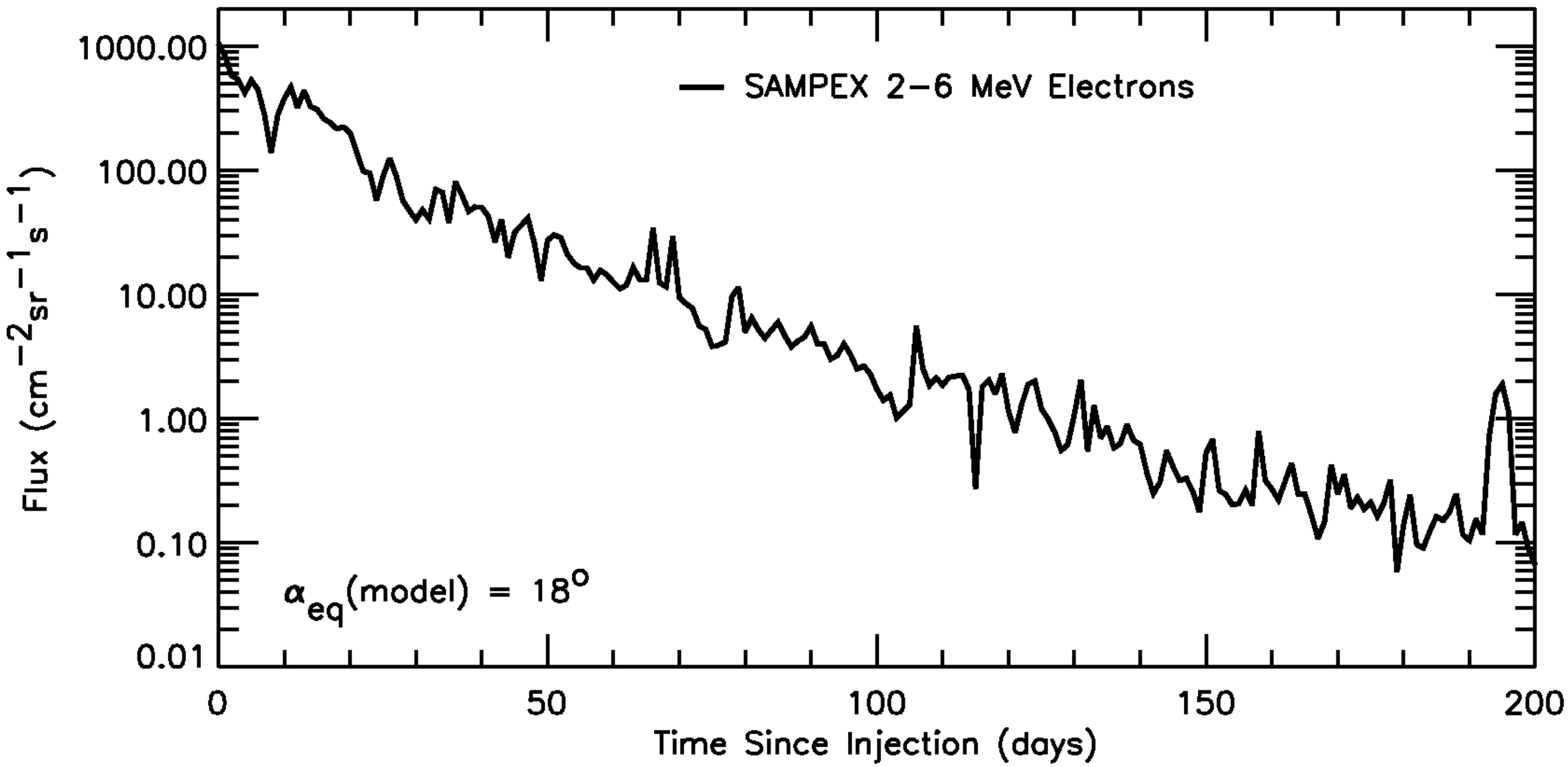
- Hiss is the dominant process responsible for loss in the outer slot region (2.3 < L < 3.0).
- Theoretical predictions based on overall loss timescales are too long at lower L.

SAMPEX Measurements at L = 2.0



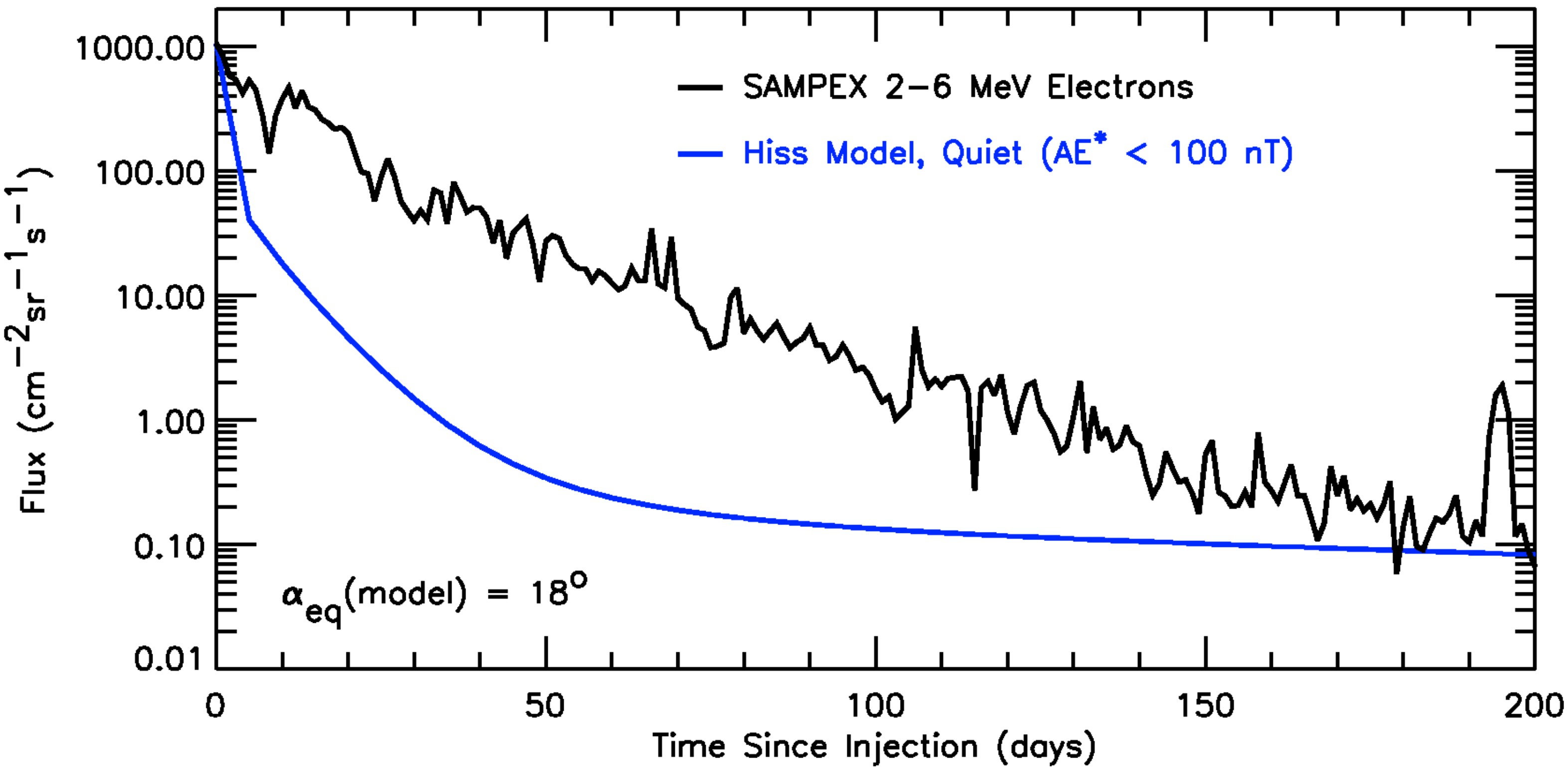
- At L = 2.0 the decay is pitch angle dependent.
- SAMPEX makes measurements at low altitudes (~600 km).
- A locally mirroring particle has an equatorial pitch angle of ~18° at L = 2.0.
- Here we should compare SAMPEX measurements with the model flux at 18°.

Flux Decay at L = 2.0



- SAMPEX measures a relatively constant exponential decay.

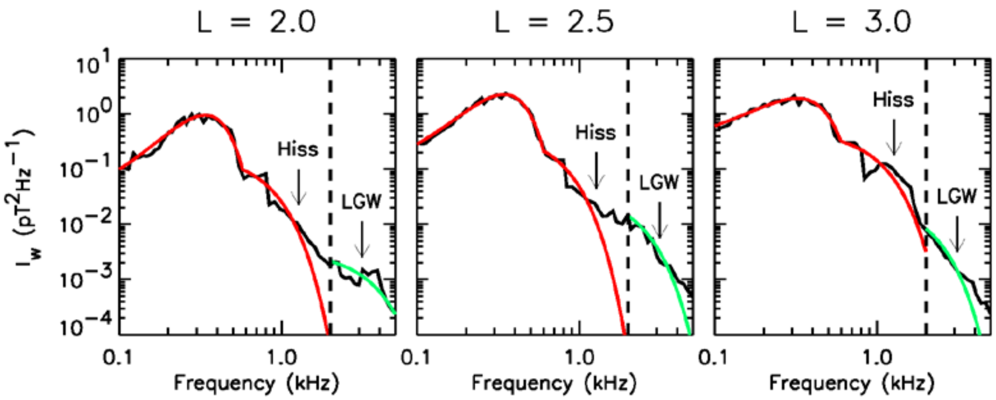
Flux Decay at L = 2.0



- Decay of the model flux at α_{eq} = 18^o is time-dependent and cannot explain the observations.

- Losses due to plasmaspheric hiss alone cannot explain the losses at L = 2.0.

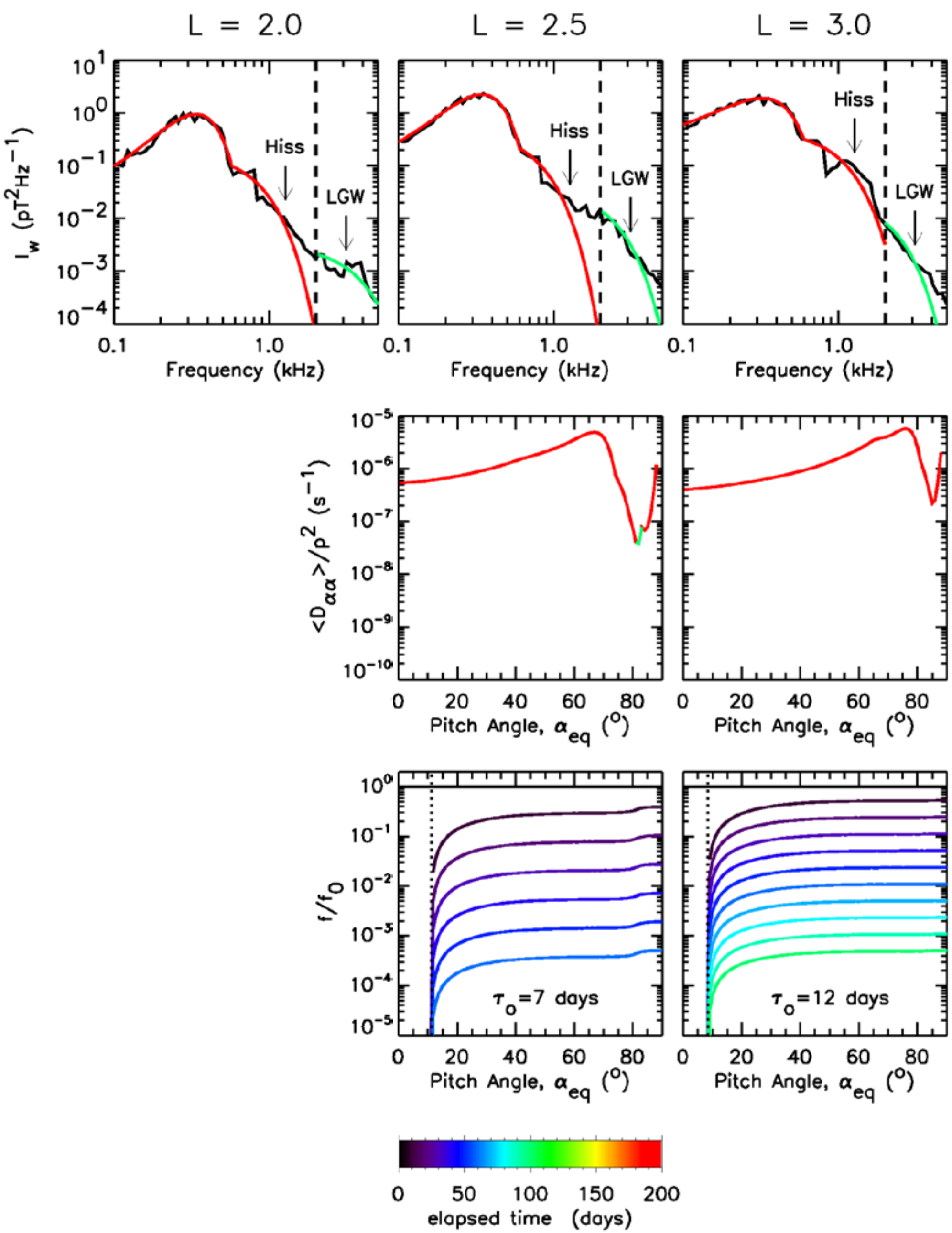
Losses due to Hiss and LGWs



- We now consider the combined effect of lightning-generated whistlers (LGWs) and plasmaspheric hiss.

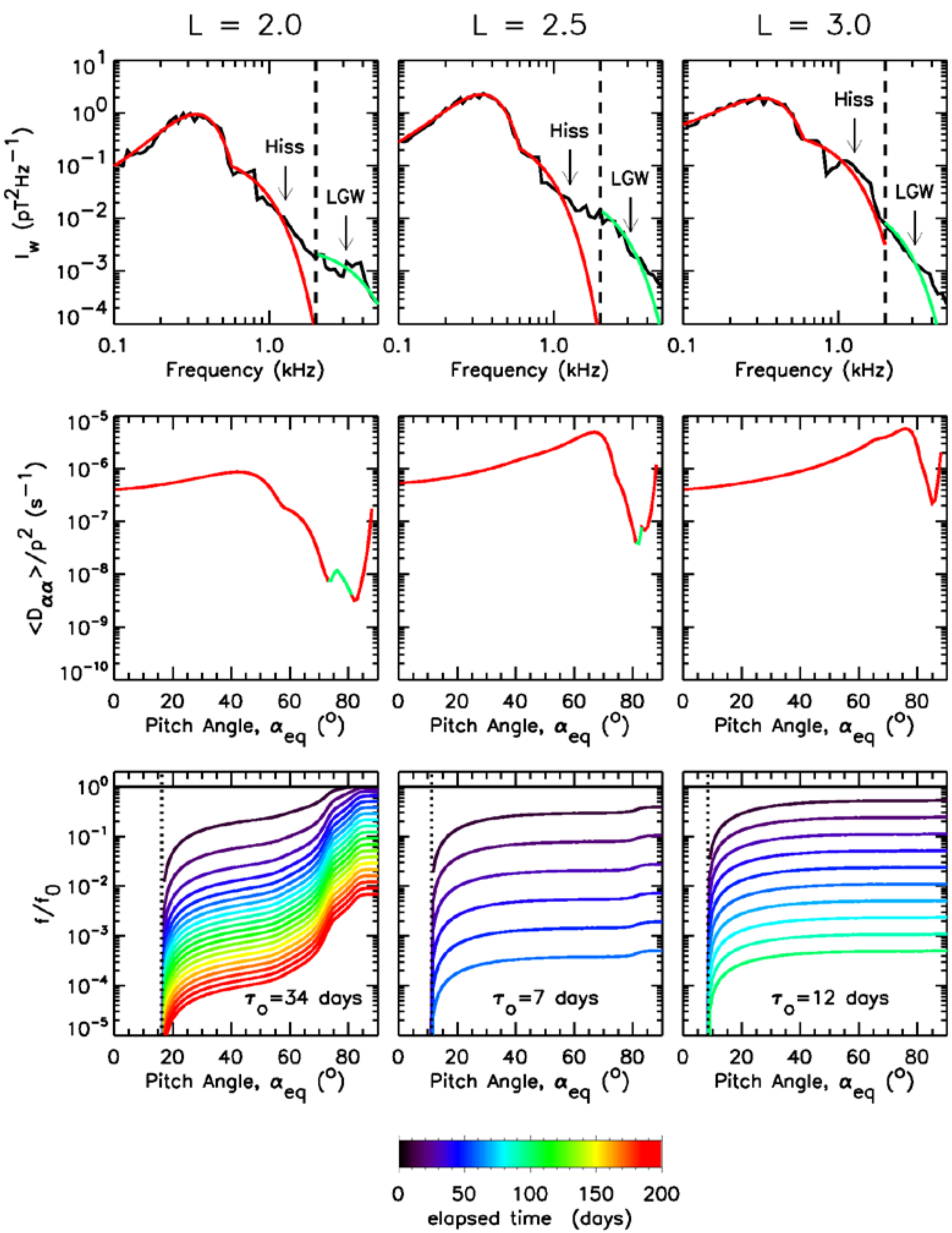
- LGWs dominate the spectrum above 2 kHz and so we add an additional component from 2-5 kHz.

- We again present the results for quiet conditions (AE* < 100 nT)



Losses due to Hiss and LGWs

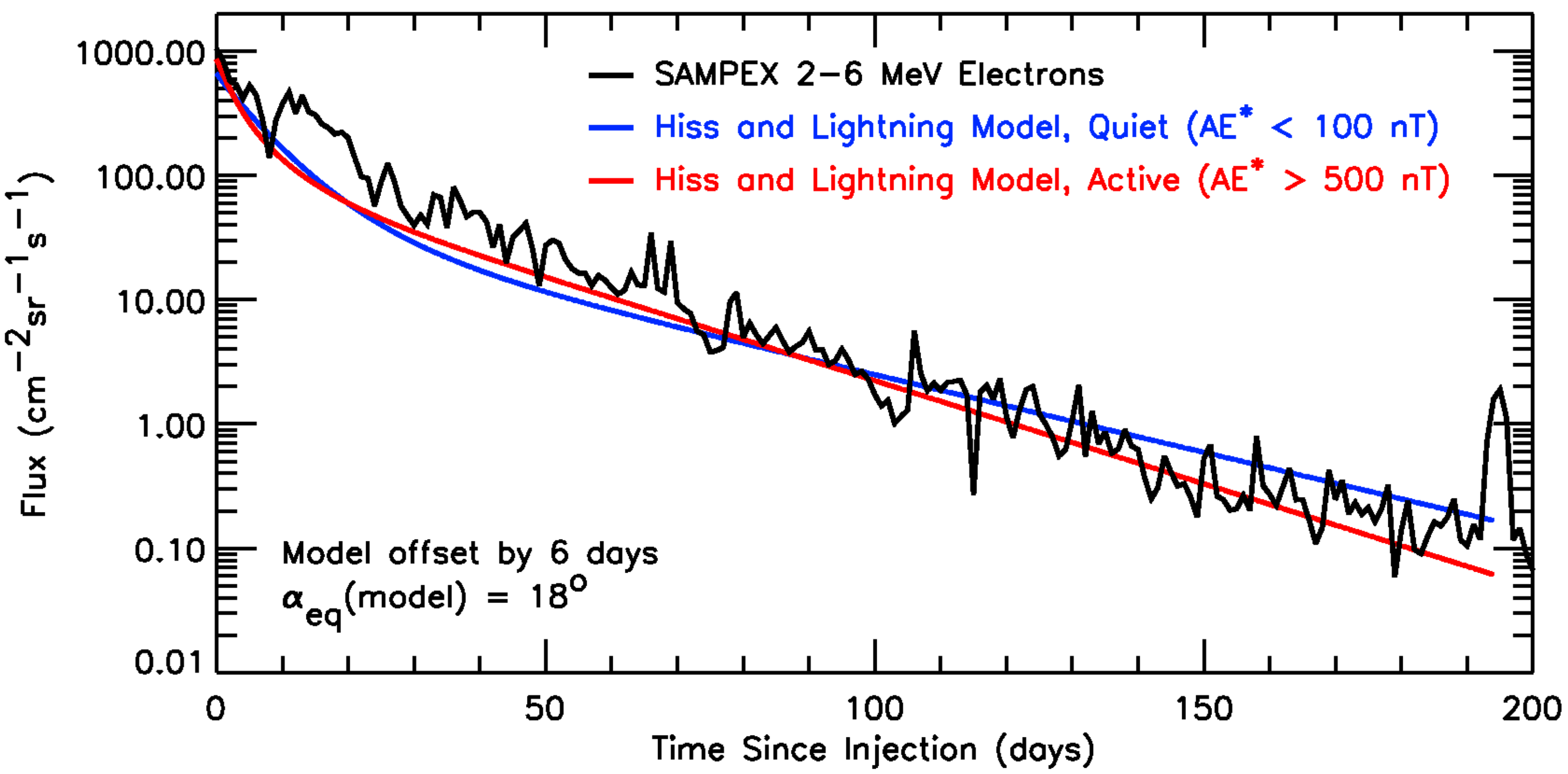
- At L = 2.5 and L = 3.0 there is little or no change in the diffusion rates and virtually no change in the loss rates.



Losses due to Hiss and LGWs

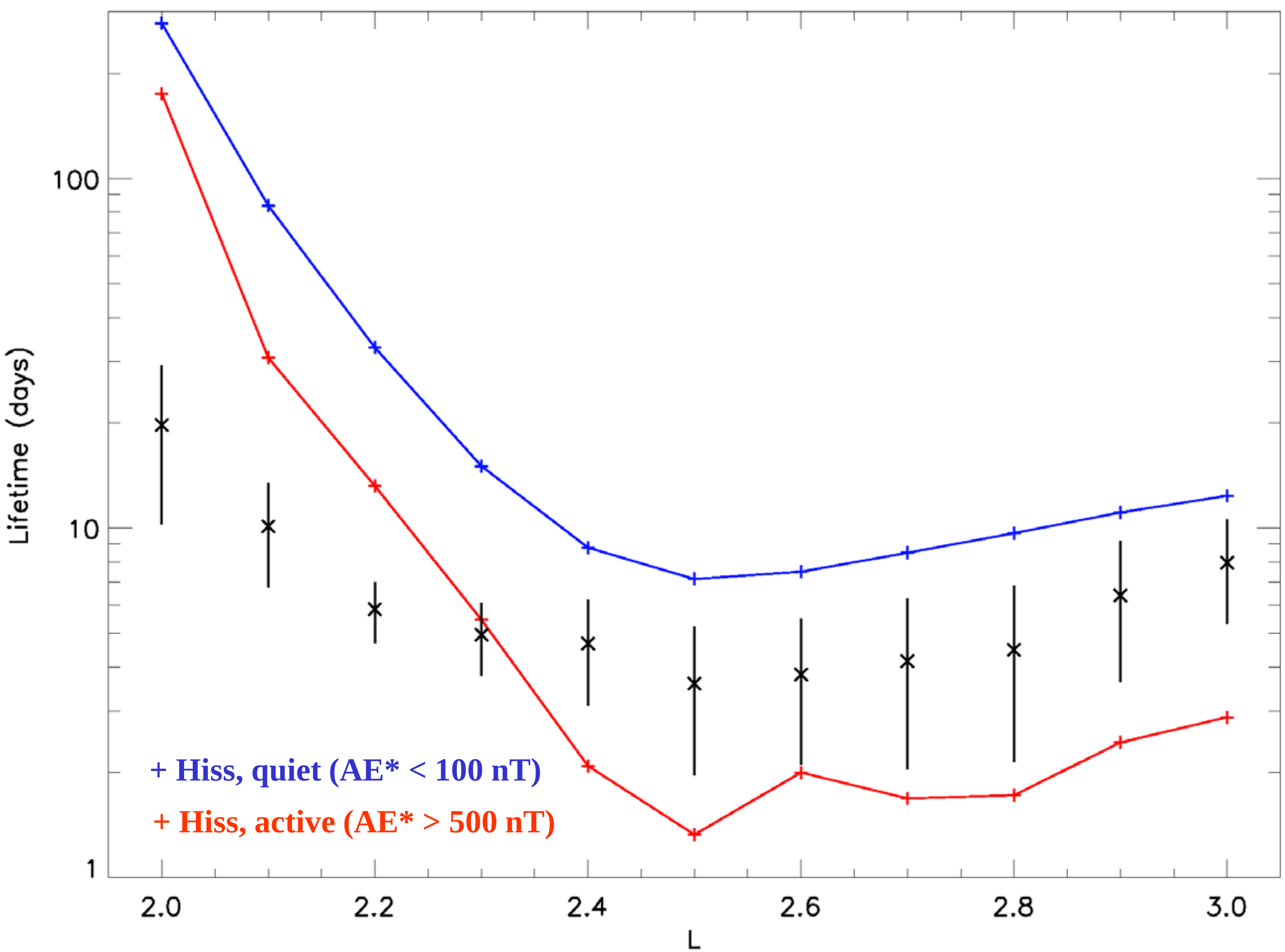
- At L = 2.0, the effect of the additional wave power is to increase the diffusion rates in the deep minimum.
- The distribution now evolves more quickly to an equilibrium state and decays with a lifetime of 34 days.

Evolution of the Flux at SAMPEX altitudes

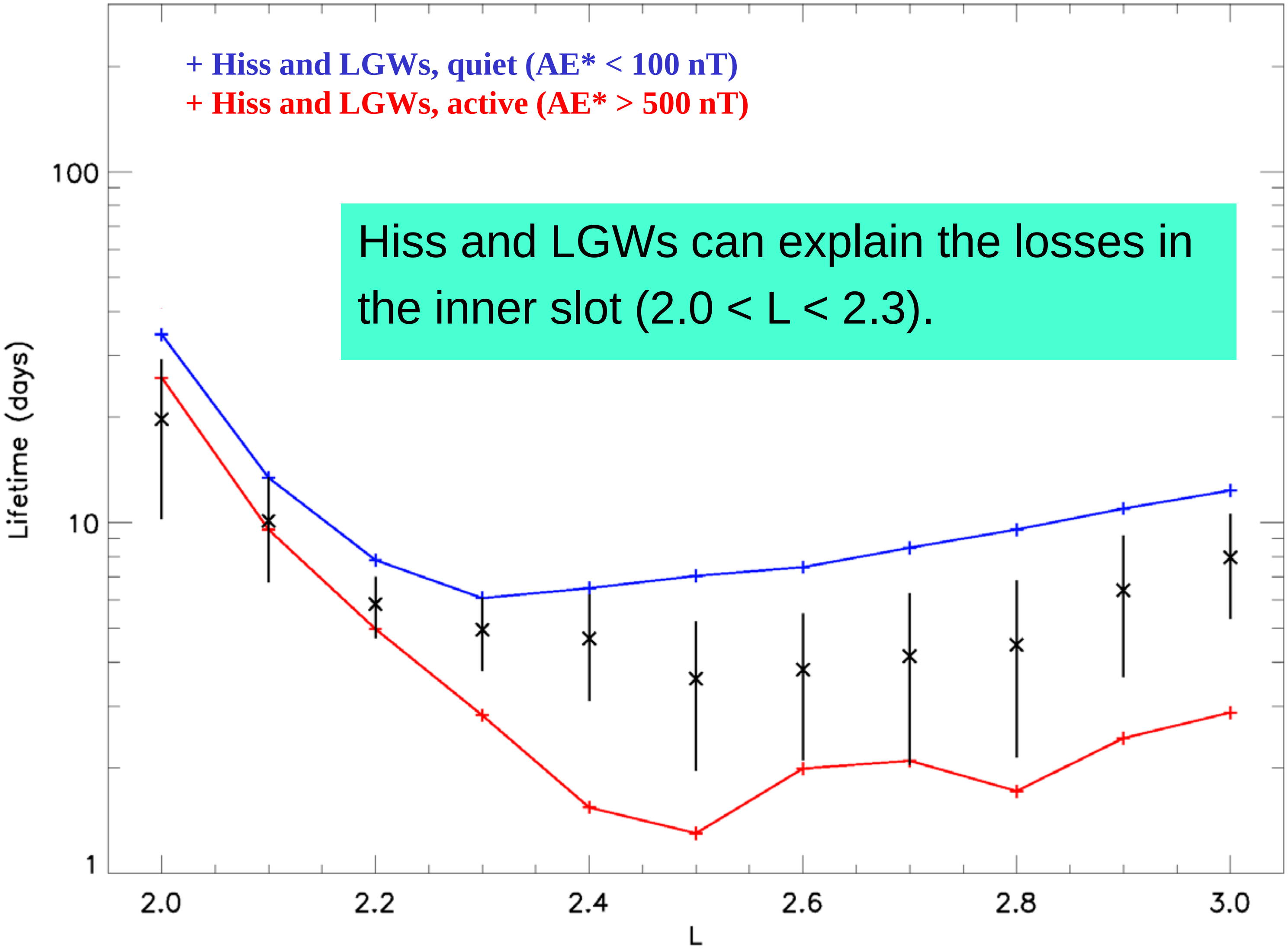


- Decay of the model flux at $\alpha_{eq} = 18^o$ gives reasonable agreement with the data.

Lifetimes due to Plasmaspheric Hiss



Lifetimes due to Hiss and LGWs

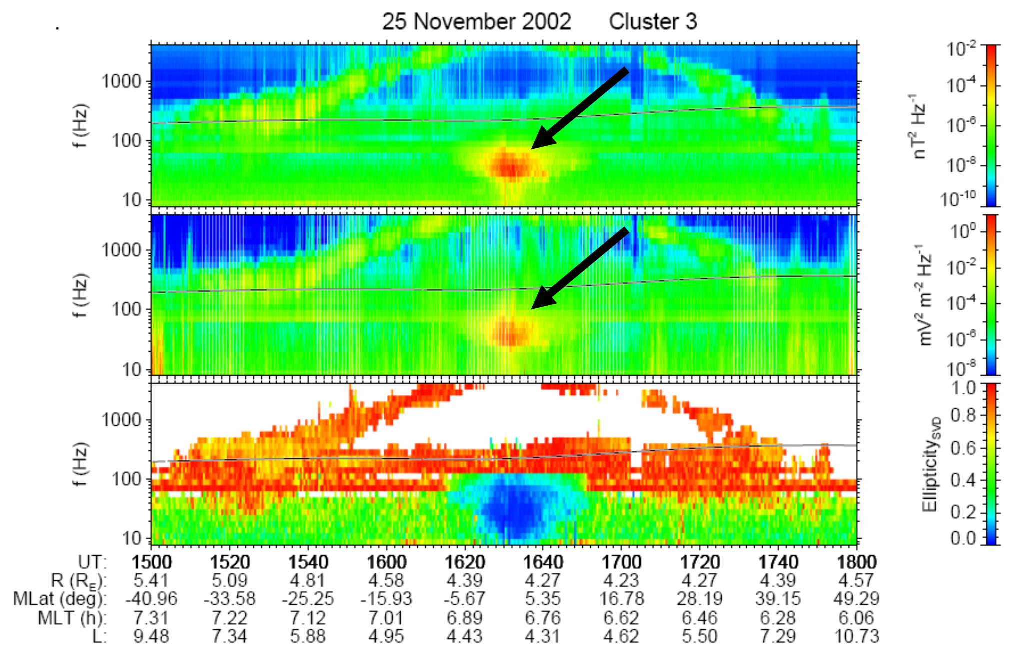


Hiss and LGWs can explain the losses in the inner slot (2.0 < L < 2.3).

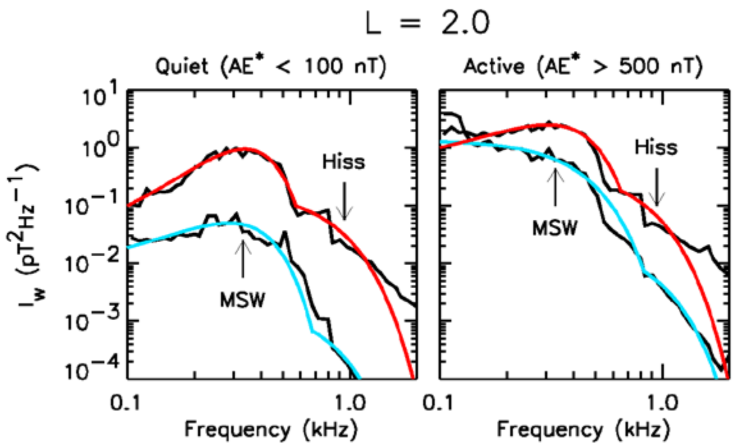
Magnetosonic Waves

- Magnetosonic waves may also scatter radiation belt electrons at large pitch angles **[Horne *et al*., 2007].**

- These waves are
  - intense electromagnetic emissions
  - $f_{cH} < f < f_{LHR}$
  - observed near the equatorial plane
  - $2 < L < 7$



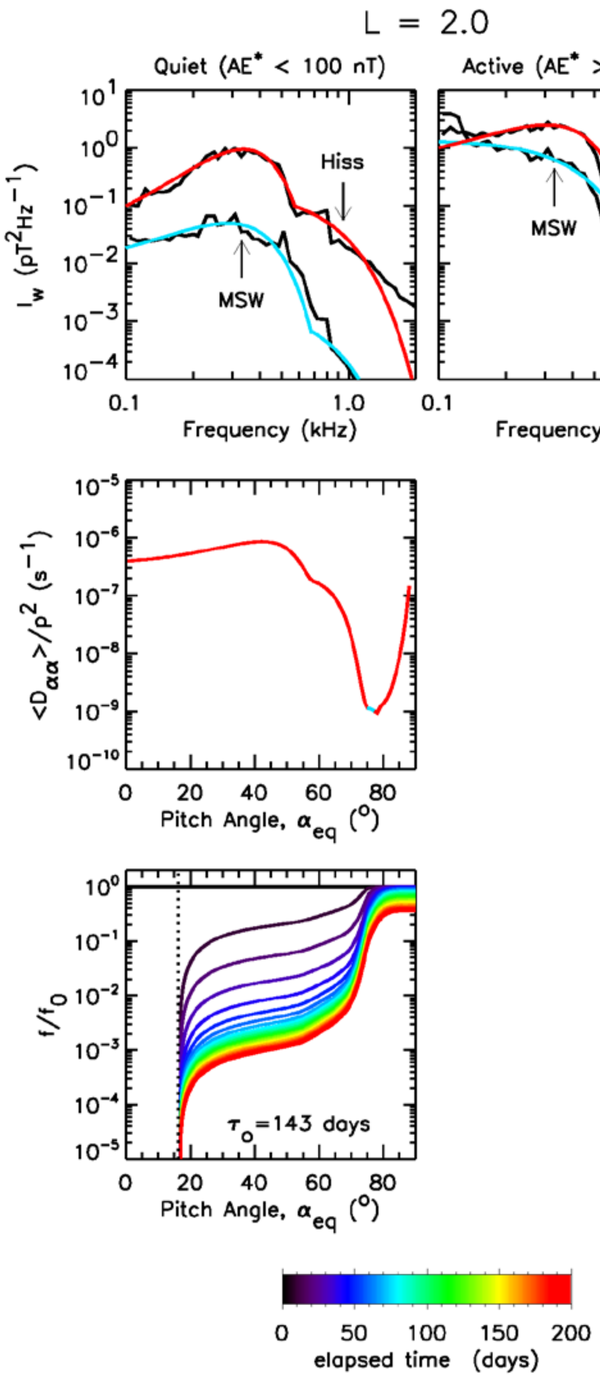
Horne *et al*., 2007



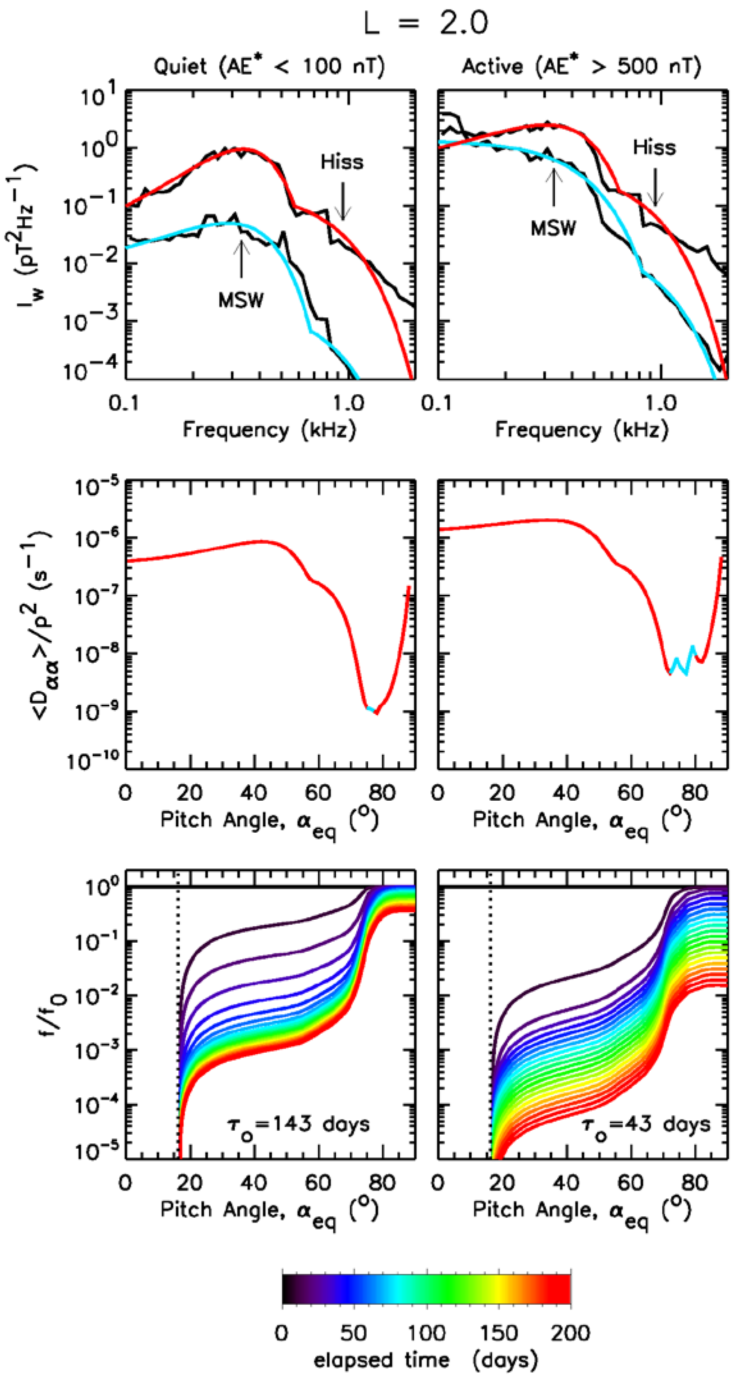
Losses due to MSWs

- We cannot uniquely identify MSWs in the CRRES data.
- We use global averages of the wave spectral intensity observed within $\pm 3^{o}$ of the equator as an estimate of the upper limit.

Losses due to MSWs

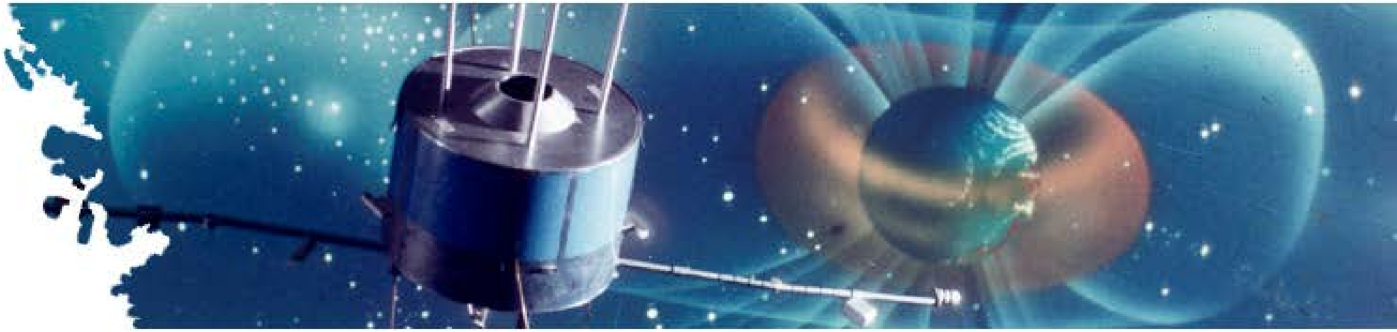


- During quiet conditions MSWs make only a small change to the diffusion rates at large pitch angles.
- The resulting lifetime of 143 days is too long to explain the observations.



Losses due to MSWs

- During active conditions MSWs increase the diffusion rates at large pitch angles.
- The resulting loss timescale is 43 days.
- MSWs could contribute to the loss timescales during active conditions.
- Better models of MSWs required to establish the role of these waves.



Conclusions

- Pitch angle scattering by plasmaspheric hiss is responsible for electron loss in the outer slot region ($2.3 < L < 3.0$)
- In the inner slot region ($2.0 < L < 2.3$) electron loss is driven by plasmaspheric hiss and lightning-generated whistlers.
- Magnetosonic waves may also contribute to electron loss at $L = 2.0$ but better wave models are required to determine the precise role of these waves.

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Loss Timescales for 2.0 < L < 4.0