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The Radiation Belts and The Plasmasphere

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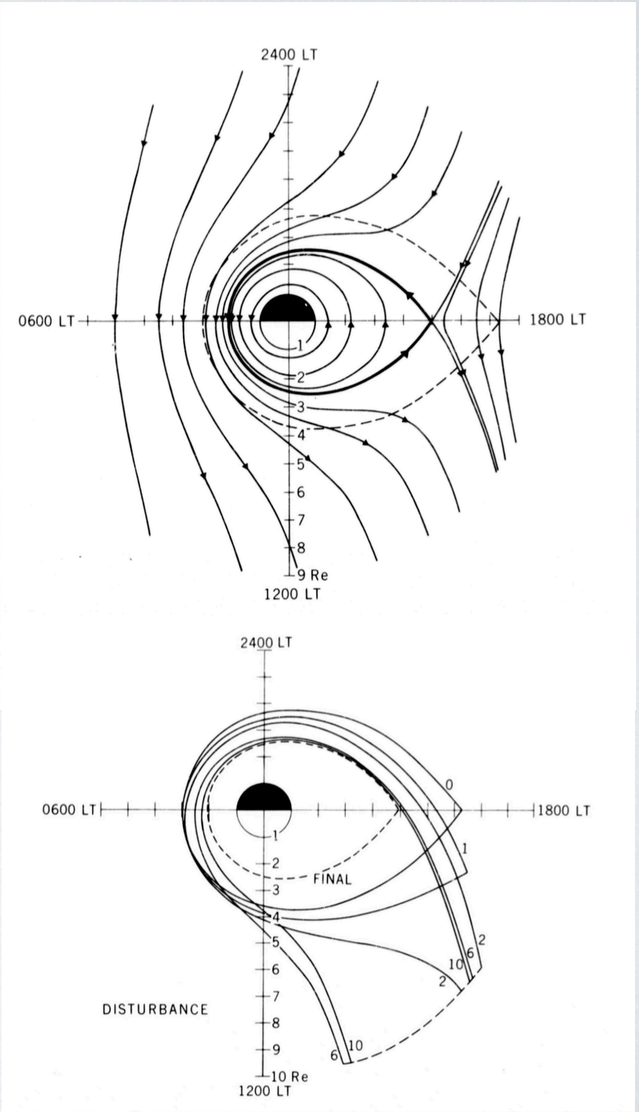
reeves research

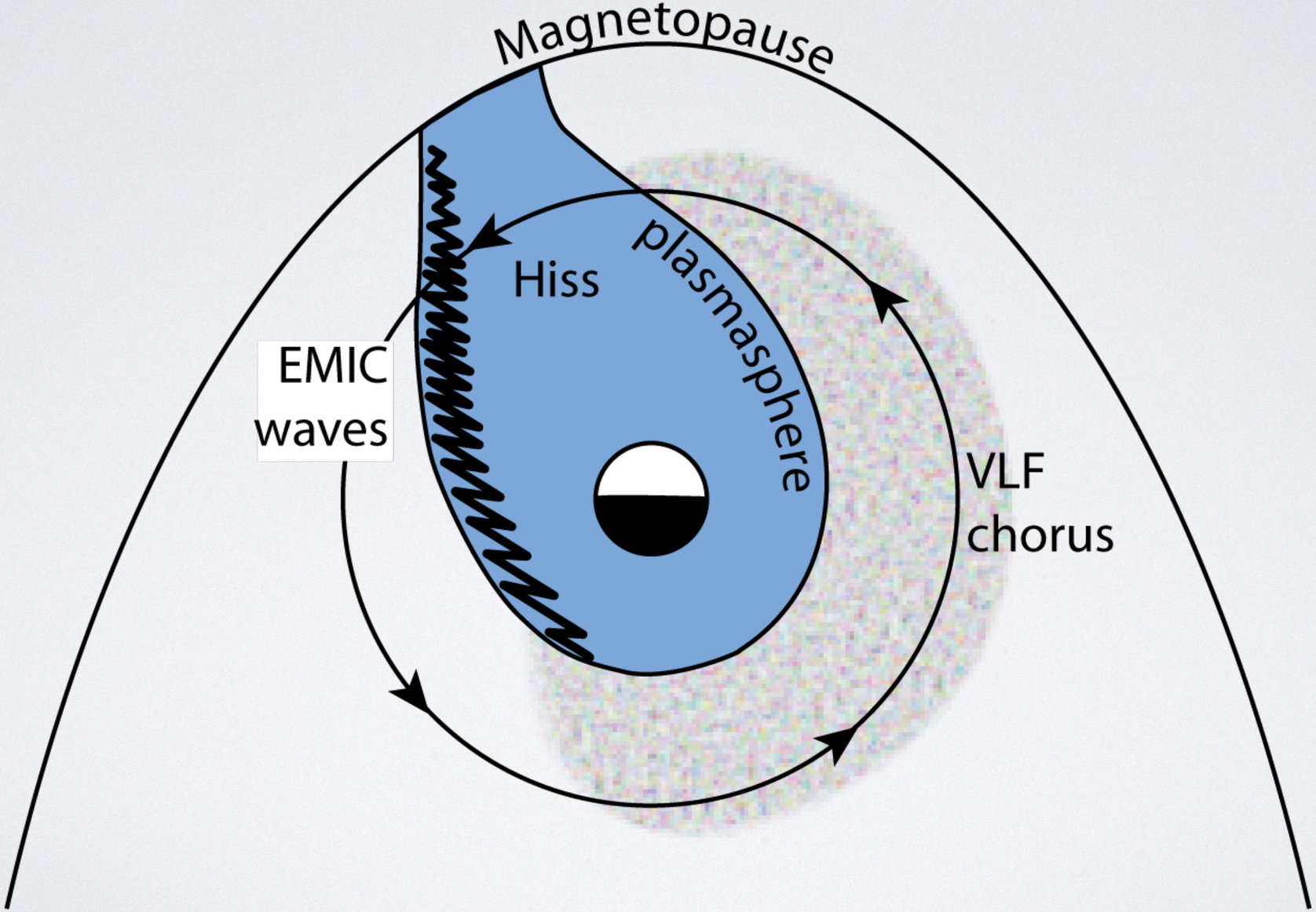
The Plasmasphere

- Cold: T ~ 1 eV
- Dense: N > 100/cc
- Quiet Time: Co-rotation region, ~ circular
- Active Times: Sunward convection forms plumes
- Return to Quiet: Refilling from the ionosphere

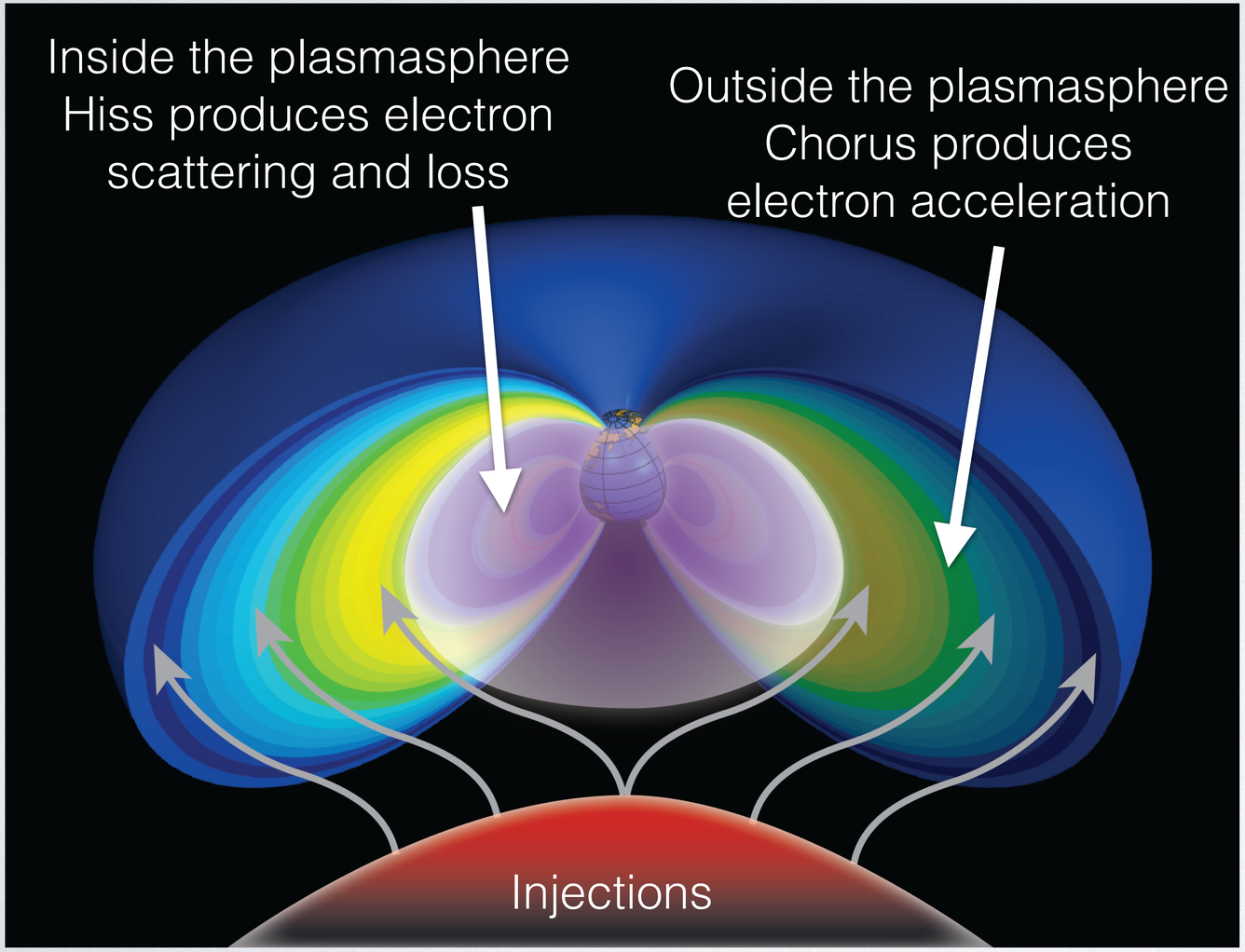


Grebowsky, JGR, 1970

Waves Inside and Outside the Plasmasphere



The Standard Picture

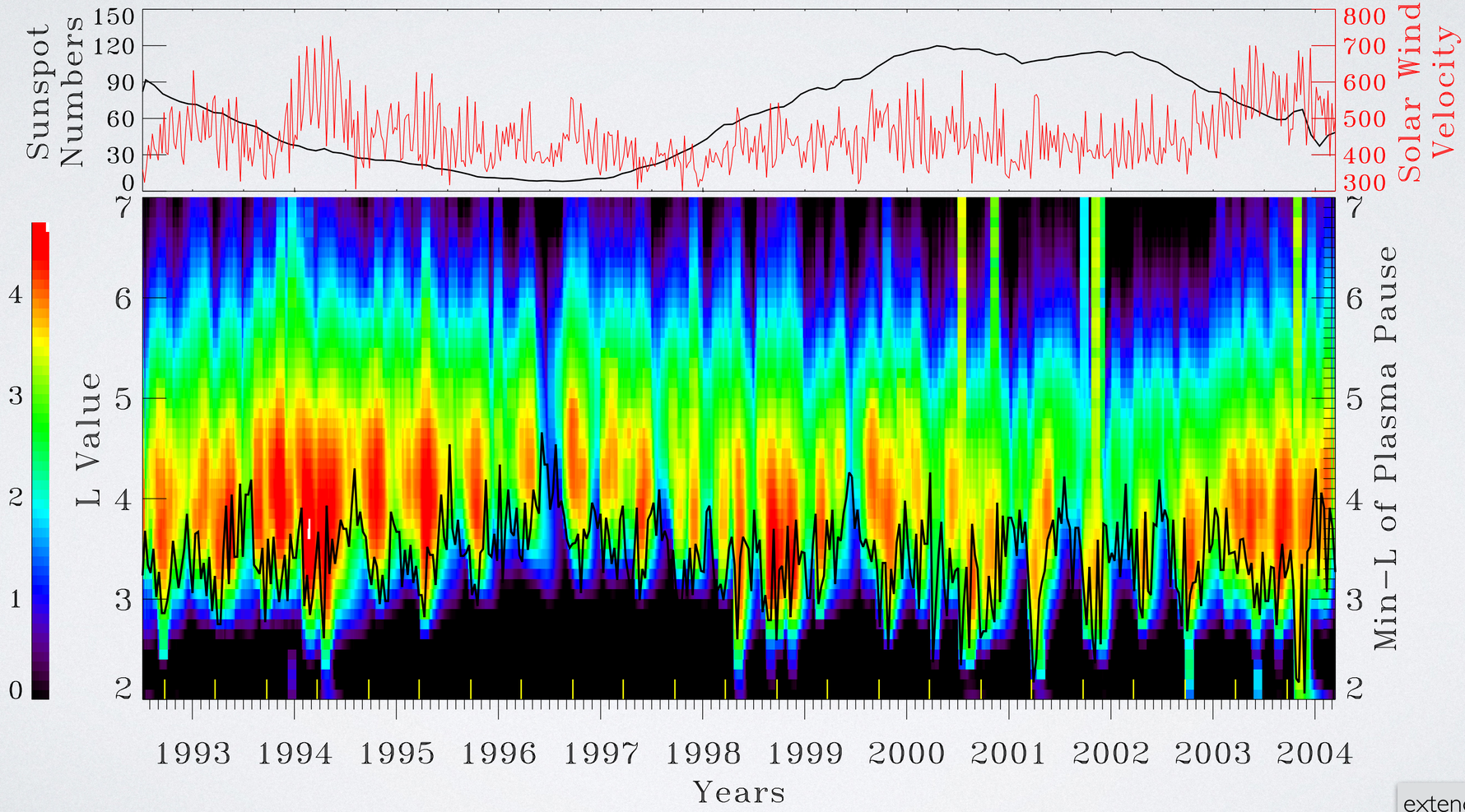


Electron injections produce the free energy to generate chorus (source electrons)

And the 100s keV particles that get accelerated to MeV energies (seed electrons)

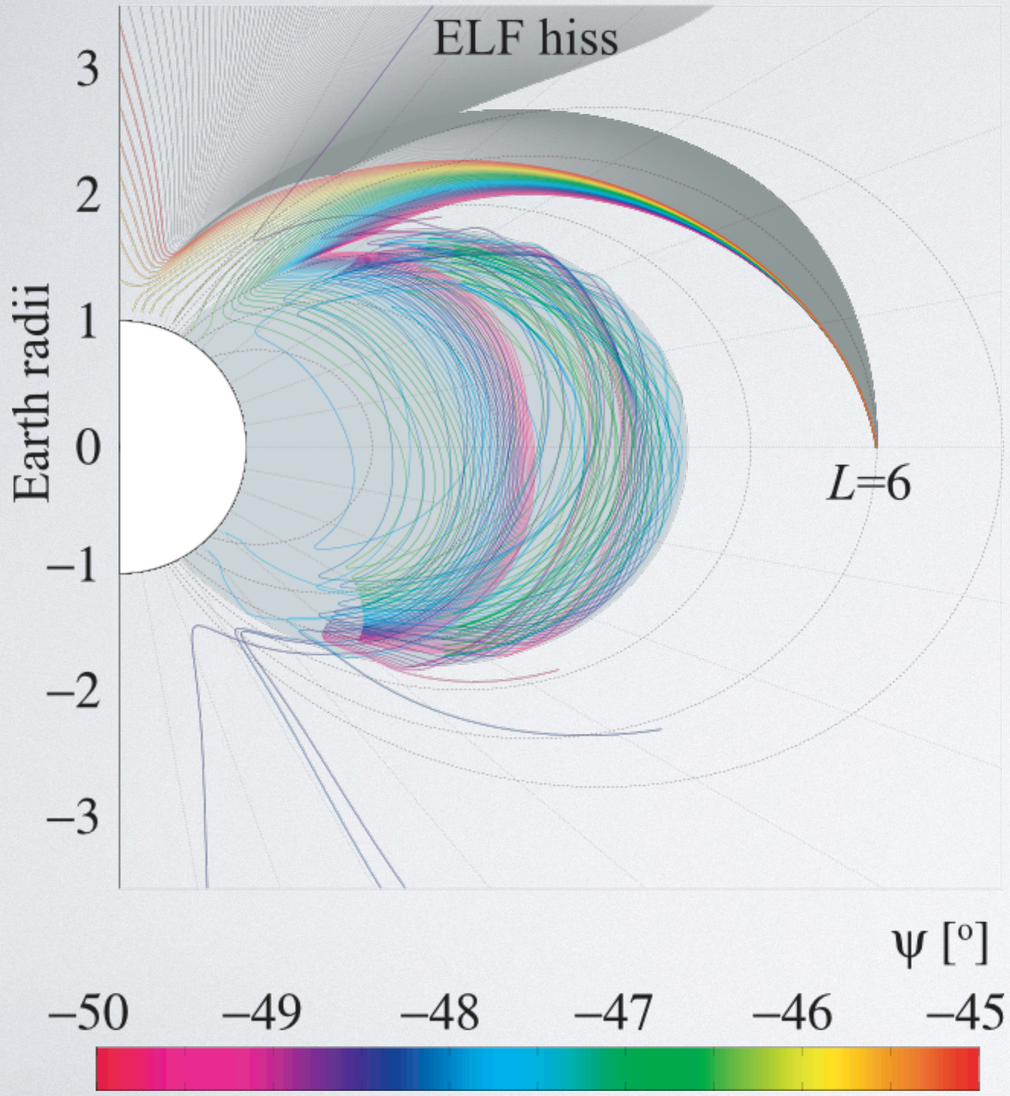
SAMPEX Observations

Radiation Belt enhancements are only observed outside the (model) plasmapause



extended from Li et al., GRL, 2001

Chorus and Hiss

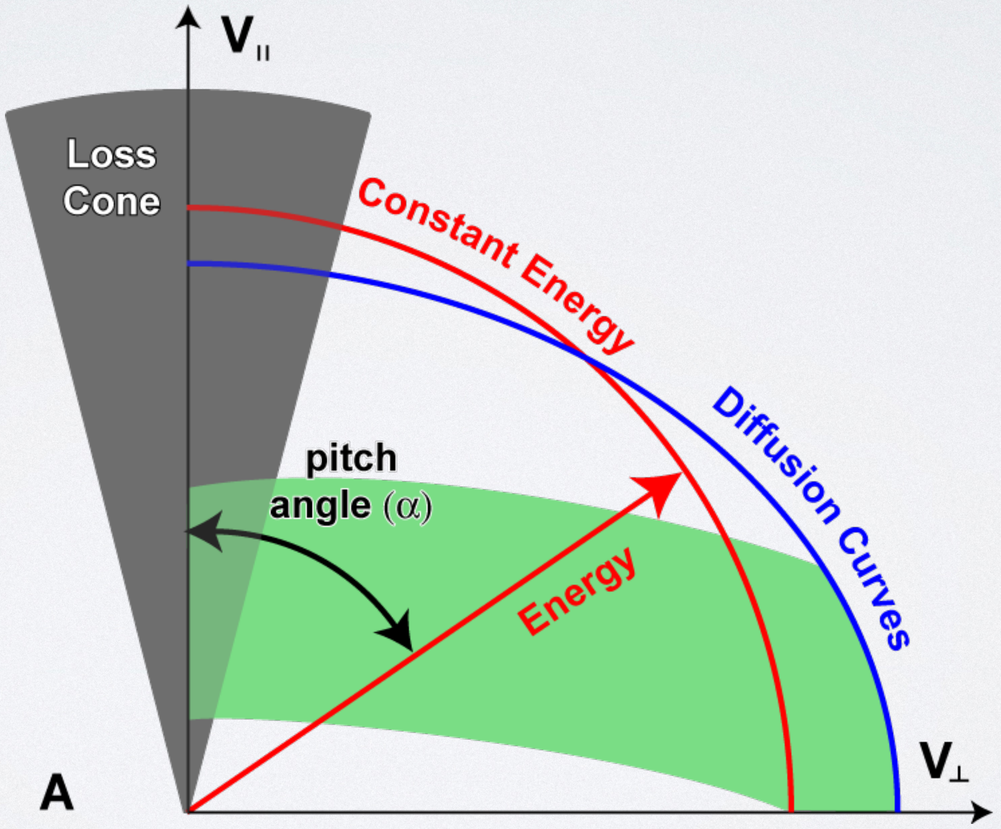


Bortnik et al., Science, 2009

- Hiss can be generated by lightning, local instabilities, or may be dominated by chorus that 'leaks' into the plasmasphere
- Chorus and Hiss are both whistler-mode waves
- Both interact with radiation belt electrons

Diffusion in Energy & Pitch Angle are Linked

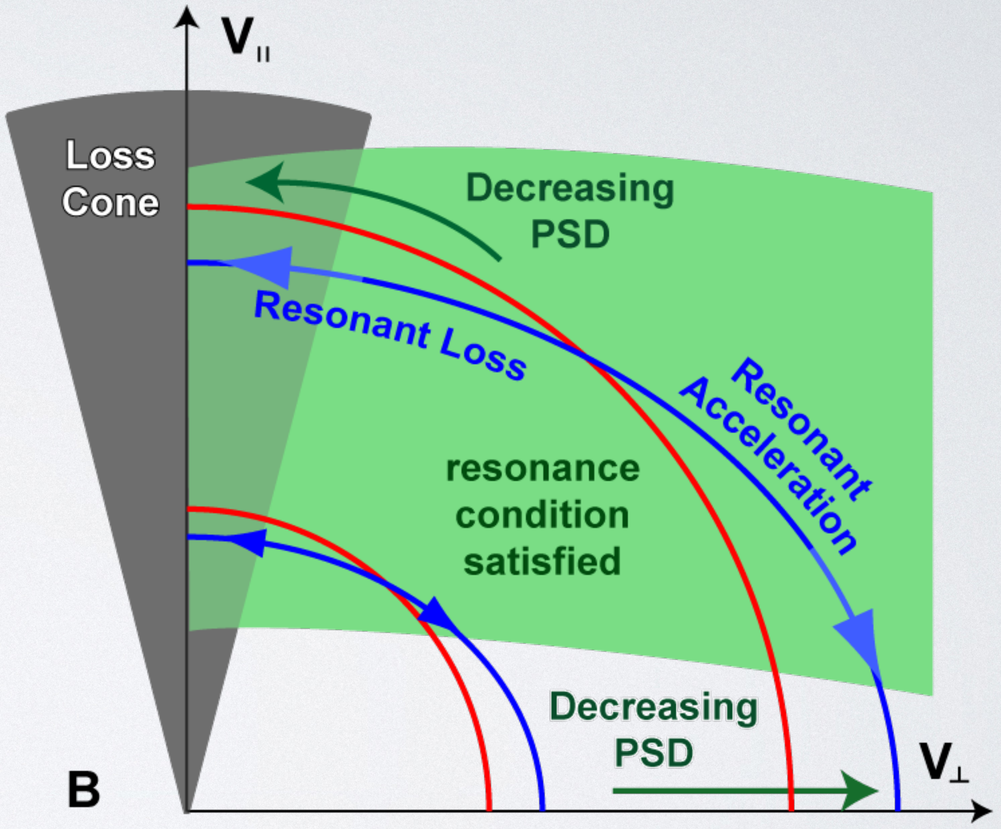
$$\frac{\partial f}{\partial t} = L^2 \frac{\partial}{\partial L}\left(D_{LL} L^{-2} \frac{\partial f}{\partial L} \right) + \frac{1}{p^2}\frac{\partial}{\partial p}\left(p^2 \left\langle D_{pp}(y,p) \right\rangle \frac{\partial f}{\partial p} \right) + \frac{1}{T(y)y}\frac{\partial}{\partial y}\left(T(y) y \left\langle D_{yy}(y,p) \right\rangle \frac{\partial f}{\partial y} \right) - \frac{f}{\tau}$$



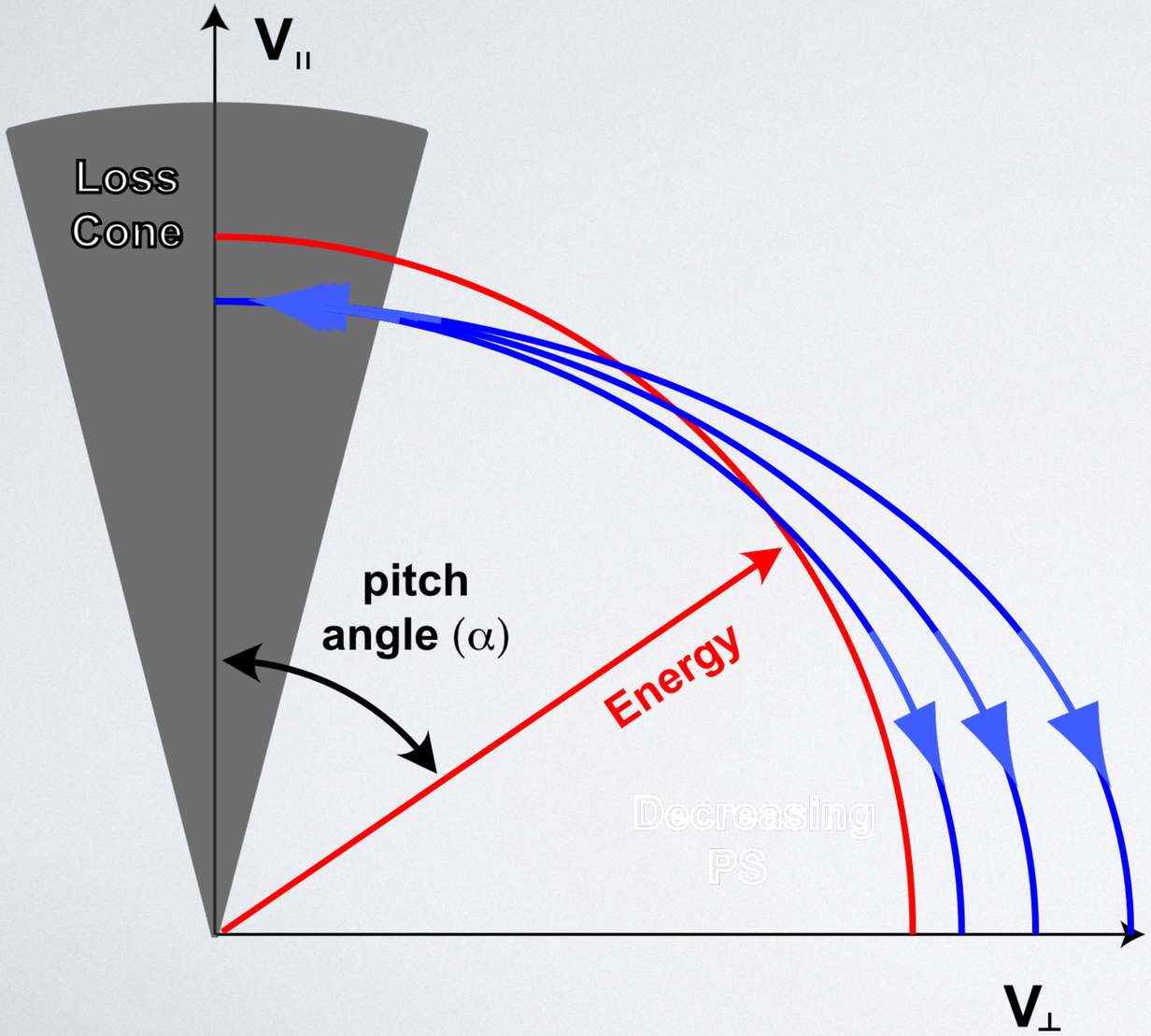
Reeves, Space Weather, 2009

Electrons ‘move’ both ways along the diffusion curve

- Diffusion always moves particles from regions of high phase space density (PSD) to low
- PSD is lower at higher energy (lower fluxes)
- PSD is lower in the loss cone (no electrons)



Density Controls the Dominant Effects



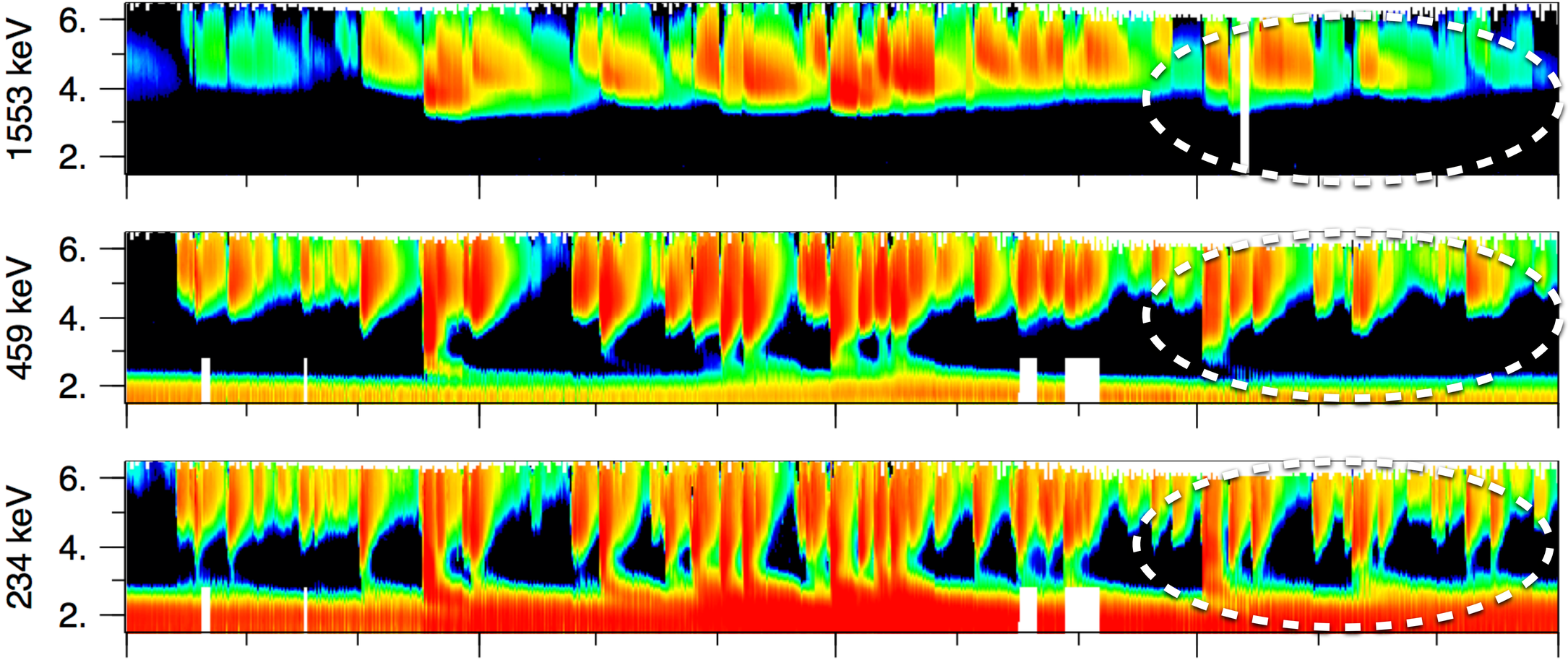
- The resonance conditions depend on the ratio of the cyclotron to plasma frequency
- Therefore the magnetic field strength and density
- More energization happens for lower densities: i.e. outside the plasmasphere

See Summers et al., JGR, 1998

So What's Wrong with the Standard Picture?

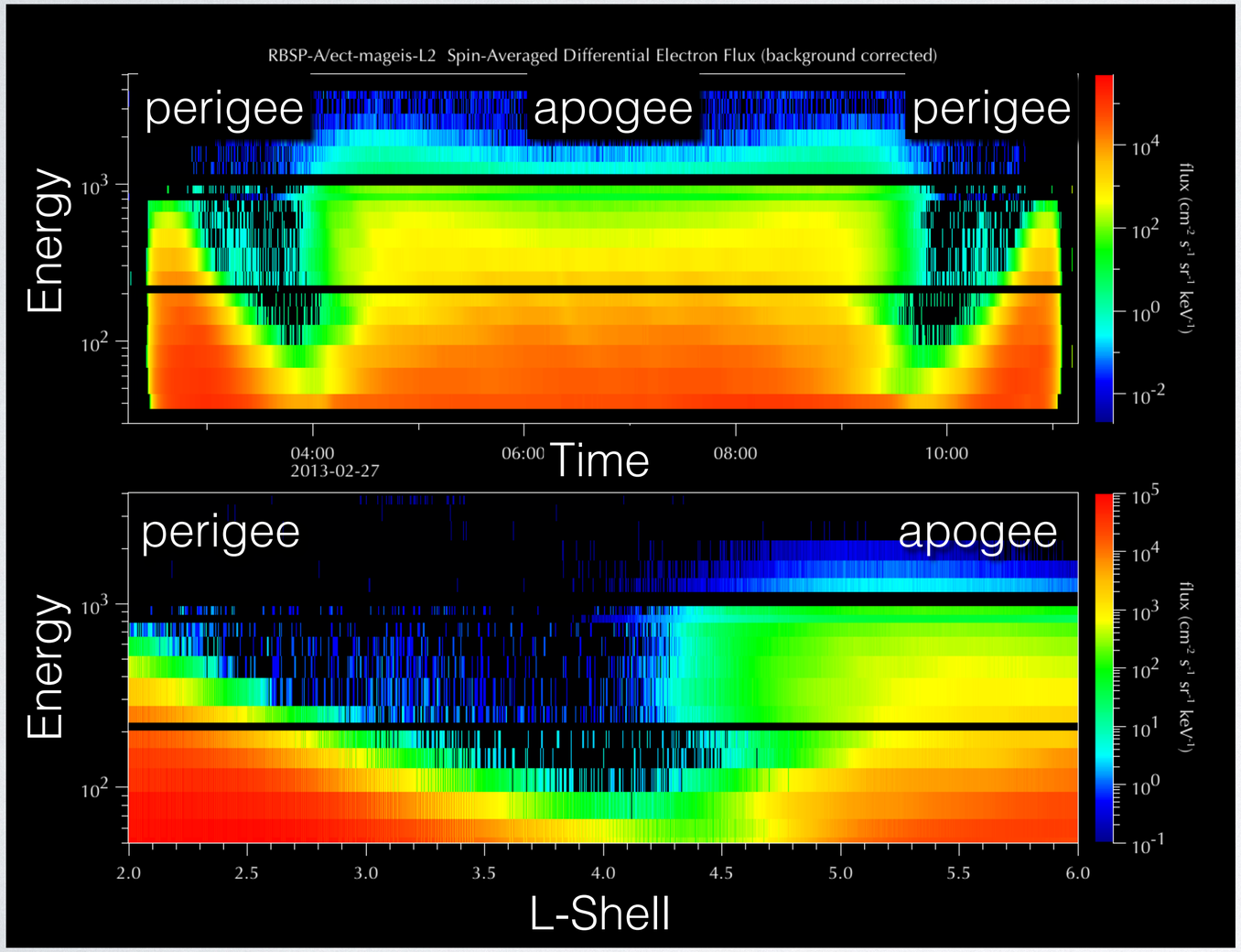
- There isn't a single 'boundary' to the inner edge of the outer electron belt. It is different for different energy electrons
- The close correlation of plasmapause and the outer electron belt is due to losses, not acceleration
- Injections **do** penetrate into the plasmasphere
- Chorus doesn't always accelerate electrons in the region with the highest ratio of cyclotron to plasma frequencies
  i.e. **not** right outside the plasmapause

The Energy-Dependent Radiation Belts



Reeves et al., JGR, 2016

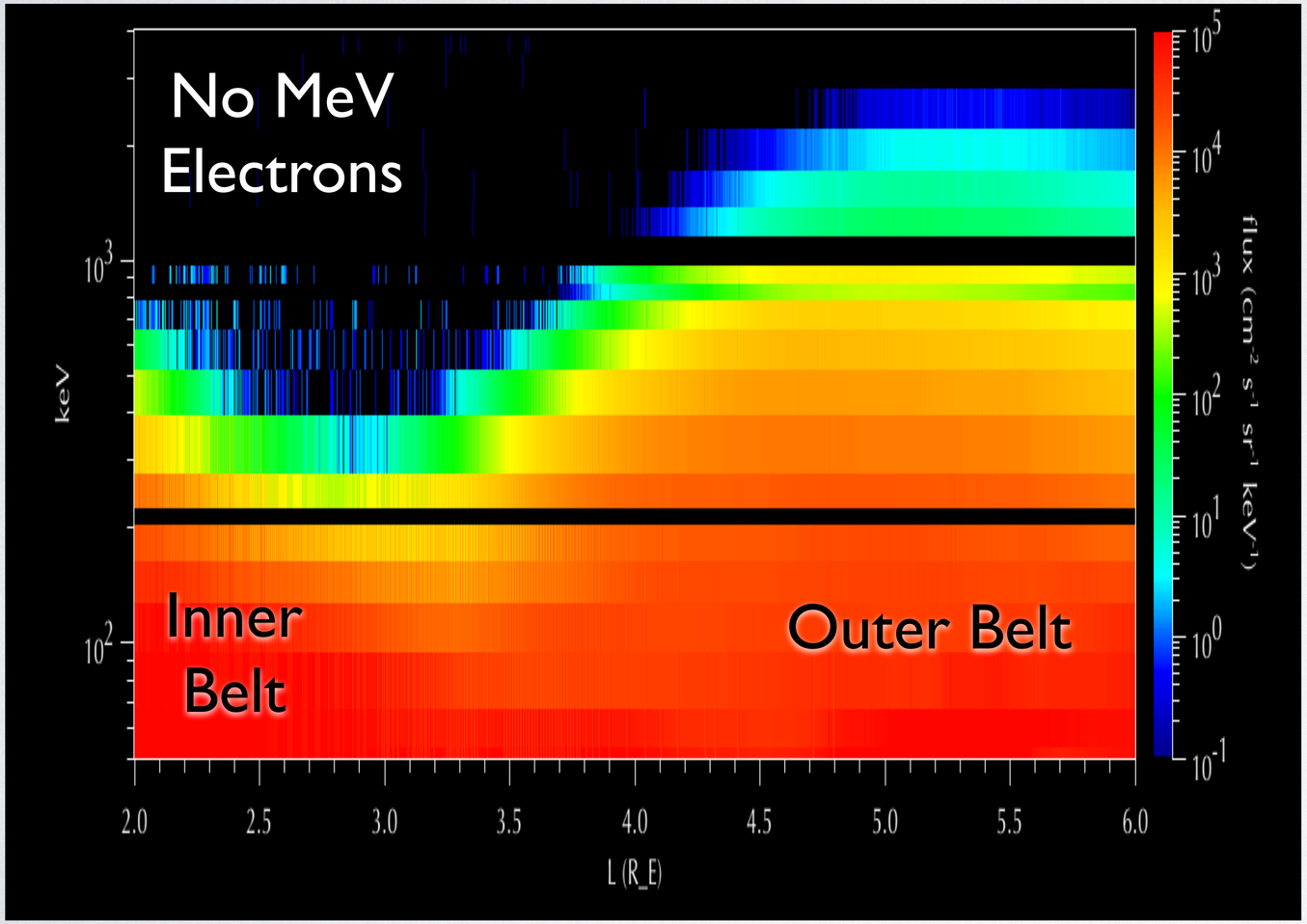
The Radiation Belts in L-shell and Energy



- Standard spectrograms plot flux as a function of energy and time
- For Van Allen Probes we can turn that into plots of flux as a function of energy and L-shell

Reeves et al., JGR, 2016

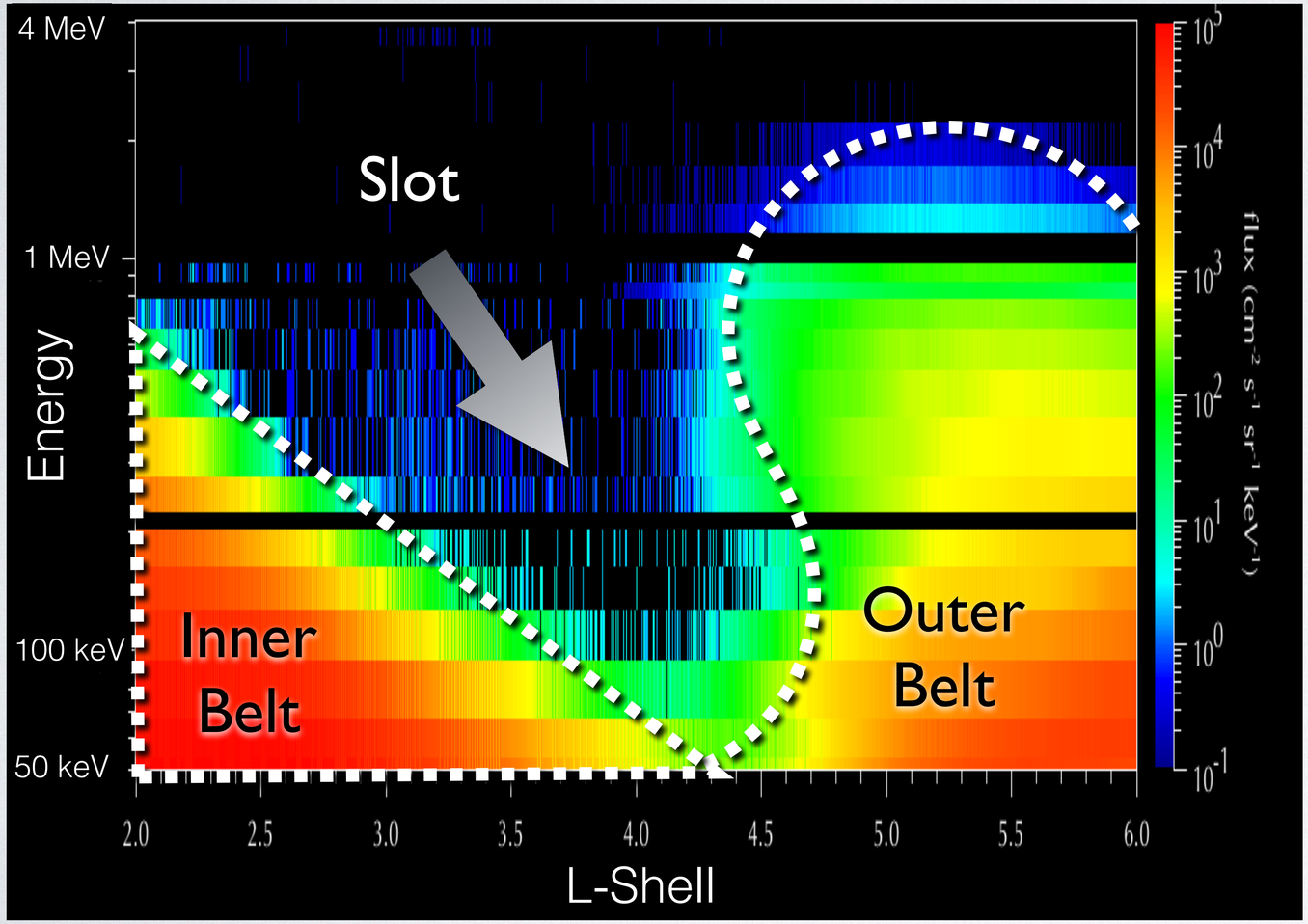
The Storm-Time Enhanced Belts



- This is a single 4.5 hr pass of Van Allen Probes through the radiation belts
- Time is the peak of an electron enhancement
- Where are electrons enhanced?
- Where is the plasmapause?

Reeves et al., JGR, 2016

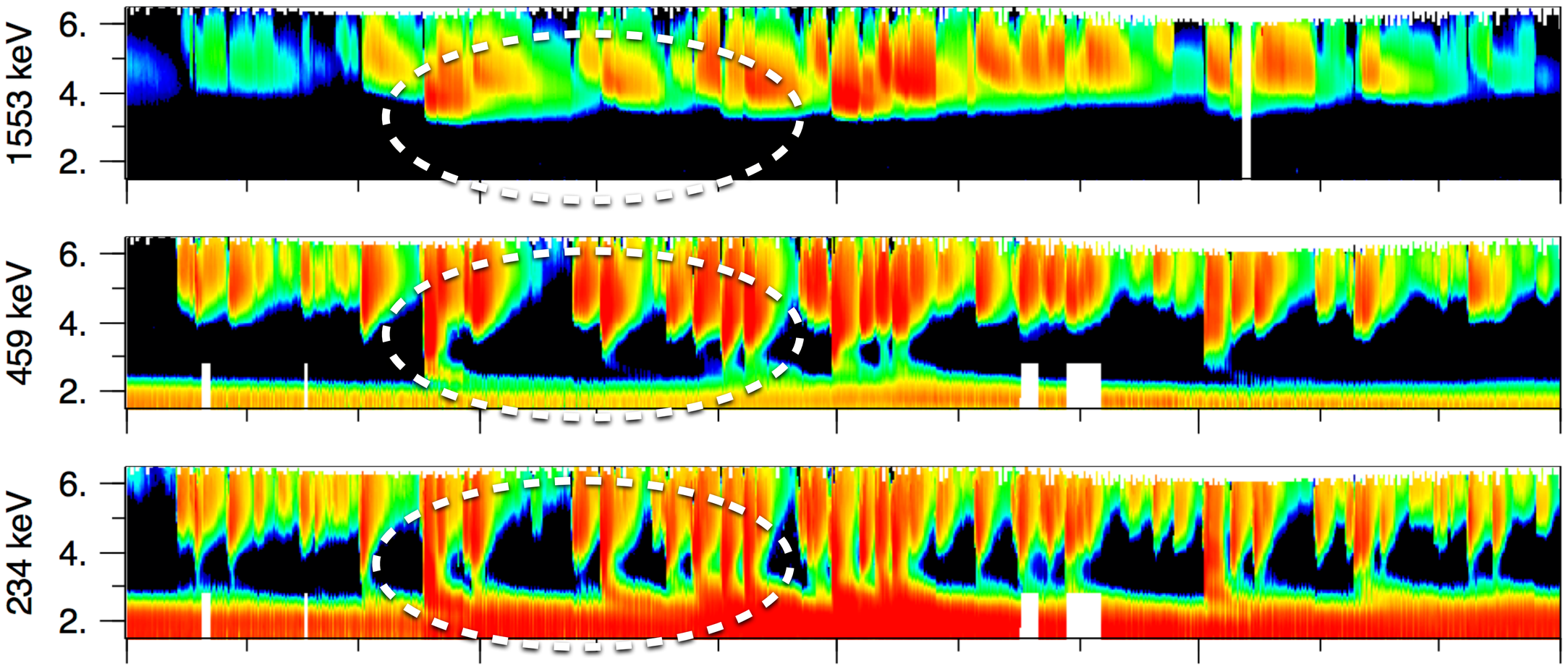
The Quiet-Time Belts



- The slot gradually forms inside the plasmasphere due to scattering by hiss
- Scattering lifetimes are both energy and L-shell dependent so the slot is too
- Ripoll et al., 2016 reproduced this theoretically

Reeves et al., JGR, 2016

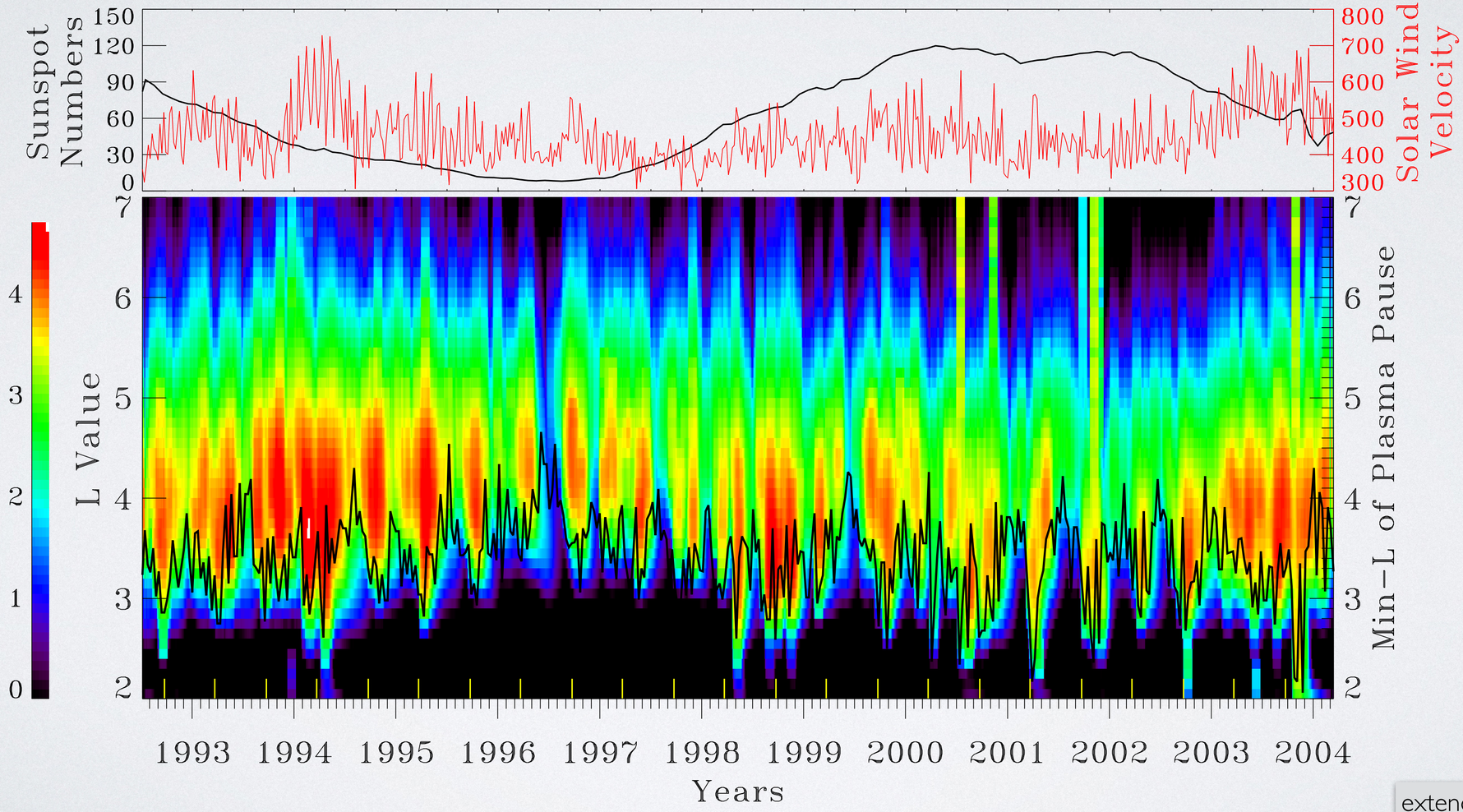
Higher Energy and Higher L Decay More Slowly



Reeves et al., JGR, 2016

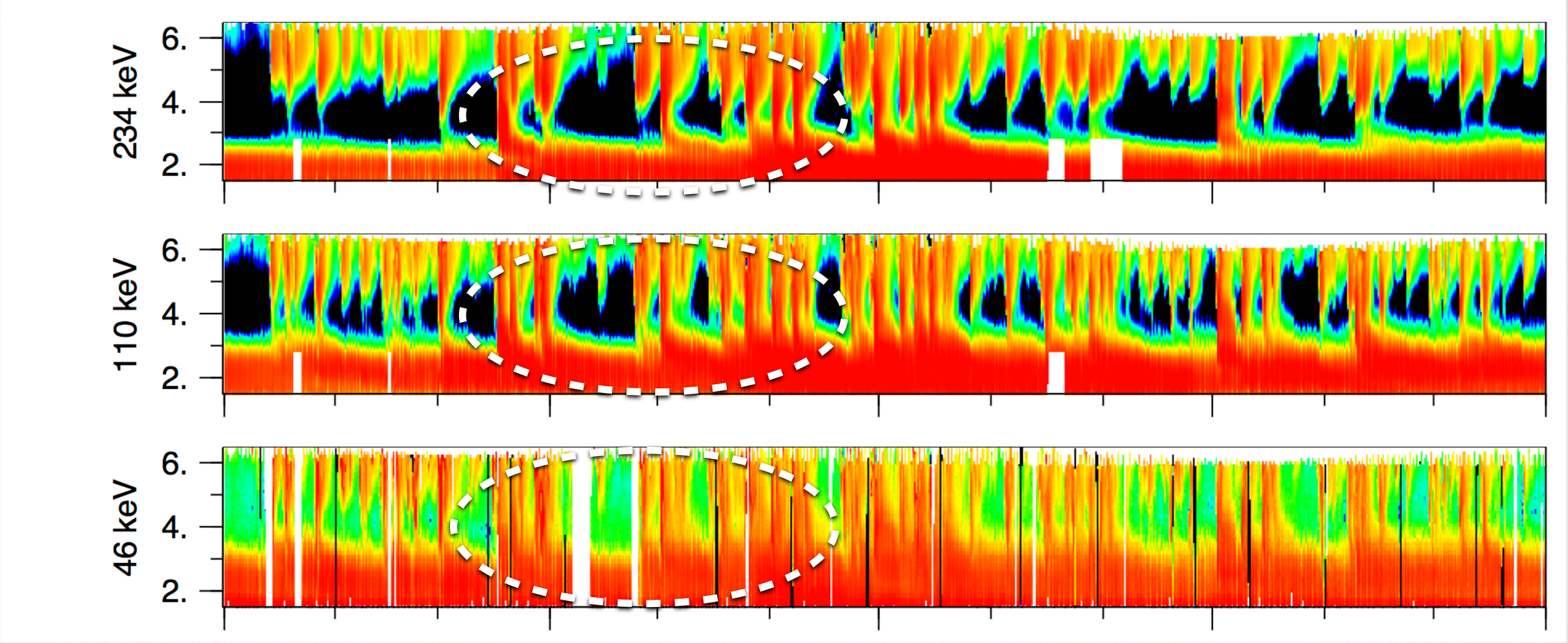
This Correlation is Due to Losses

These are 30-day averages so they are dominated by quiet times



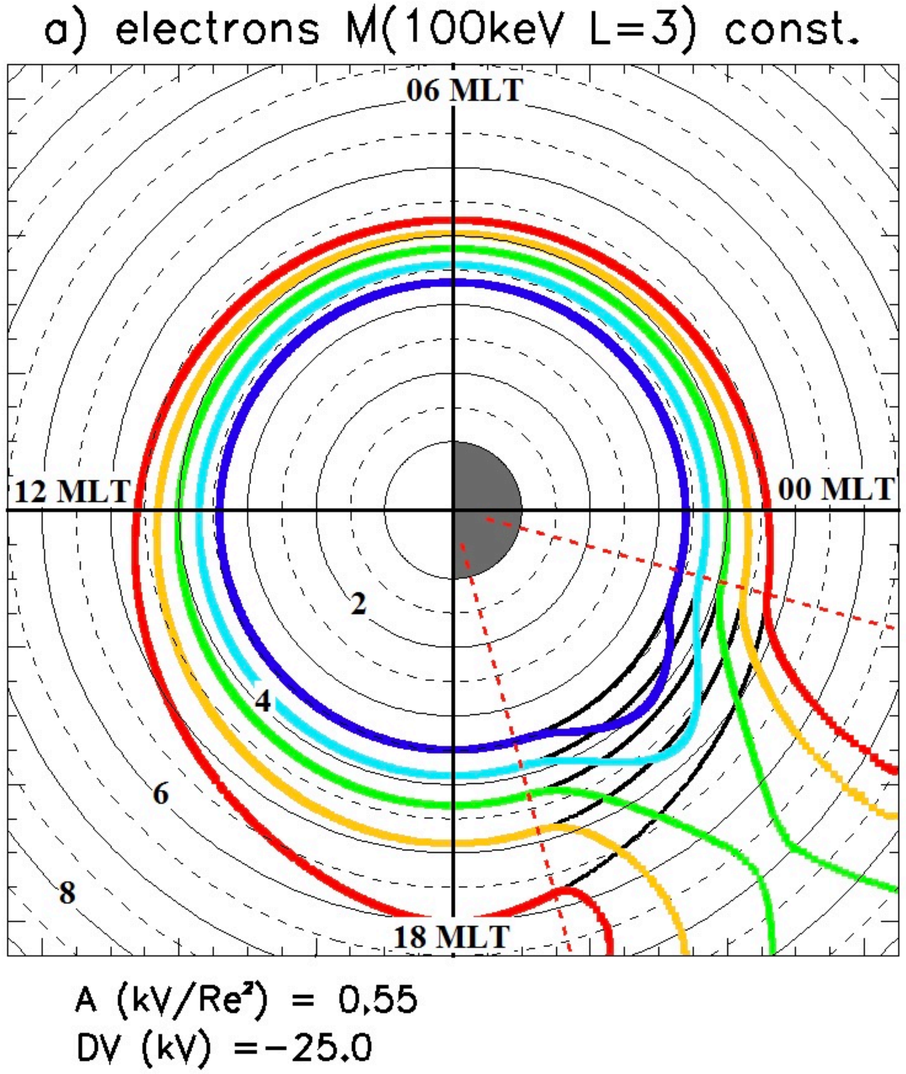
extended from Li et al., GRL, 2001

Injections Do Penetrate into the Plasmasphere



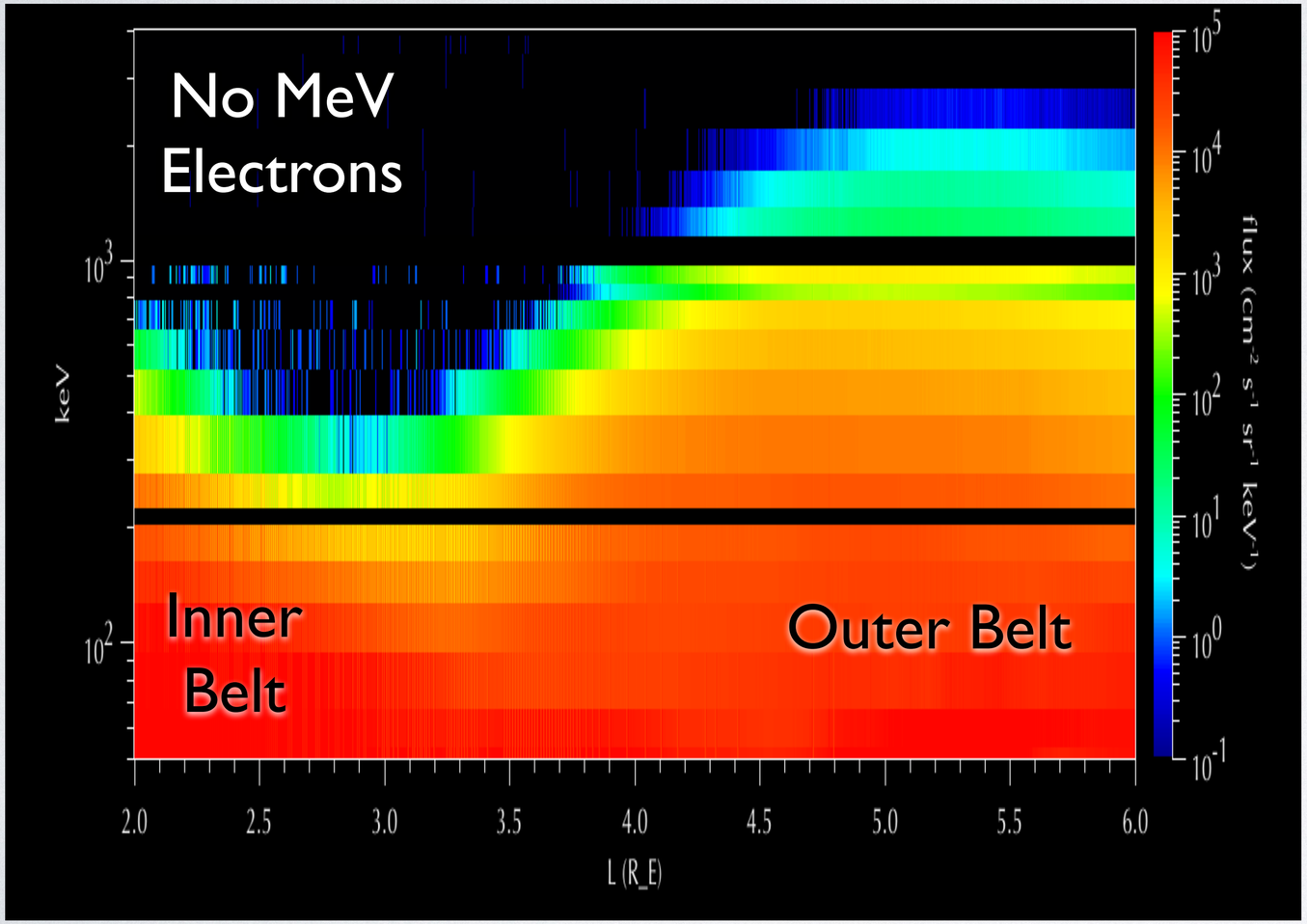
Reeves et al., JGR, 2016
see also Turner et al., JGR, 2015

Storms and SAPS



- Lejosne et al., 2018 showed that Sub-Auroral Polarization Streams (SAPS) open access to low L
- Low energy particles get to lower L
- SAPS are also related to SAID, SA-Red Arcs, and STEVE
- They are a storm phenomenon, not a substorm phenomenon

The Storm-Time Enhanced Belts

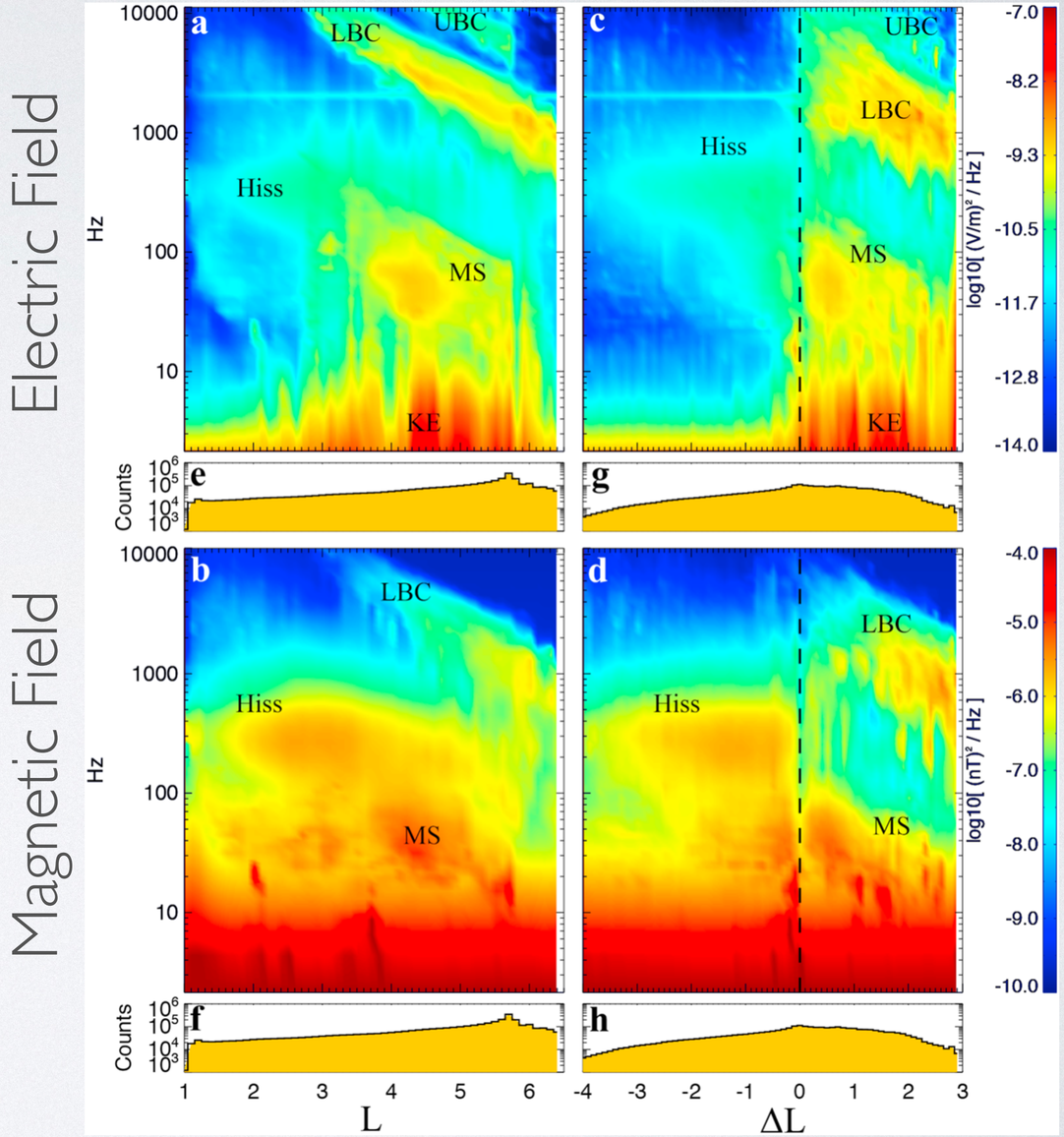


- Reeves et al. 2016 did not analyze where the plasmapause was located during the studied events
- Let's do that now

Reeves et al., JGR, 2016

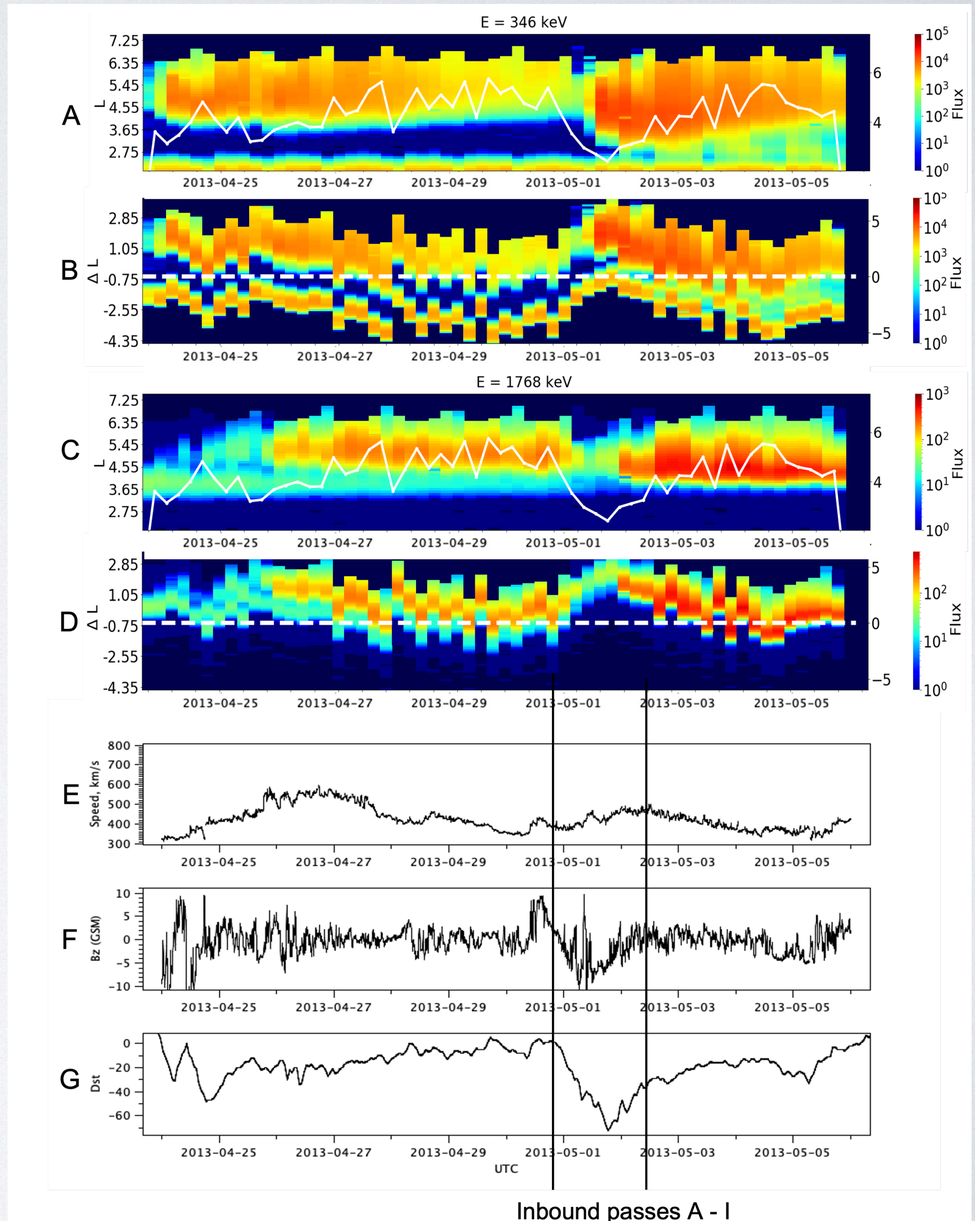
The Plasmapause is an Excellent Boundary for Waves

- Malaspina et al., 2016 found that sorting wave power by L showed lots of overlap
- But sorting by $\Delta L = L - Lpp$ organized the waves very well at all activity levels
- LBC = lower band chorus

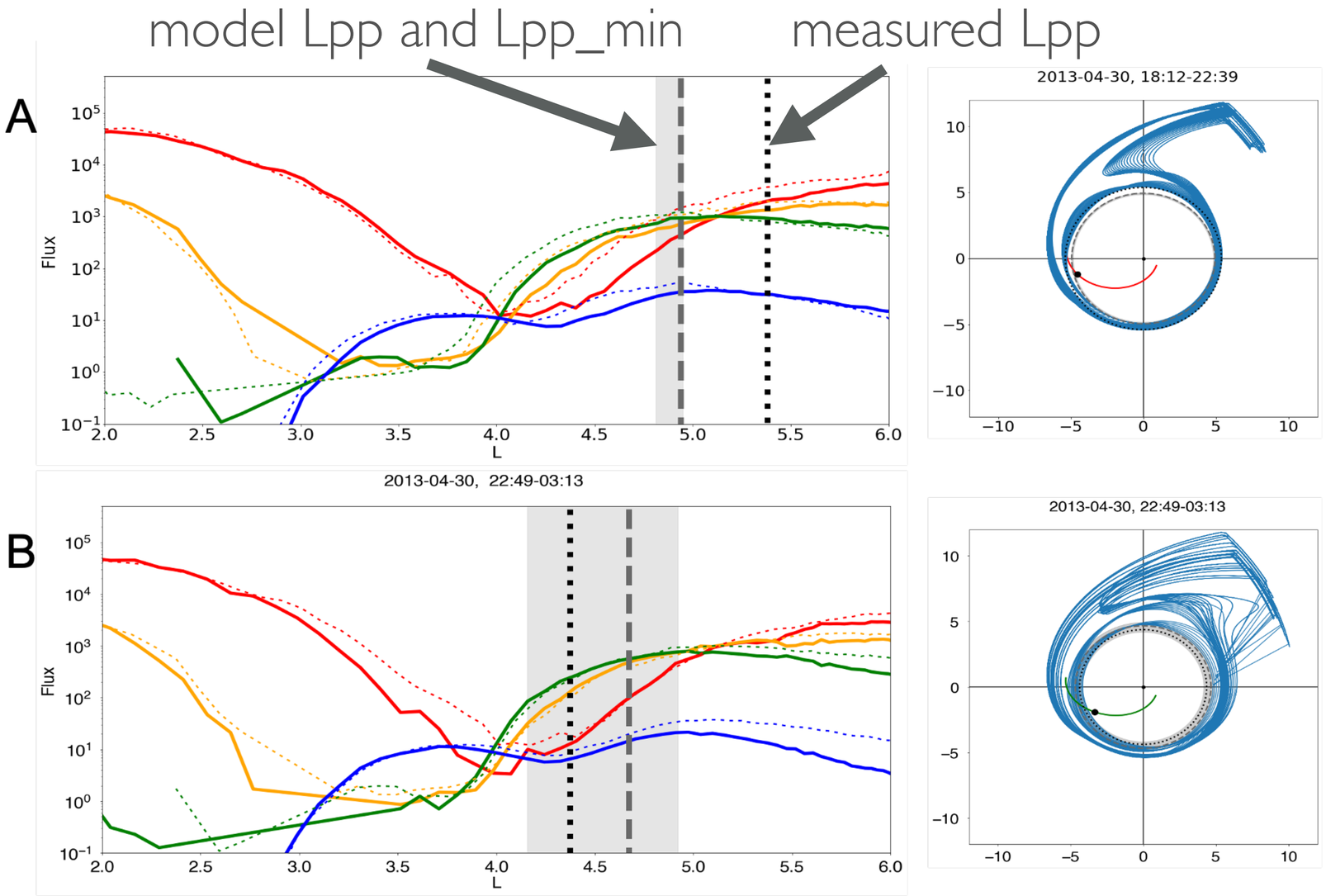


That is Not True for Radiation Belt Fluxes

- Theory says chorus should accelerate most efficiently just outside the plasmapause where $\omega_{ce} / \omega_{pe}$ is large
- But Voskresenskaya & Reeves (submitted) find that $\Delta L = L - Lpp$ does not organize radiation belt fluxes well
- At quiet times (without averaging) this makes sense due to different lifetimes

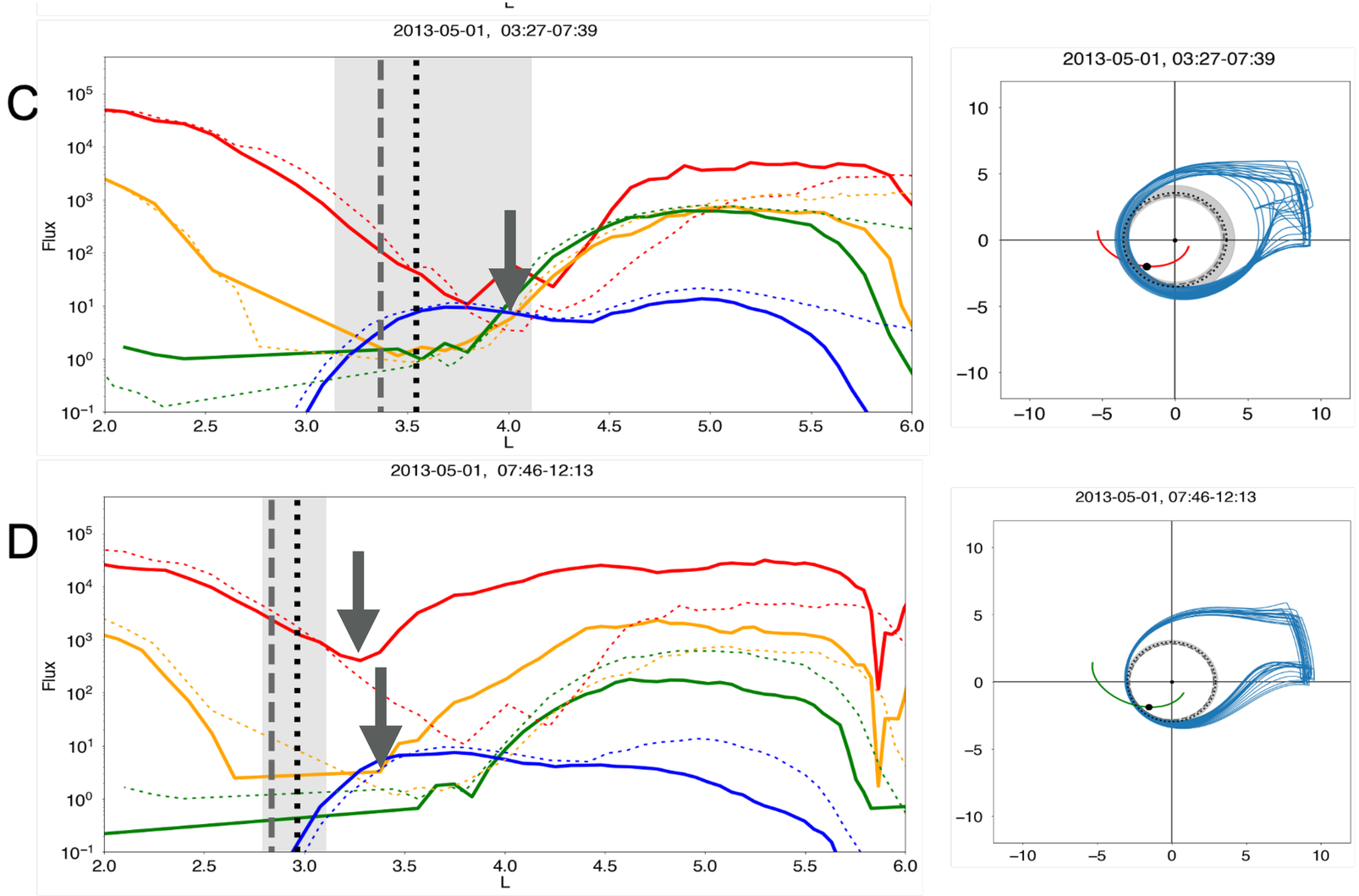


Pass-by-Pass (2.25 hrs) in the Acceleration Phase



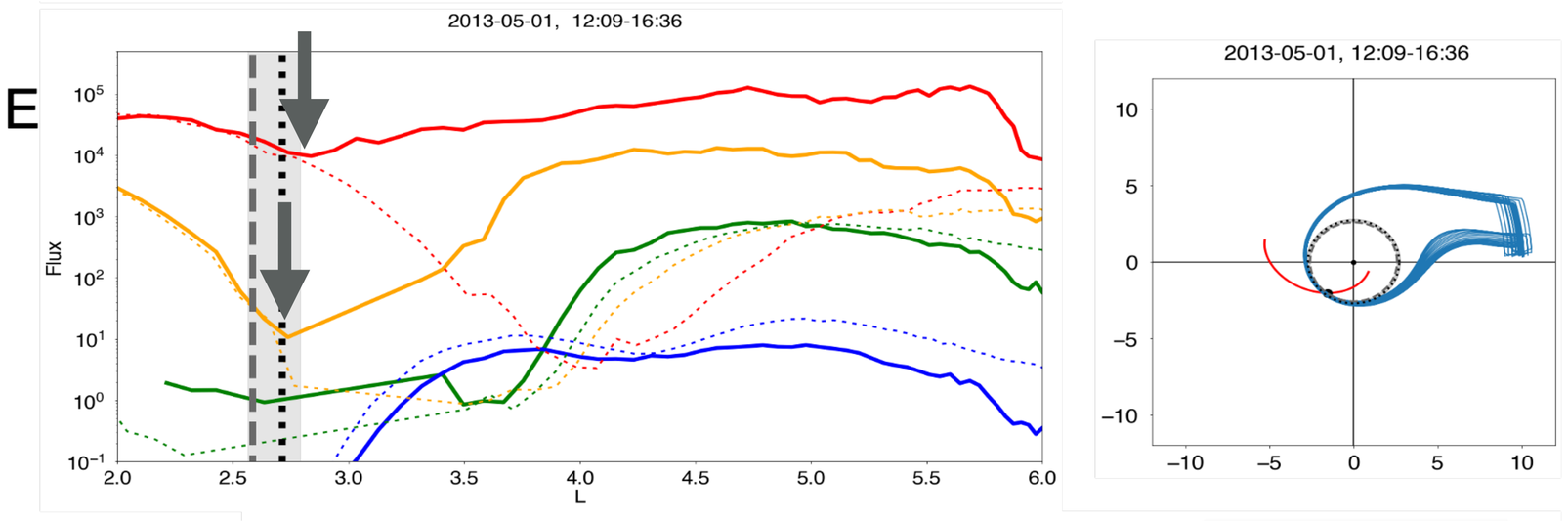
- Left: fluxes
  141 keV - 2.5 MeV
- Right: Goldstein plasmapause model
- Dotted fluxes = previous pass

Pass-by-Pass (2.25 hrs) in the Acceleration Phase



- For each 2.25 hr inbound pass, compare solid and dotted lines
- Arrows mark minimum L where enhancements occurred (if any)
- High energy fluxes decreasing

Pass-by-Pass (2.25 hrs) in the Acceleration Phase



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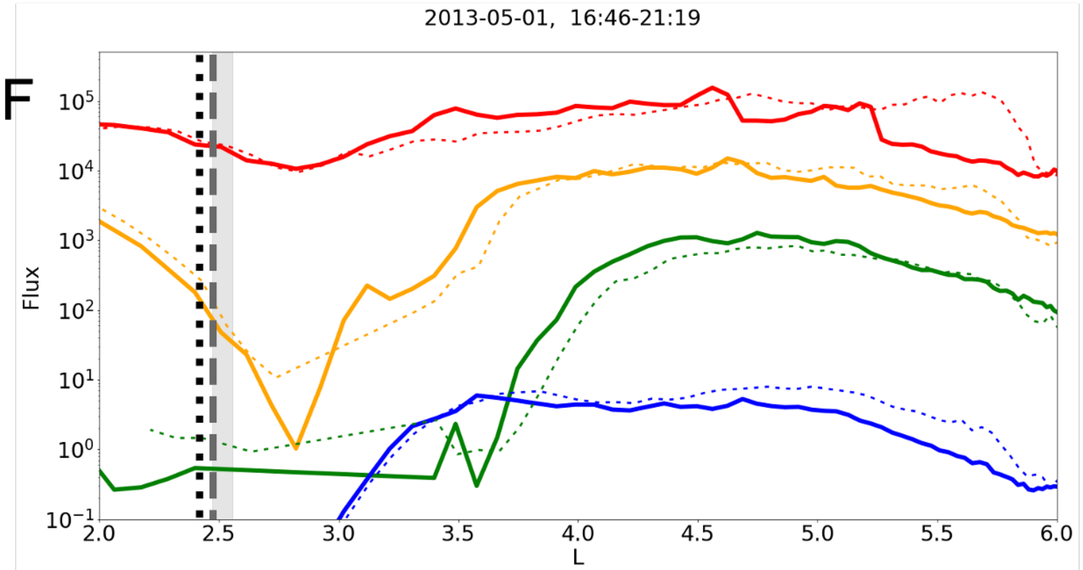
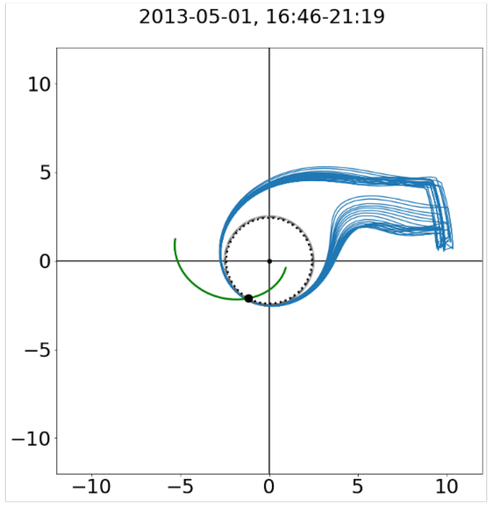
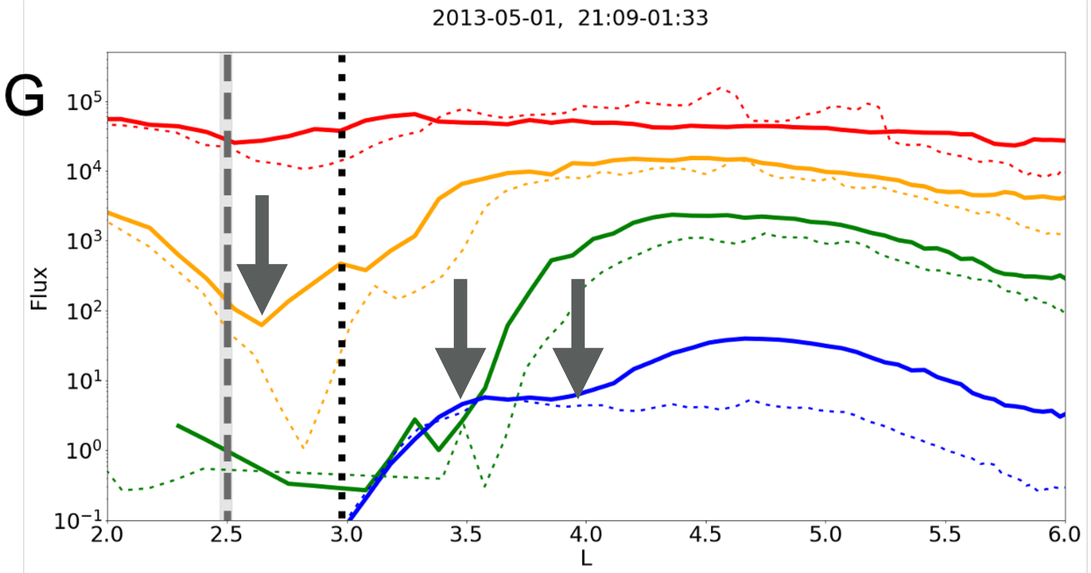
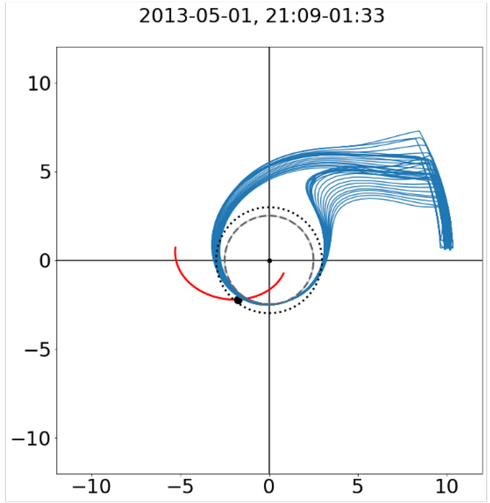
Early Recovery Phase



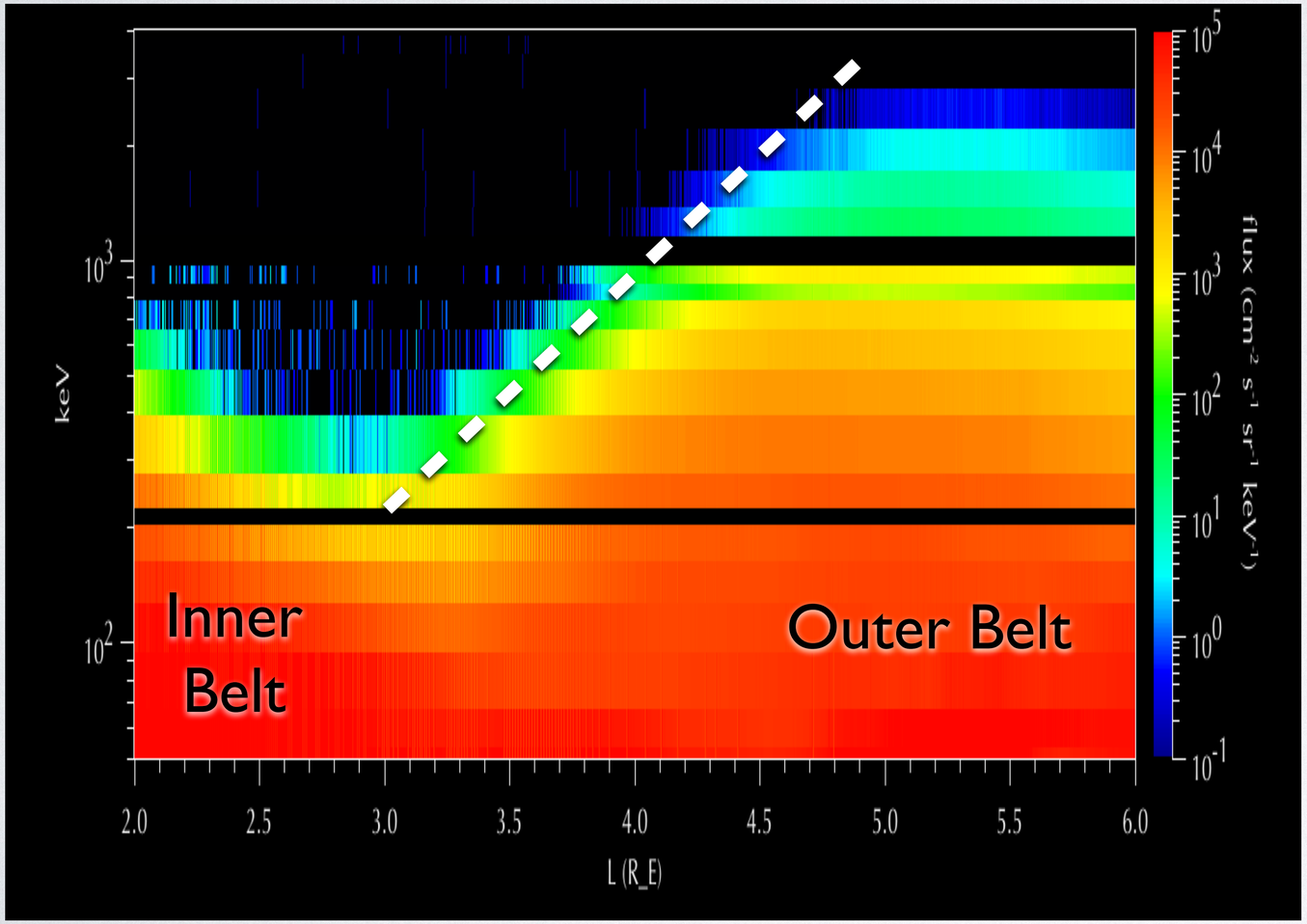






- Pass F:
  little happens
- Pass G:
  First enhancements of 0.9 and 2.5 MeV electrons
- Higher energies only appear at higher L

This Occurs in Essentially All Events



- Next Steps:
- Look at PSD
- See if simulations produce the same Energy - L dependence

Reeves et al., JGR, 2016

Conclusions

- The ‘standard picture’ of the radiation belts and plasmasphere organizes observations fairly well in many aspects
- Waves and wave particle interactions are fairly well understood
- Scattering by hiss explains energy and L-dependent losses but primarily after the plasmasphere has expanded to cover most of the outer belt
- The location of enhancements with respect to the plasmapause and the dependence on energy is a bit of a puzzle to me
- There is still much to learn about the plasmasphere and radiation belts