The inward radial diffusion and slow decay of energetic electrons in the Earth’s radiation belts

Qianli Ma (qianlima@atmos.ucla.edu), Wen Li, Richard M. Thorne, and Binbin Ni
University of California, Los Angeles

• **March 2013**: a remarkable case for **quiet-time** gradual diffusion study.

• *During 06 – 16 March:*
  a) Geomagnetically quiet condition indicated by $B_z$, pressure, and $Dst$ index;
  b) Weak dayside **chorus** waves;
  c) Modestly strong dayside **hiss** waves;
  d) Weak $\sim 100$ keV electron **injections** in association with chorus activities;
  e) Gradual diffusion of 3.6 MeV electrons.
Electron flux observed by Van Allen Probes
(*pitch angle = 90°*)

- **a)** Radial peak of 3.6 MeV electron flux moved from $L^* = 4.5$ to 4 in 10 days;
- **b)** Electron fluxes decreased by $\sim 1$ order in 10 days.
- **c)** Coupling of pitch angle scattering and radial diffusion is required.
Radial diffusion coefficients \((D^{E}_{LL}+D^{M}_{LL})\)

[Brautigam and Albert 2000 JGR]

Electric field fluctuation:

\[
D^{E}_{LL} = \frac{1}{4} \left( \frac{cE_{rms}}{B_o} \right)^2 \left[ \frac{T}{1 + (\omega_D T/2)^2} \right] L^6,
\]

\[
\omega_D = \left( \frac{3Mc}{eL^2R_k^2} \right) \left( 1 + \frac{2MB}{E_o} \right)^{-1/2},
\]

\[
E_{rms}(Kp) = 0.26(Kp-1) + 0.1 \text{ mV/m, } Kp=1 \text{ to } 6.
\]

Magnetic field fluctuation:

\[
D^{M}_{LL}(Kp,L) = 10^{0.506Kp - 0.325} L^{10}, \quad Kp=1 \text{ to } 6,
\]

Timescale for 1 MeV electron at \(L = 5\) is 14 days.
- The $< \sim 1$ MeV electron lifetime due to hiss scattering is **tens of days**.
- Lifetime of $\sim 3.6$ MeV electron due to hiss scattering is **hundreds of days**.
- **EMIC wave intensity** is $B_w^2 = 0.1 \text{ nT}^2$.
- EMIC wave distribution is from Meredith et al. [2014].
- The $> 1$ MeV electron lifetime due to EMIC scattering is **several days** when $Kp \geq 2$. 
- Consistency:
  a) Inward diffusion by $\sim 0.5\, R_E$ in 10 days;
  b) Decay of electron flux by $\sim 1$ order in 10 days.

- No EMIC: $3.6\, MeV$ electron flux intensifies when diffusing inward.
Conclusions

• The Van Allen probes have provided ideal observation of the gradual diffusion of energetic electrons in March 2013.

• The radial diffusion in our simulation produces L-time profiles of energetic electrons consistent with observations.

• The global plasmaspheric hiss model provides reasonable loss rates for the electrons below ~1 MeV, and causes the observed flattened pitch angle distributions.

• The weak EMIC wave activity based on the statistical results is able to account for the loss of the electrons above ~1 MeV.
Plasmaspheric hiss wave amplitude

**THEMIS**
- $B_w > \sim 20$ pT near noon.

**Van Allen Probes**
- $B_w \sim 10$ pT near nightside.
• Hiss $B_w$ are inferred from the local observations and quiet-time statistical ratios.
• $B_w$ are updated every 6 h.
• $B_w$ averaged over the 10-day period between 4 and 5 $R_E$ is 18 pT.
• Pitch angle distributions at \( L = 4.5 \) 
(0.5 – 1 MeV)
• EMIC waves cannot scatter lower energy electrons.

'Radial' overlaps with 'Radial+EMIC', 'Full' overlaps with 'Radial+Hiss'.

• The pitch angle distributions from full simulation results are consistent with observations.
• Hiss wave scattering causes the decay of electrons and the flattened pitch angle distributions.

Observation
Simulation (Full)
Simulation (Radial + EMIC)
Simulation (Radial + Hiss)
Simulation (Hiss + EMIC)
• Pitch angle distributions at $L = 4.5$

$(2 - 4 \text{ MeV})$

• EMIC waves cause the loss of electrons at pitch angles below $\sim 60^{\circ}$, but cannot scatter higher pitch angle electrons.

• Hiss waves cannot cause the decay of electrons in 10 days, but can lead to the flattened pitch angle distributions.

• Weak EMIC wave scattering is necessary to account for the observed electron decay in 10 days.

• Observation
  
  Simulation (Radial + EMIC)
  
  Simulation (Radial + Hiss)
  
  Simulation (Hiss + EMIC)