

1 The dynamics of the radiation belts revisited

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9 In an effort to explain the formation of a narrow third radiation belt at ultra-relativistic energies
10 detected during a solar storm in September 2012, Mann et al.² present simulations from which they
11 conclude it can be explained by an outward radial diffusion alone and additional loss processes by
12 higher frequency waves are not needed in this case. The comparison of observations with the model
13 in Figures 2 and 3 of their Article clearly shows that even with strong radial diffusion rates, the
14 model predicts a third belt near $L^*=3$ that is twice as wide as observed and approximately an order
15 of magnitude more intense. We therefore disagree with their interpretation that “*The agreement*
16 *between the absolute fluxes from the model and those observed by REPT shown on Figs 2 and 3*
17 *is excellent*”. At multi-MeV energies, observations show an extremely narrow remnant belt. Radial
18 diffusion tends to smooth the gradients in phase space density (PSD) and cannot produce narrow
19 structures and sharp gradients.

20 Previous studies³ have shown that outward radial diffusion plays a very important role in the
21 dynamics of the outer belt and is capable of explaining rapid reductions in the electron flux. It has
22 been also shown that it can produce remnant belts (Figure 2 of this long-term simulation study⁴).
23 However, radial diffusion alone cannot explain the formation of the narrow third belt at multi-
24 MeV during September 2012. An additional loss mechanism is required.

25 Higher radial diffusion rates cannot improve the comparison of the Ref 2 model with observations.
26 A further increase in the radial diffusion rates (reported in Figure 4 of the Supplementary
27 Information of Ref. 2) results in the overestimation of the outer belt fluxes by up to 3 orders of
28 magnitude at energy of 3.4 MeV.

29 Observations at 2 MeV where belts show only a 2-zone structure, were not presented in the
30 Reference 2. Simulations of electrons with energies below 2 MeV with the diffusion rates and
31 boundary conditions used by Mann *et al.* would likely produce very strong depletions down to
32 $L=3-3.5$, where L is radial distance from the center of the earth to the given field line in the
33 equatorial plane. Observations do not show a non-adiabatic loss below $L\sim 4.5$ for 2 MeV. Such
34 different dynamics between 2 MeV and above 4 MeV at around $L=3.5$ are another indication that
35 particles are scattered by electromagnetic ion cyclotron (EMIC) waves that affect only energies
36 above a certain threshold.

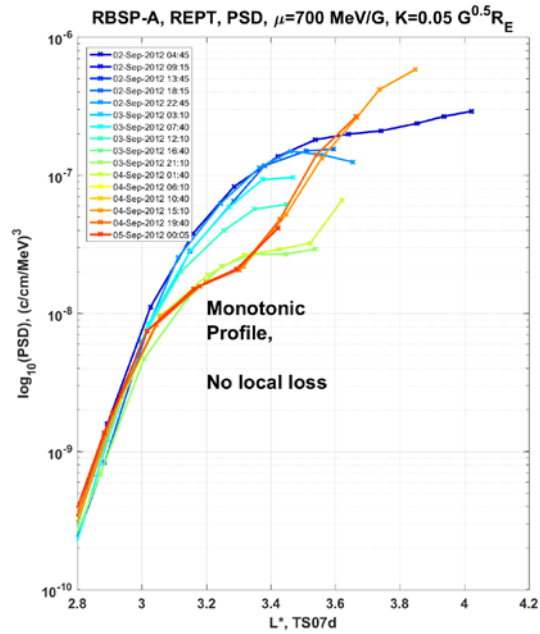
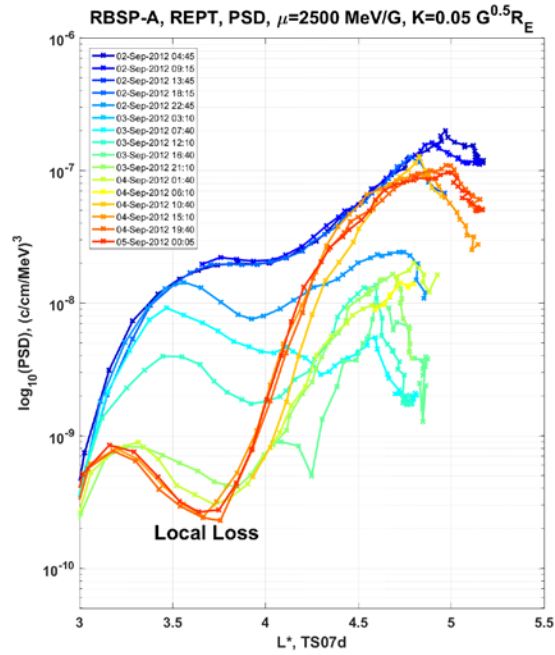
37 Observations of the Phase Space Density (PSD) provide additional evidence for the local loss of
38 electrons. Around $L^*=3.5-4$ PSD shows significant decrease by an order of magnitude starting in
39 the afternoon of September 3 (Figures 1a), while PSD above $L^*=4$ is increasing. The minimum in
40 PSD between $L^*=3.5-4$ continues to decrease until September 4. This evolution demonstrates that

41 the loss is not produced by outward diffusion. Radial diffusion cannot produce deepening
42 minimums, as it works to smooth gradients. Just as growing peaks in PSD show the presence of
43 localized acceleration⁵, deepening minimums show the presence of localized loss.

44 The minimum in the outer boundary is reached on the evening of September 2. After that, the outer
45 boundary moves up, while the minimum decreases by approximately an order of magnitude,
46 clearly showing that this main decrease cannot be explained by outward diffusion, and requires
47 additional loss processes. The analysis of profiles of PSD is a standard tool used, for example, in
48 the study about electron acceleration⁵ and routinely used by the entire Van Allen Probes team. In
49 the Supplementary Information, we show that this analysis is validated by using different magnetic
50 field models.

51 Deepening minimums at multi-MeV during the times when the boundary flux increases are clearly
52 seen in Figure 1a. They show that there must be localized loss, as radial diffusion cannot produce
53 a minimum that becomes lower with time. At lower energies of 1-2 MeV, which corresponds to
54 lower values of the first adiabatic invariant μ (Figure 1b), the profiles are monotonic between
55 $L^*=3-3.5$, consistent with the absence of scattering by EMIC waves that affect only electrons
56 above a certain energy threshold^{6,7,8,9}.

57 In summary, the results of the modeling and observations presented by Mann *et al.* do not lend
58 support to the claim of explaining the dynamics of the ultra-relativistic third Van Allen radiation
59 belt in terms of an outward radial diffusion process alone. While the outward radial diffusion
60 driven by the loss to the magnetopause² is certainly operating during this storm, there is a
61 compelling observational and modeling^{6,2} evidence which shows that very efficient localized
62 electron loss operates during this storm at multi-MeV energies, consistent with localized loss
63 produced by EMIC waves.



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65 **Figure 1** a) Similar to Supplementary Figure 3 of Ref. 2, but using TS07d¹⁰ model and for $\mu=2500$
 66 MeV/G, $K=0.05 G^{0.5}R_E$. b) Similar to Supplementary Figure 3 of Ref. 2, but using TS07D model
 67 and for $\mu=700$ MeV/G, corresponding to MeV energies in the heart of the belts.

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