Things we don’t yet understand about solar driving of the radiation belts

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Making the Case for Prediction

What feature(s) on the sun and/or in the solar wind directly cause a radiation belt response? *What response?*

What feature(s) in the solar wind/magnetosphere/ionosphere set up a chain of actions/reactions that ultimately effect a radiation belt response? *What response?*

**FEATURE**  \[\rightarrow\]  **RESPONSE**

*Are we there yet?*
What do we know or think we know?

State of radiation belts depends on competing sources, enhancement, transport, and loss

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**Loss through the magnetopause**

Sudden inward motion of the magnetopause due to solar wind pressure pulse (CME or HSS). Charged particles find themselves outside the last closed drift shell and are lost – termed magnetopause shadowing.

Outward radial transport due to ULF waves.

Can be associated with main phase of geomagnetic storm, or independent.

\[ L^* > \sim 4 \]

**Energization by inward radial diffusion**

\~1MeV electrons at geosync orbit mainly due to global convection, injections from the plasma sheet.

Inward radial diffusion seen for HSS with no evidence of a shock and weak \( B_z / Dst \).

Radial diffusion model vs data; discrepancy due to local heating not included in RD model.

RD better explains dynamics for low \( \mu \) electrons, while a local acceleration mechanisms becomes important for high \( M \mu \) electrons.

**Loss into the atmosphere**

EMIC and Chorus waves cause pitch angle diffusion - scattering - into the loss cone. Occur under conditions of geomagnetic storms, high AE, SymH, growth favorable with temperature anisotropy.

ULF waves correlated with losses into atmosphere.

EMIC waves causing loss are most effective for high energy (\( \mu \)), high mirroring latitude (K)

Chorus waves causing loss are most effective for low energy (\( \mu \)).

\[ L^* < \sim 4 \]

**Energization by local acceleration**

Multiple examples of local acceleration in the heart of the radiation belts.

Chorus scattering solely responsible for the evolution of energy and angular distribution of relativistic e flux increase for some storms.

To explain different behavior in different storms, diffusion in all three dimensions coupled with data-driven, event-specific inputs, and boundary conditions is required.

Sometimes radial diffusion explains data better.
Sudden solar wind pressure increase causes inward motion of magnetopause and subsequent loss of high energy electrons.

Electron Flux Dropouts in 2nd case

Turner et al., 2014b
ICME-shock with $P_{\text{dyn}}$ increase but $B_z$ northward or modestly southward.

Compression from the shock impact led to the loss of radiation belt electrons.

BARREL observations of precipitation in close conjunction with Van Allen Probes and GOES satellites

Halford et al., 2015
An azimuthal electric field impulse generated by magnetopause compression caused inward electron transport and minimal loss.

Chorus waves were responsible for most of the precipitation observed outside the plasmapause.

ULF waves were correlated with the structure of the precipitation.

Chorus is excited following injection of 1-30 keV plasma sheet electrons into the inner magnetosphere during geomagnetically disturbed times. [Li et al., 2010]

Could chorus be excited by temperature anisotropy like EMIC?

Halford et al., 2015
Loss/Enhancement can be initiated by solar wind event

HSS (High Speed Stream)  
P_{\text{dyn}} \text{ increase}  
CME (Coronal Mass Ejection)  
IMF B_z \text{ southward}

Take simplest (?) case

**FLUX DROPOUT EVENTS**

The drastic decrease in relativistic electron flux over a broad range in energy, equatorial pitch angle, and radial distance in only a few hours. The dominant mechanisms responsible remain a topic of debate.

Can we predict when this will occur?
Numerous Case Studies of Electron Flux Dropouts
(see review by Turner et al., 2012)

Some Statistical Studies of Electron Flux Dropouts
superposed epoch analysis in context with geomagnetic storms
using geosynchronous and other data
(most recent, Gao et al., 2015)

Gao et al. found that
• BOTH solar wind dynamic pressure, \( P_{\text{dyn}} \), and IMF \( B_z \) play key roles in causing dropouts.
• Either **by themselves** are capable of producing significant depletion.
• Dropouts occurred when magnetopause is compressed, but also when magetopause at \( \sim 10 R_E \).

Need to examine statistics of Van Allen Probes dropout events.
Do Solar Wind Speed and Dynamic Pressure add clarity?
Van Allen dropout events (~90 so far)

Results ~ as expected?

- Loss (L = 6 to 5.5) occurs with no storm or nominal storm (moderate $P_{\text{dyn}}$ increase, $B_z$ usually negative)
- Loss (L = 5 to 4.5) occurs with storm (moderate $P_{\text{dyn}}$ increase, $B_z$ negative)
- Loss (L = 4) occurs with large storm (variable $P_{\text{dyn}}$ increase, $B_z$ negative & large)
- Loss (L = 3.5) occurs with very large storm ($P_{\text{dyn}}$ change positive and negative, $B_z$ negative & large)
Conclusions

• A lot left to do to be able to make accurate predictions even for simplest response (dropouts) at one energy (2.3 MeV)
  • How large must $P_{\text{dyn}}, B_z$ be for loss to occur at each L level?
  • Does duration of increase matter?
  • Does $V_{\text{sw}}$ matter?
  • Does it matter which increases first?
• Are other solar wind features important?
• Need more simulations of the smaller events
• Need to better understand the processes, chain-of-events
• Need to add in all energies, multipoint observations in all relevant regions.