Explaining the Apparent Impenetrable Barrier to Ultra-relativistic Electrons in the Outer Van Allen Belt

One of the most remarkable recent discoveries made by the NASA Van Allen probes is the existence of an apparent impenetrable barrier at the inner edge of the ultra-relativistic outer electron radiation belt. The physical processes responsible for this apparent impenetrable barrier have not yet been fully identified. However, recent studies have suggested that fast loss, such as that associated with scattering into the atmosphere from man-made very-low frequency (VLF) transmissions, is required to limit the Earthward extent of the belt. Here we present simulation results of the ultra-relativistic electron flux driven entirely by ultra-low frequency (ULF) wave radial diffusion, without any man-made VLF wave loss processes or local acceleration mechanisms included. These results show that the steep drop off in flux at the implied barrier location is consistent with ULF wave driven inward diffusion of the electron phase space density from an outer boundary, and that the penetration of these electrons to the barrier can occur on the timescale of days rather than years as previously reported. Moreover, our simulation results also show that the Earthward extent of these ultra-relativistic electrons in the outer belt is limited by the finite duration of enhanced solar wind driven ULF wave power which can encompass only a single geomagnetic storm. Overall, the activity and very strong L-shell dependence of ULF wave transport explains the location of the apparent impenetrable barrier to ultra-relativistic electrons. The sharp gradients in phase space density and flux at the barrier can be created and maintained by the activity and L-dependence of radial diffusion, and do not require the existence of any sharp physical boundaries in scattering losses to the atmosphere.