

Electron Radiation Belts

The Earth is surrounded by two doughnut-shaped regions of energetic electrons, trapped in the Earth's magnetic field, known as the Van Allen electron radiation belts. The inner belt, which extends from 1,200 km to 6,500 km above the surface of the Earth, is relatively stable whereas the outer belt, which extends from 13,000 km to 40,000 km, is highly variable. The belts are usually separated by a gap, known as the slot region which contains very few energetic electrons.

In the highly dynamic outer belt the fluxes change dramatically and may vary by up to five orders of magnitude on timescales of several hours to a few days. In exceptional circumstances, such as occurred during the 24 March 1991 geomagnetic storm, the fluxes may vary by orders of magnitude on a timescale of minutes. Understanding this variability, including determining the dominant acceleration and loss processes, is the primary objective of two new space missions scheduled for launch in 2012.

The Earth's Electron Radiation Belts

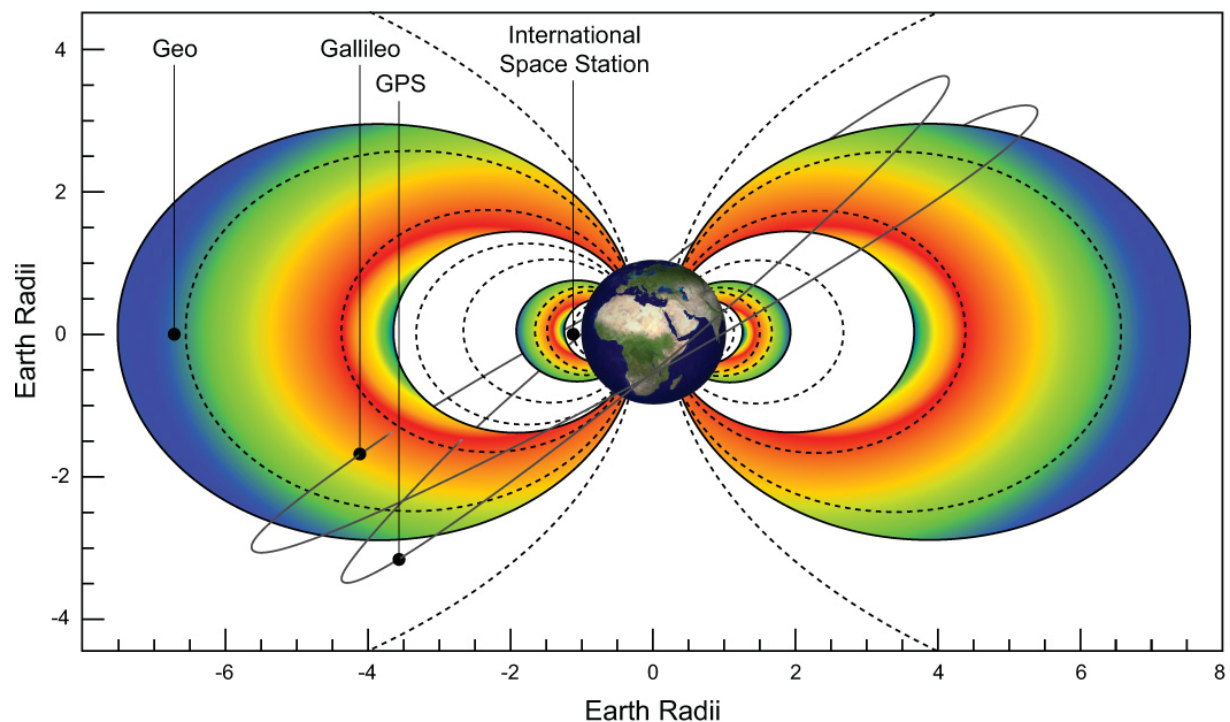


Figure 1. Schematic of the Earth's Electron Radiation Belts

Figure 1 shows a schematic of the Earth's electron radiation belts, together with the principle satellite orbits which traverse the belts. Most telecommunications satellites are located in geosynchronous orbit (Geo), which is located at the outer edge of the outer radiation belt. In contrast, most navigation satellites, such as GPS and Galileo, operate in medium Earth orbit and subsequently pass through the heart of the outer radiation belt where they may subsequently experience much higher levels of radiation. The International Space Station and most Earth-observation satellites operate in low Earth orbit and may also experience higher levels of radiation if their orbits traverse the South Atlantic Anomaly or the auroral zones.

Relativistic electron ($E > 1$ MeV) variability in the radiation belts is driven by changes in the solar wind which are ultimately driven by activity on the Sun. Episodic storms caused by solar wind disturbances driven by coronal mass ejections peak during solar maximum and may lead to strong enhancements in the flux of relativistic electrons. However, the strongest flux increases are associated with recurrent storms caused by high speed solar wind streams from coronal holes. The highly dynamic nature of the outer belt, over the timescale of approximately one solar cycle, is illustrated in Figure 2. The bottom panel shows SAMPEX measurements of $E > 2$ MeV electrons in the Van Allen radiation belts and the top panel shows the variation of sunspot number (black) and the solar wind velocity (red). The outer belt radiation belt is clearly most intense during the declining phase of the solar cycle in years 1993-1995 and 2003-2004, due to the recurrent high speed streams from coronal holes.

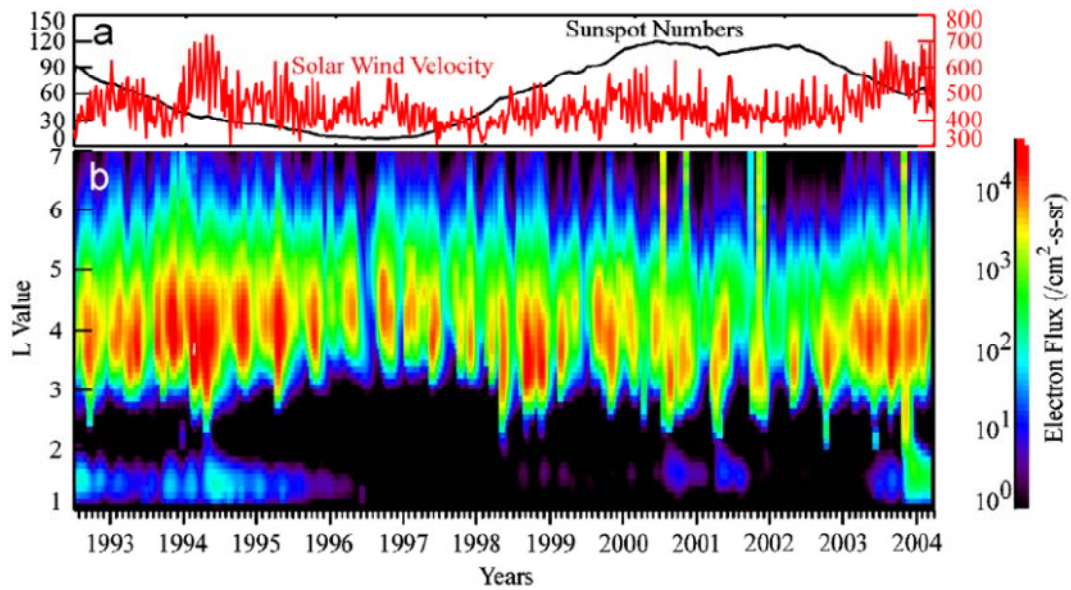


Figure 2. Solar Cycle Variation of the Van Allen Radiation Belts [Baker and Kanekal, 2008]

During a typical geomagnetic storm the relativistic electron flux in the outer radiation belt usually drops dramatically during the main phase and subsequently increases to levels that may exceed the initial level by several orders of magnitude on a timescale of several days during the recovery phase. Indeed, the flux of relativistic electrons ($E > 1$ MeV) in the outer zone are enhanced by a factor of 2 or more in ~50% of all moderate and intense storms [Reeves *et al.*, 2003]. However, surprisingly, ~20% of all moderate and intense storms decrease the fluxes by a factor of 2 or more. Why some storms cause a net increase in flux while others do not is an unresolved question.

Understanding the variability of relativistic electrons in the outer radiation belt is a complex problem involving a variety of source, transport and loss processes. In the SPACECAST project we will produce forecasts of the radiation belts by improving the physics of existing physics-based research models and transforming them into space weather models.

References

Reeves, G. D., K. L. McAdams, R. H. W. Friedel, and T. P. O'Brien (2003), Acceleration and loss of relativistic electrons during geomagnetic storms, *Geophys. Res. Lett.*, *30*(10), 1529, doi:10.1029/2002GL016513.

Baker D. N., and S. G. Kanekal, Solar cycle changes, geomagnetic variations, and energetic particle properties in the inner magnetosphere, *J. Atmos. Sol. Terr. Phys.*, *70* (2008) 195–206.