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Continuing SAMPEX Observations of Shock-Injected Ultrarelativistic Electrons

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Abstract

On 24 March 1991, the CRRES satellite observed the sudden creation of a belt of ultrarelativistic (>15 MeV) electrons at around L = 2. This was modeled by Li et al. (1993) as the result of the impact of a strong interplanetary shock on the magnetosphere. The remnants of this belt were observed for more than a year after the 3 July 1992 launch of the SAMPEX satellite.

Continuing analysis of the SAMPEX ultrarelativistic electron database has resulted in the discovery of another shock-related injection of these particles, on 21 February 1994. This belt was injected at a higher L value than the earlier one, but over time both belts' remnants mingled as they migrated inward, reaching L = 1.3 by the end of 1998. We find that, while electrons with energies around 10 MeV are present in the outer zone during especially strong relativistic-electron enhancement events (such as those in February 1994, which at the time of arrival of the shock on 21 February may have provided a seed population for the new belt), over time the dominant population of ultrarelativistic electrons in the magnetosphere is instead due to these rare injections of persistent belts at low L.

1 Previous Observations:

On 24 March 1991, immediately following the arrival at Earth of an extremely strong and abrupt interplanetary shock wave, sensors aboard the CRRES satellite observed the sudden appearance of protons and electrons with energies of a few tens of MeV (Blake et al., 1992a, b; Vampola & Korth, 1992). These particles formed a new radiation belt between L = 2 and L = 3.5, which CRRES continued to observe until the satellite failed in October 1991. Following the launch on 3 July 1992 of the SAMPEX satellite, observations of the new belt of ultrarelativistic electrons resumed, and its decay was followed for more than a year in an early analysis of SAMPEX data (Looper et al., 1994).

Li et al. (1993) modeled the generation of this belt as the result of compression of the magnetosphere by the strong interplanetary shock. Since the 24 March 1991 event was highly unusual in its magnitude and abruptness, we have been interested to see if lesser events might also generate weaker belts of ultrarelativistic electrons. SAMPEX has been in operation for almost seven years at this writing, so we undertook a reanalysis of the most-energetic electron observations to look for such injections.

2 Instrumentation:

The payload of SAMPEX includes PET, the Proton/Electron Telescope, a silicon solid-state detector stack optimized to measure energetic electrons and isotopes of hydrogen and helium. The particular channel used in this work is called RNG, which counts particles that stop in the detectors P4 through P7 of the telescope, corresponding to ranges from 19 to 31 mm of silicon (Cook et al., 1993). Consistency checks on the energy deposit and range information for a sampling of individual particle events are used to determine the fraction of the basic RNG countrate attributable to electrons (rather than to protons or to chance coincidences and pulse pileup), and a built-in livetime pulser is used to correct for the deadtime induced in the electronics by high counting rates. The result is a very clean separation of ultrarelativistic electrons from protons and noise, even in the inner zone where protons are overwhelmingly dominant.

The EGS4 electron-photon shower Monte Carlo code was used by Looper et al. (1994) to calculate the response of PET to electrons. In that analysis of PET observations of the March 1991 electron belt, we also used arguments based on particle range to show that the spectrum of the remnant was very similar to that originally injected; however, later observations of weaker fluxes do not afford enough statistics to apply this technique, so we simply identify the RNG channel as 10-20 MeV electrons based on the EGS4 simulations.

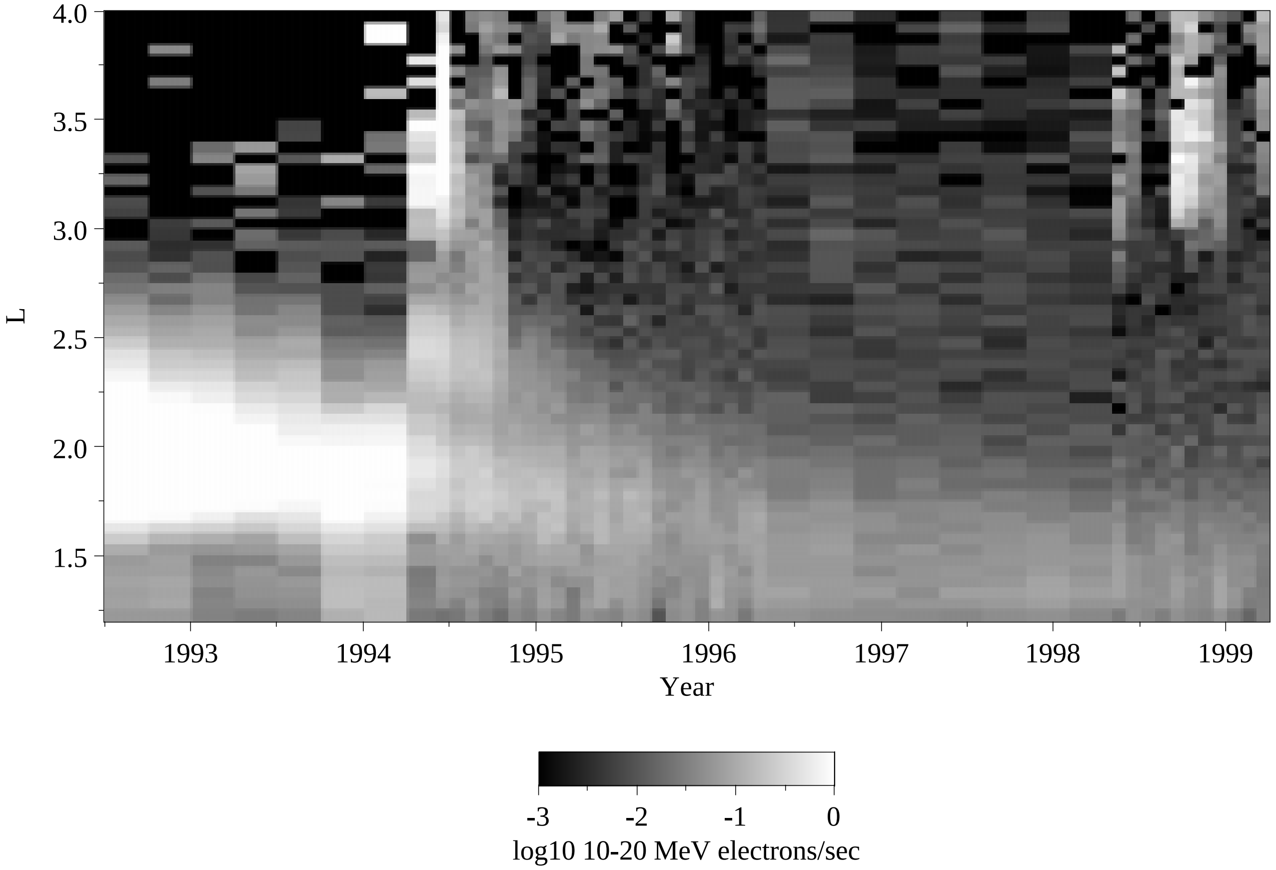

Figure 1: L vs. time “spectrogram” of RNG electrons mirroring nearest equator, over the SAMPEX mission.

3 Overview of Observations:

An overview of ultrarelativistic electron observations from L = 1.2 to 4 over the entire SAMPEX mission (through March 1999) is given in Figure 1. This is our best attempt at presenting a homogeneous data set; changes in instrument operating and spacecraft pointing modes have all been corrected for, with the exception of some ineradicable background at the lowest values of L from about October 1993 to February 1994. The averaging period varies from one to three months depending on whether or not it was necessary to average over half the (6-month) orbital precession period to remove pointing-mode artifacts. The data summarized here were restricted to periods when PET was looking within 10° of perpendicular to the local magnetic field and when the local magnetic field magnitude B was such that locally-mirroring particles would have pitch angles within 16° of perpendicular to the field at the lowest value of B reached by SAMPEX in its 600 km near-polar orbit. Thus the data presented are a uniform sample (as best we can achieve) of particles mirroring near the lowest value of B observed.

The remnants of the March 1991 belt are clearly visible around L = 2, decaying from their highest flux before the start of the mission. Some outer-zone activity is also visible above L = 3 on occasion; in contrast to lower-energy electrons that are often present, electrons at these ultrarelativistic energies only occur in substantial numbers when the outer zone is extremely active. In between these two populations, one can see a second long-lasting belt beginning at about March 1994, which moved inward from its origin at L = 2.5 over the next year or two. We identify this as another shock-injected electron belt, this time associated with the event of 24 February 1994; a closer look shows it moving inward toward the March 1991 belt, with the merged, decaying remnants migrating even further inward to form the faint, persistent band that reaches L = 1.5 and below by the end of the time period in the plot.

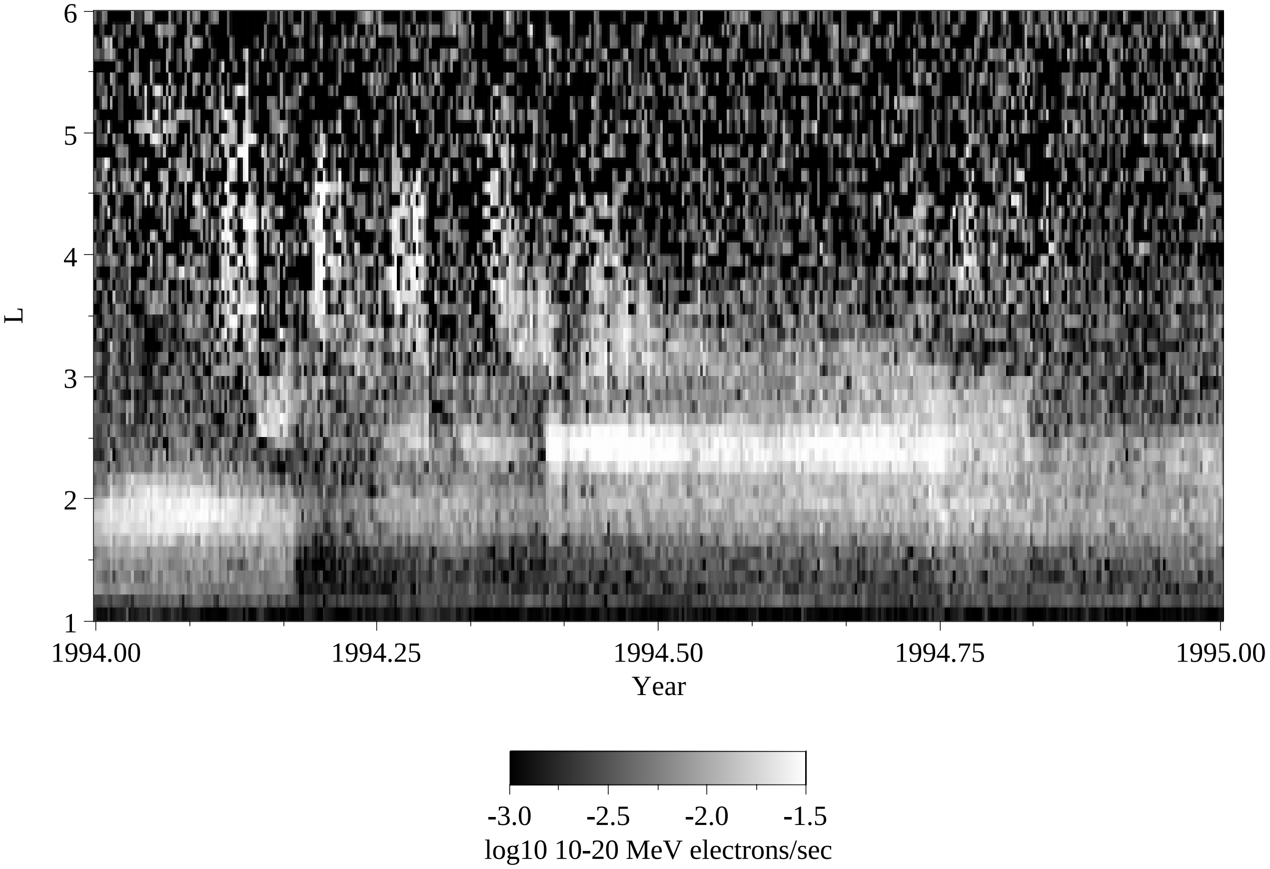

Figure 2: L vs. time “spectrogram” of all RNG electrons observed in 1994, with one-day resolution.

4 Origin of New Belt in February 1994:

Figure 2 shows a detailed view of PET ultrarelativistic electron observations for L from 1 to 6, with one-day time resolution, throughout 1994. Note that on this fine timescale we cannot average out artifacts of changes in operational modes, so some of the apparent changes in flux in this figure are spurious. In particular, most of the variations in intensity of the band near L = 1.9 (due to the March 1991 event) are attributable to changes in instrument mode or spacecraft pointing, and the strong intensification of the band around L = 2.5 on 26 May 1994 is due to a pointing mode change that resulted in greatly improved coverage of the direction perpendicular to the magnetic field. Nonetheless, leading up to this brightening one can see an interrupted band at higher L than the March 1991 remnant, starting around L = 2.7 and migrating slightly inward. The creation of this new belt occurred on 21 February 1994, and we associate it with the strong interplanetary shock that arrived that day. Above L = 3 one can see outer-zone activity recurring with the 27-day solar rotation period from early February through about June; this solar-wind-driven enhancement may have contributed the "seed" population that was accelerated to form the new belt.

The flux in the new belt around L = 2.5 declined rather abruptly in October 1994, to a level comparable to that in the older belt around L = 1.9; this appears to be real, not an artifact of spacecraft or instrument operations, but we have not identified a causative geophysical event. In Figure 3, we show a plot similar to the previous one, following the ultrarelativistic electron belts through 1995. The two bands can be seen to drift toward lower L, eventually merging and reaching L = 1.5 by the end of 1995. As seen in Figure 1, the merged belt persists at a low level to the present day. Looking at the various contributions to the trapped ultrarelativistic population in Figure 1, we can say that over time the dominant signal is that due to these persistent belts, rare though their injection is. We hope to observe more instances as solar maximum nears.

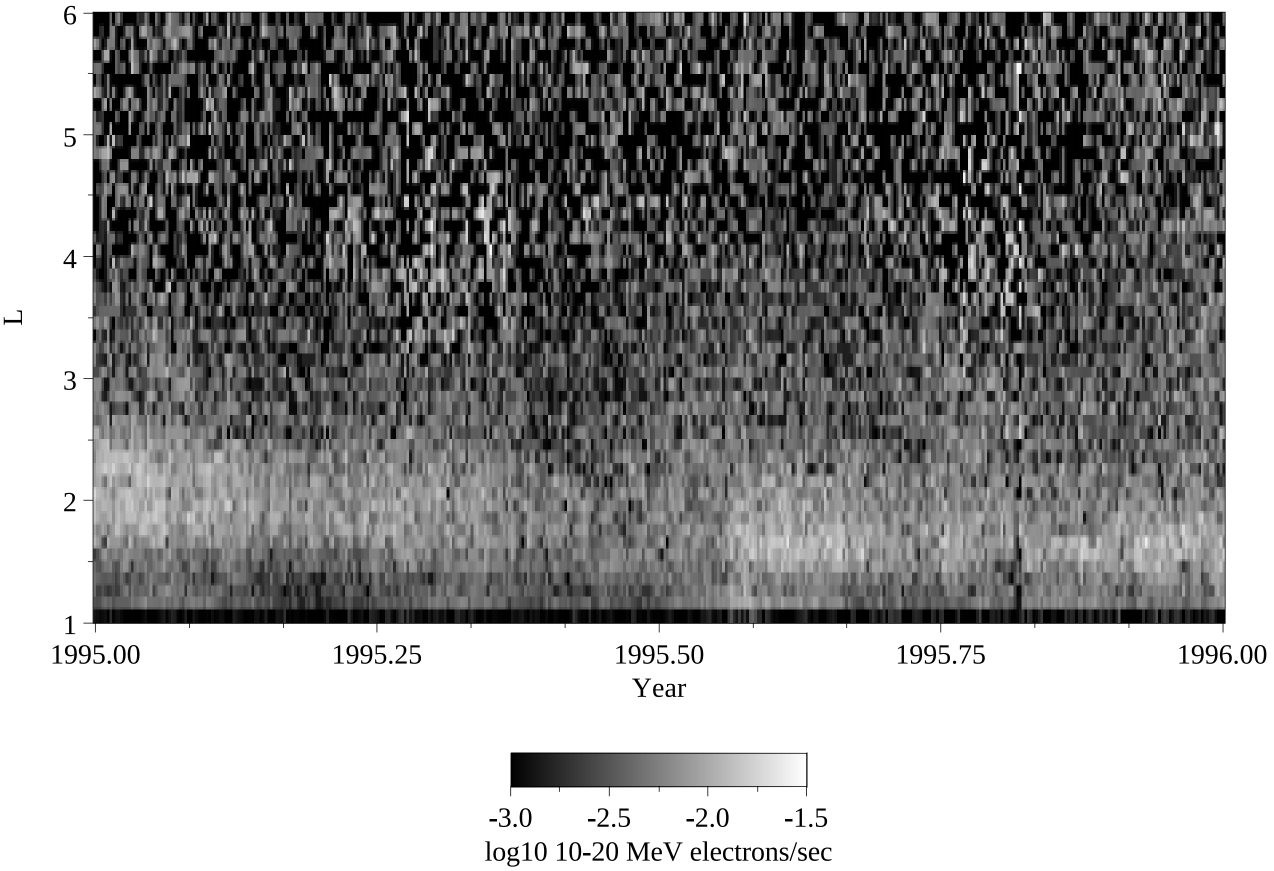

Figure 3: L vs. time "spectrogram" of all RNG electrons observed in 1995, with one-day resolution.

References

Blake et al. 1992a, IEEE Trans. Nucl. Sci. 39, 1761
Blake et al., 1992b, Geophys. Res. Lett. 19, 821
Cook et al., 1993, IEEE Trans. Geosci. & Remote Sensing 31, 565
Li et al. 1993, Geophys. Res. Lett. 20, 2423
Looper et al. 1994, Geophys. Res. Lett. 21, 2079
Vampola & Korth 1992, Geophys. Res. Lett. 19, 625