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Changes in HILT High Time Resolution Data over the SAMPEX Mission

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Abstract

The HILT (Heavy Ion Large Telescope) instrument aboard SAMPEX (the Solar, Anomalous, and Magnetospheric Particles Explorer satellite) measured heavy ions via multi-detector coincidences involving a flow-through isobutane ionization chamber and a pair of proportional counters, plus silicon solid-state detectors and CsI scintillators, until the isobutane ran out in 1995. Throughout the mission, all the way up to re-entry in 2012, it also returned data in the form of high time resolution single-detector countrates. This document briefly describes the changes in HILT operating modes that affected these rates over the course of the mission.

Acknowledgments

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1. HILT High Time Resolution Rates

HILT (Heavy Ion Large Telescope) aboard SAMPEX (the Solar, Anomalous, and Magnetospheric Particle Explorer satellite) was an energetic-particle telescope consisting of two position-sensitive proportional counters on either side of an ionization chamber, the three composing a single volume of isobutane, with layers of 16 silicon solid-state detectors (SSDs) and 16 CsI scintillators behind the isobutane chamber to measure total particle energy.[*] The SSDs were arranged by rows into four compound detectors, each with its own pulse-height analysis and countrate channels, while the light coming from all 16 CsI crystals was read out as a single detector. Before the isobutane ran out at the end of 1995, the combination of these detectors measured heavy ions; individually, countrates from the ionization chamber, the rear proportional counter, and the four solid-state detector rows were also read out at high time resolution.

At launch, all six of these rates were sampled at 100 ms time resolution; as the mission went on, and in particular after the isobutane ran out, the high time resolution rates sent down in the telemetry were changed several times, as detailed in a chart at http://www.srl.caltech.edu/sampex/DataCenter/docs/HILThires.html at the SAMPEX Data Center. Through the end of the nominal NASA mission (June 2004), events affecting HILT are listed in Table I.3 of the MDF (Master Data File) description document, also available online at http://www.srl.caltech.edu/sampex/DataCenter/docs/MDF_description_V1.6.pdf. The purpose of the present document is to discuss in more detail the effects of some of these changes, and to extend the discussion through spacecraft re-entry in 2012. (By the way, there is a typo in Table I.3: there is mention of disabling the “HILT HHR subcom” in August 1996, but this has nothing to do with the high time resolution rates discussed here. Rather, the subcommutated *low* resolution HILT rates detailed in Table 7.3 of that document were frozen except for a brief period around downlink for diagnostic purposes, so as not to waste a lot of telemetry space on zeroes from the disabled proportional counters and ionization chamber after the isobutane ran out.)

[*] Klecker, B., D. Hovestadt, M. Scholer, H. Arbinger, M. Ertl, H. Kästle, E. Künneth, P. Laeverenz, E. Seidenschwang, J. B. Blake, N. Katz, and D. Mabry, “HILT: A Heavy Ion Large Area Proportional Counter Telescope for Solar and Anomalous Cosmic Rays,” *IEEE Trans. Geosci. Remote Sensing* **31**(3), pp. 542-548 (1993), doi: 10.1109/36.225520.

2. Operation with Isobutane

Figure 1 shows the daily averaged rate of the rear proportional counter (PCRE) as a function of L between 1 and 9 from just after launch to the end of 1993; this rate responds to electrons above about 150 keV and protons of a few MeV. Like the high time resolution rate values archived in the SAMPEX Data Center, these countrates are not corrected for detector deadtime; an algorithm for such a correction is given in the Appendix to this document. Data used in this plot were restricted to times when the spacecraft was in the drift loss cone; that is, particles at the location of the spacecraft would be lost to the atmosphere within a single complete drift around the Earth, and therefore any particles present must have been scattered from the higher-altitude trapped population on the timescale of a drift period. HILT has a heavy door to protect the foils that cover its aperture and seal in the isobutane gas; this did not open properly after launch until day 1992/232, so the early countrates before the black bar denoting the absence of HILT data in the MDFs are significantly less intense than after. In particular, note that multi-MeV electrons, which can penetrate the lid, are seen around L = 4, but the lower-energy electrons of the inner zone around L = 2 are blocked by the closed lid. (Protons are largely excluded from this plot because they don't scatter much on drift timescales and thus are absent from the drift loss cone.) After the data gap and door opening, PCRE and other high time-resolution data are homogenous through this period.

In order to conserve the finite supply of isobutane gas, HILT was periodically turned off and replenishment of the gas that exited through the calibrated leak vent was shut off. The solid-state detectors and CsI crystal do not depend on isobutane, of course, so HILT was designed so that it could also

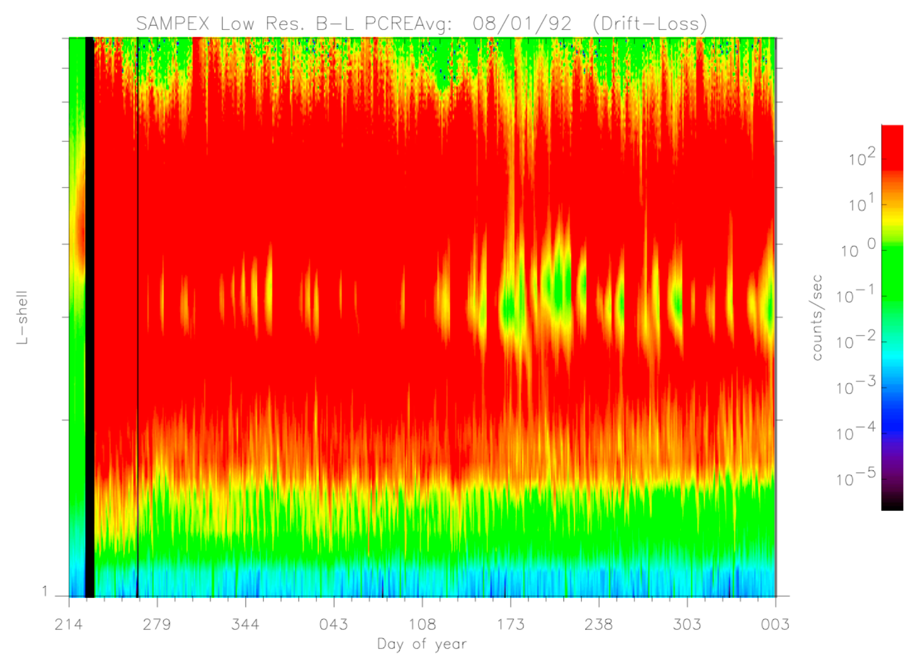

Figure 1. Rear proportional counter rate in drift loss cone, 1992-1993.

operate with just these detectors. Figure 2 shows the PCRE rate in the drift loss cone through 1994 and 1995, with periods when the chamber was emptied and HILT was turned off showing as black bands. The first such gap, starting on 1994/069, actually ended on 1994/137 when the chamber was repressurized; however, PCRE high time resolution data does not reappear until day 1994/237 because the high time resolution rate definitions were changed (to State 2 in the chart on the Data Center website referenced above) to report the rate of the first row of SSD detectors (SSD1) at 20 ms time resolution and the fourth (SSD4) at 100-ms resolution, and no PCRE rates. When the PCRE data reappears in Figure 2, the rate definitions had been changed again (to State 3 in the chart) so that SSD1 and PCRE were each sampled at 30-ms resolution (with 10-ms idle time per 100 ms to maintain telemetry structure).

The distinct drop in intensity after the restart of PCRE high time resolution data on 1994/237, however, is not due to the changed sample time; rather, a threshold was also changed that had been biasing the PCRE data toward more intense periods. At the start of the mission, collection of high time resolution HILT data was triggered when 6 counts were recorded in the SSDs in 100 ms; this meant that PCRE data for >150 keV electrons would only be collected when and where magnetospheric activity was intense enough that higher energy electrons (>1 MeV) were also present to trigger the SSD high time resolution rates. With the resumption of PCRE high time resolution data on 1994/237, this threshold was changed so that collection was triggered if there were 6 PCRE counts in 30 ms. This removed the bias introduced by including only time periods and orbital segments with higher activity in the daily averages plotted in Figure 1 and the early part of Figure 2.

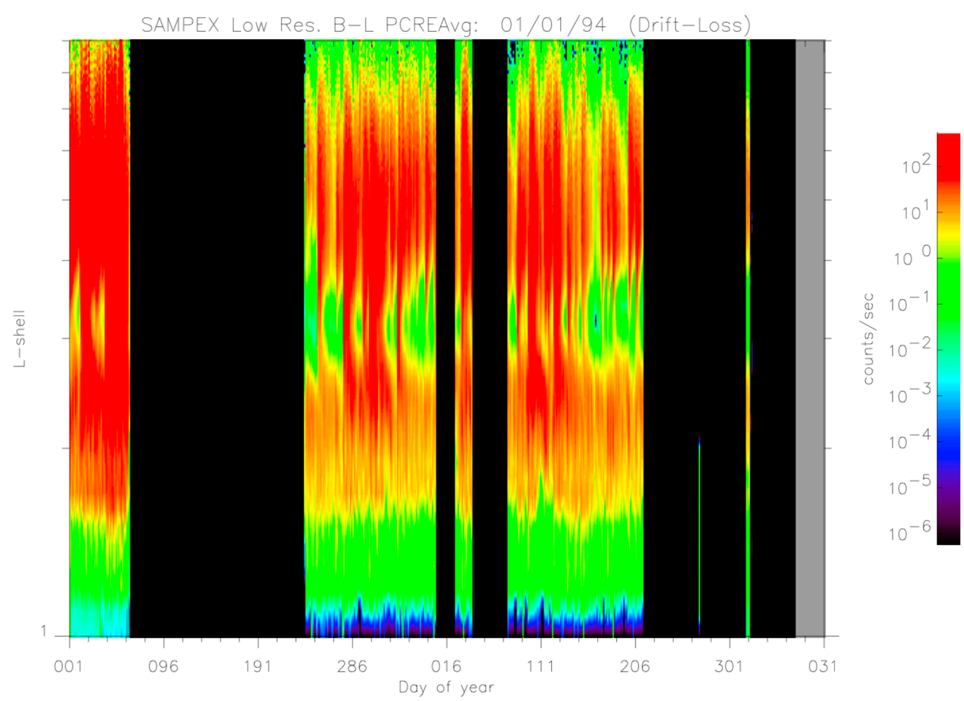

Figure 2. Rear proportional counter rate in drift loss cone, 1994–1995.

3. Operation Without Isobutane

After the last brief stripe of data in Figure 2, ending on 1995/322, the isobutane gas ran out, having lasted through the three years of the spacecraft's prime mission, as designed. After waiting long enough to be very sure that internal pressures had vented to below the level where there was danger of corona discharge, HILT was switched to "high energy mode" in which the coincidence equations were changed to omit the no-longer-functional proportional counters and ionization chamber, and the high time resolution rates were changed back to the launch configuration, despite the fact that two of the six 100-ms rates were now zero. (Triggering was also switched back to the SSDs.) Data collection resumed on 1996/044; then on 1996/220 a final configuration (State 4 in the chart) was put into effect, with SSD4 being sampled at 100-ms resolution and the sum of all four SSD rows being sampled at 20-ms resolution.

This configuration was nominally in place throughout the remainder of the mission; Figure 3 shows the SSD4 data (>1 MeV electrons) in the drift loss cone from the start of 2012 through re-entry in mid-November. With the end of the official NASA mission in June 2004, there was no longer funding available to correct processing crashes in the MDF generator software or chase down missing telemetry files, so there are a larger number of sporadic gaps (gray bands) due to missing MDFs. There were two safeholds during the period plotted, starting on days 2012/102 and 2012/263, with recovery complete by 2012/115 and 2012/276 respectively; black bands indicate that we had MDFs,

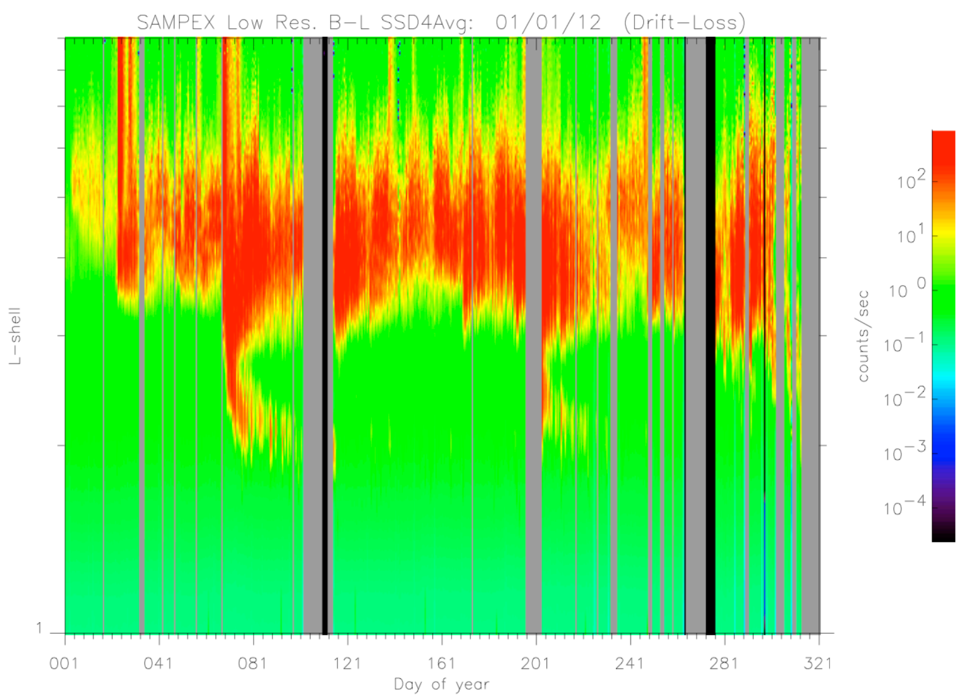

Figure 3. SSD4 rate in drift loss cone, 2012.

but HILT had not been turned back on yet during recovery. HILT continued returning high time resolution measurements until 2012/312, less than a week before burning up. (The apparent bifurcation of the outer zone at the very end of the mission is due to ephemeris errors caused by the spacecraft's extremely low altitude. The orbit propagator on the spacecraft, designed to correct for the residual atmospheric drag near the launch altitude of 600 km, was unable to keep up with the rapidly changing orbit just before re-entry. This resulted in significant along-track errors, so that the value of L reported was actually encountered later, and thus L plotted here is too high on orbit legs heading toward the poles and too low on legs heading toward the equator. See Appendix B of Looper and Mazur, ATR-2017-00035.)

There were other safeholds during the period after the isobutane ran out; during recovery from these, the HILT high time resolution rate definitions would have reverted to the launch configuration until commands could be sent to resume the 20-ms accumulation. The final high time resolution state was first implemented at 63225 seconds on day 1996/220; Table 1 shows dates and times when HILT dropped out of this state and when it returned to it.

Finally, the HILT cover was designed to close in the event that power to the instrument was lost. In order to ensure that it would not get stuck in the closed position if it ever shut during a safehold, leaving the sensor permanently in the state it was in at the beginning of the mission (Figure 1), it was decided to exercise the cover by closing and opening it about every two months. This took about five minutes, so it is a very small fraction of the data; however, we do not have at hand a tabulation of when it was done after the end of Table I.3 in the MDF description document (which ended with the nominal NASA mission in June 2004), so such periods will have to be identified by inspection of analog housekeeping telemetry values in the MDFs if their presence is suspected in a particular stretch of data after that date.

Table 1. Periods After 1996/220 Not in the Nominal Final High Time Resolution Rate State

Year/Day/Time out of State 4	**Year/Day/Time State 4 resumed**
1999/339/53016	1999/342/77665
1999/359/73249	1999/362/71237
2007/348/22512	2007/362/67134
2008/191/70526	2008/204/66544
2009/087/53008	2009/111/60675
2011/275/33506	2011/340/58402
2012/101/52046	By 2012/115/00000 (data gap days 112-114)
2012/263/11447	2012/276/54106

Appendix—Deadtime Correction

The high time resolution values in the SAMPEX Data Center are converted from those in the MDFs by applying a look-up table to the compressed values directly from the telemetry, but no other scaling is done to convert them to rates. Units are given for each rate (i.e., counts per 20 ms, 30 ms, or 100 ms) in the chart at the SAMPEX Data Center referred to at top. In addition, a deadtime correction can be applied, as follows:

$$R = \frac{R_0}{(1 - R_0\tau)}$$

where R is the real rate, R_0 is the observed rate, and τ is the value from Table A1 for the respective rate.

Table A1. Deadtime Correction Constants for High Time Resolution Rates

High Time Resolution Rate	Deadtime Constant τ (seconds)
SSD1	8.681×10^{-6}
SSD2	8.311×10^{-6}
SSD3	9.527×10^{-6}
SSD4	9.084×10^{-6}
PCRE	23×10^{-6}

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