The ABC of XTE

HEXTE Issues

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Introduction

This chapter is not a substitute for the parts of the *Technical Appendix* that deal with the HEXTE (High Energy X-ray Timing Experiment). Rather, it covers those aspects of the HEXTE that pertain directly to data reduction, namely:

- **How the structure and operation of the HEXTE determine the overall structure of the data**
- **How the configuration determines the detailed structure of the data**
- **How the properties of the data determine how they should be reduced.**

Note that unlike the PCA, the HEXTE is not connected to the EDS. It has its own on-board data processors that package the data for telemetry.

HEXTE Structure, Operation and Properties

HEXTE Structure and Operations

The essential aspects of the HEXTE and how they determine the nature and overall structure of HEXTE data are as follows:

1. **The HEXTE comprises two independent clusters of detectors.** The clusters are known as

Cluster-A and Cluster-B or as Cluster-0 and Cluster-1. Each cluster produces its own telemetry streams, i.e. no HEXTE files contain data from more than one cluster.

2. **During normal operation, the two clusters rock on and off target to collect background data.** The rocking has the following properties:
    - When Cluster-0 is on target, Cluster-1 is off target and vice versa.
    - The period of the rocking is set by the observer. The default setting is 32 seconds.
    - The amplitude is also set by the observer and can be +/- 1.5 degrees or +/- 3 degrees. The default is +/- 1.5 degrees.
    - The rocking axes of the two clusters are orthogonal resulting in a total of four different background fields (two per cluster) for each on-source pointing.
    - Regardless of the period and amplitude of the rocking, it takes 2 seconds for the clusters to change position, during which no data are taken. As a result, each background dwell is 4 seconds shorter than each on-source dwell.
    - Data acquisition is synchronized to the cluster rocking; that is, the boundaries of data frames occur when the Cluster changes position.
    - Reflecting the contents of the telemetry, HEXTE data files are not initially segregated by cluster position.
3. **Each cluster comprises four NaI(Tl)/CsI(Na) phoswich detectors.** The detectors are numbered 0-3. Depending on the configuration, the data files may contain either the summed signal from all the detectors or separate signals from the individual detectors.

    Important note: As described in a HEXTE Team memo, Detector-2 in Cluster-1 has been incapable of providing spectra (PHA) information since March 6, 1996. It should be omitted from spectral analysis, but may be included in non-spectral temporal analysis.
4. **Each detector is split into two volumes,** the primary NaI detector crystal and the CsI shield/light guide crystal. X-rays produce scintillations in the NaI crystal, while particles can produce scintillations in the both the NaI and CsI crystals. Since the scintillations in the two crystals, as recorded by the photomultiplier tube, have different rise times, the two kinds of event can be distinguished.
5. **Events that survive rise-time rejection** pass through - or not, as the case may be - the lower and upper pulse-height discriminators and through the pulse-shape discriminators. These clean NaI-only events are then subjected to pulse-height and pulse-shape analyses.
6. **Each detector is equipped with a collimator** comprising a honeycomb of hexagonal tubes that restrict the FOV to about 1 degree FWHM and 2.2 degree FWZI (full width at zero intensity).
7. **Each detector is covered by a thin window of beryllium.** The effect of the window is to curtail

the lower boundary of the pass band at around 5 keV. The default setting for the lower level discriminator, however, is set at 10 keV.

8. **Each detector contains a calibration source** which allows the gain to be continually monitored and maintained.

9. **Each detector measures deadtime and lost events continuously**. In practice, however, deadtime is corrected with software as part of the reduction procedure.

HEXTE Properties

The instrumental properties of the HEXTE are:

```
Energy range:       10 - 250 keV
Energy resolution:  15% at 60 keV
Time resolution:    8 microsec
Spatial resolution: collimator with 1 degree FWHM
Collecting area:    2 x 800 square cm
Sensitivity:        1 Crab yields 360 counts/s per Cluster
Background:         50 counts/s per Cluster
```

What HEXTE Data Are Like Before Being Telemetered

Before looking at HEXTE data modes, it's a good idea to review briefly the nature of HEXTE data before they are packaged for telemetry. In particular, we'll examine the information associated with each event. Telemetry provides a subset of this information.

HEXTE events are processed separately by each Cluster at a rate of 4.915 MHz (i.e. every 1/2**22 seconds). For the clean NaI-only events, i.e. the good ones, information from the various detectors and subsystems are combined to form a 56-bit event code. Of these 56 bits:

- 8 bits are devoted to the 256 PHA channels
- 17 bits are devoted to encoding the time of the event
- 6 bits are devoted to the pulse shape
- 2 bits are devoted to the detector ID

The remaining 23 bits are used to count the science frames and for various flags - more details in the HEXTE chapter of the *Technical Appendix*.

HEXTE Modes

A HEXTE mode is the broad scheme for packaging the data, while the configuration is the specific implementation of the mode. When you work with HEXTE data, the configuration is more conspicuous than the mode itself - in XDF, for example, you'll specify "`E_8us_256_DX0F`" data to reduce rather than "Event List Mode" data. In fact, as a general rule, data in different configurations - even of the same mode - should not be reduced together. And of course, contemporaneous data in different configurations must never be combined since they're the same events!

Note that although there are five HEXTE data modes, there are only two basic formats used for the FITS data files, namely, Science Array (for Archive, Histogram Bin and Multiscalar Bin modes) and Science Event (for Event List mode). Nearly all targets can be observed using Event List mode.

Here, we've summarized the modes and provided links to detailed descriptions of their configurations listed below. These descriptions focus on the data reduction aspects of the configurations, and, where file formats and keywords are discussed, complement the more general information in the Data Files chapter. Given that your data set will include, per cluster, at most two configurations from the much larger number of possibilities, the descriptions are written to be complete and self-contained: you only need to read about your particular configurations:

1. **Archive Mode** is roughly equivalent to PCA Standard-1 and Standard-2. Always run, it is meant to provide a uniform and continuous archive of data collected over the lifetime of the mission. Under XDF, it appears as:

   ```
   CL0ArchData Archive
   CL1ArchData Archive
   ```

   and always provides 64-channel spectra per detector, as well as 1.0-second lightcurves in four energy bands.

2. **Event List Mode** provides time-tagged information about every event that survives background rejection and passes through the various discriminator windows. A typical Event List configuration is `E_8us_256_DX1F`.

3. **Histogram Bin Mode** provides PHA histograms, separated by Detector (or not, as the case may be) every 1-16 seconds. A typical Histogram Bin configuration is `B_16s_256_0_255_DF`.

4. **Multiscalar Bin Mode** provides time histograms, with a resolution of 0.5 ms to 1 s, separated by Detector or not, in 2, 4, 6 or 8 PHA bands. A typical Histogram Bin configuration is `B_1ms_1T_15_250_Q`

5. **Burst List Mode** is a triggered version of Event List Mode providing event-by-event information for a short time period, thereby staying within average telemetry limitations. The configuration `CE_8us_256_DX0F` is an example.

HEXTE Configurations: Archive

Since the Archive mode is always run, your data will include some Archive data. Below we discuss:

- Packaging of Archive data
- Time and energy resolution
- Reduction requirements and options
- Other features

Packaging of science data

Files containing Archive data are in science array format. The science data occupy the first, `XTE_SA` extension in various columns. Each row in the `XTE_SA` extension spans the rocking period. **However, because no data are telemetered when a cluster rocks on and off target, the off-target rows contain 4 seconds less data than the on-target rows.** So, for example, with 32 second rocking, each off-target row contains 28 seconds of good data. In the analysis, this is taken into account by the ftool **hxtdead**. In archive mode, the accumulation time is 16 seconds regardless of the rocking interval.

In HEXTE Archive mode science data:

- **Time** occupies the `Time` column which gives the time of the *start* of each 16-second accumulation.

- **The counts themselves**, that is, the NaI-only events that survive background rejection and pass through the pulse-height and pulse-shape discriminators, occupy *two* sets of columns containing the *same* counts:

  1. **`SpecDet0`, `SpecDet1`, `SpecDet2`, `SpecDet3`** contain pulse-height histograms for each detector in the cluster, accumulated every 16 seconds. The pulse-height histograms have 64 channels.

  2. **`TimSerCnt`**, contains four time histograms, each with 1-second bins, covering four different channel ranges. The channel boundaries are contained in the columns `MsLimit1`, `MsLimit2`, `MsLimit3`, `MsLimit4`, `MsLimit5`.

- **The cluster position**, encoded as a single integer, occupies the `ClstrPosition` column. The values it can assume are:

1.5-degree rocking		3.0-degree rocking	
0	on-target	3	on-target
1	+1.5 deg	2	+3.0 deg
5	-1.5 deg	4	-3.0 deg

In common with other RXTE science array files, Archive mode files have two additional extensions containing good time intervals (GTI). Both are called **`GTI`**.

Time and energy resolution

1. **`SpecDet0`, `SpecDet1`, `SpecDet2`, `SpecDet3`:** The time resolution is 16 seconds. The spectra have 129 channels, binned according to the following scheme: channels 0-63 (binned by a factor of 2); channels 64-127 (binned by a factor of 4); channels 128-255 (binned by a factor of 8). Very roughly, each unbinned energy channel covers 1 keV.

2. **`TimSerCnt`:** The time resolution is 1 second. There are four energy bands spanning the channels 15-29, 30-61, 62-125, 126-250.

Reduction requirements and options

Since Archive mode yields science array files, **saextrct** is used for extracting light curves and spectra. Apart from adjusting screening criteria, your primary reduction options include:

1. **`SpecDet0`, `SpecDet1`, `SpecDet2`, `SpecDet3`:**
   - Separating on-source and off-source data.
   - Selecting and/or combining data from the four detectors
   - Increasing the size of time bins when extracting a light curve
   - Selecting a channel range when extracting a light curve
   - Extracting 129-channel spectra

   Note that both light curves and spectra must be corrected for deadtime using **hxtdead**.

2. **`TimSerCnt`:**
   - Separating on-source and off-source data.
   - Increasing the size of time bins when extracting a light curve
   - Selecting a channel range when extracting a light curve

   Note that to extract TimSerCnt, you must replace the 1CPIX12 keyword with a value which the extractor can understand, e.g. 0:3. Specify the channels appropriately (e.g. 0, 1, 2, or 3).

See the RXTE Cookbook recipe Reduction and Analysis of HEXTE Data for further details on working with HEXTE Archive data.

Other features

In addition to the columns described above - namely, `Time`, `SpecDet0`-`SpecDet3`, `TimSerCnt`, `ClstrPosition` - Archive mode files also contain the following:

1. **`IDFNo`** - the Instrument Data Frame Number at the end of each 16-second accumulation.

2. **`GoodCnt`** - the total accumulated "good" counts, i.e. the NaI-only events that survive background rejection and pass through the pulse-height and pulse-shape discriminators. For each 16-s accumulation, the value in `GoodCnt` equals the sum of the all the values in the `SpecDet0`-`SpecDet3`

columns and equals the sum of the all the values in the `TimSerCnt` column.

3. **`LiveTimeDet0-3`** - HEXTE was designed to monitor dead time continuously. The `LiveTimeDet0-LiveTimeDet3` columns are read by the deadtime correction tools hxtdeadpha and hxtdeadlc.

HEXTE Configurations: Event List

- General Description
- Detailed Description
- Time and energy resolution
- Reduction requirements and options

General Description

Event List mode data configurations are designated with a character string beginning with E, e.g. `E_8us_256_DX1F`. Files containing Event data are in science event format. The science data occupy the `XTE_SE` extension in the form of individual time-stamped binary event words, one per line, which fill the **`Event`** column. The words themselves are strings of ones and zeros, the combinations of which define the properties of each event with respect to a template of all possible properties within the configuration. This template is broken up into sections which, depending on the particular configuration, refer to things like Detector ID, PHA channel, etc. Thus, an individual event word, with its particular combination of ones and zeros, picks out, say, one Detector, one PHA channel, etc. The time stamps occupy the **`Time`** column, but are also encoded in the event word. The cluster position (see below) occupies the **`ClstrPosition`** column.

Detailed Description

The naming convention of the configuration provides a summary of the properties of the data. > For Event List data, the format

`E_ttt_ccc_Dxxx`

gives

E	- mnemonic denoting a generic binned mode
ttt	- the time bin size ("us" denotes microseconds)
ccc	- the number of energy channels
xxx	- hexadecimal byte mask indicating which bytes are telemetered

For example, in the `E_8us_256_DX1F` configuration, events are time-stamped with 8-microsec resolution, in 256 PHA channel bands. "`DX1F`" designates that 5 event bytes are to be included in the telemetry, giving full spectral and timing resolution with detector ID. > For more details about the different HEXTE Event List mode configurations, please consult the *Technical Appendix*.

The configuration name does not, however, give a complete description of the data. Rather, the key to understanding your Event data lies in "decoding" the event word template. The template itself occupies the `TEVTB4` keyword in the header of the `XTE_SE` extension. It is written in DDL - the Data Descriptor Language - and can be displayed on the screen using the ftool fkeyprint. But since the `TEVTB4` keyword can be somewhat long, it is often better to look first at the neighbouring - and complimentary - `TDDES4` keyword. Also written in DDL, the `TDDES4` keyword describes which events have been selected by the HEXTE processors. As an example, here is the value of `TDDES4` in the `E_8us_256_DX1F` configuration:

```
TDDES4  = 'D[0~3] & E[0~131071] & C[0~255] & T[0~16]'
```

which, broken into its parts, means:

- **`D[0~3]`** –events come from Detectors 0-3 (DDL's ~symbol denotes a range).
- **`E[0~131071]`** –each event is tagged with various kinds of detector information in addition to time, detector and channel.
- **`C[0~255]`** –events come from channels 0-255.

Now let's look at the `TEVTB4` keyword for the same `E_8us_256_DX1F` configuration:

```
TEVTB4  = 'E[0:63] {6}, E[CAL] {1}, T[0:15;1] {4}, D[0:3] {2},
           E[LE1,LE0] {2}, T[0:1;7.62939453125e-6] {17}, C[0:255] {8}'
```

This looks a bit confusing at first, but the key to understanding what it means is to focus on the non-E tokens:

- **`D[0:3] {2}`** – Detectors 0-3 (DDL's `:` symbol indicates a range). The `{2}` means that two bits are used to identify the Detector: 00 identifies Detector-0, 01 Detector-1, and so on.
- **`T[0:1;7.62939453125e-6] {17}`** – Timing information. The `{17}` means that seventeen bits are used to specify the time when the event occurred - one bit for each inverse power of 2 from 1 to 17 giving a time resolution of 1/2**17 seconds. The zero at the beginning of the token is the value of the offset to be added to the time. **When the original telemetry is converted on the ground to FITS, this timing information is decoded and written into the `Time` column.**
- **`C[0:255] {8}`** – Channels 0-255, i.e. the full 256 channel range of the HEXTE (256 = 2**8).

The E-tokens are for supplemental information about the events, most of which is actually redundant:

- **`E[0:63] {6}`** – There are 64 channels devoted to pulse *shape*. In principle, pulse shape forms a third dimension of the response matrix, but present response matrices apply to all accepted pulse shape values together. *There is no need to select events based on this token.*

- **`E[CAL] {1} -`** Each detector has a radioactive calibration source in its field of view. A value of 1 for this token indicates a calibration event, not a cosmic photon, but since calibration events are vetoed, they do not appear in data files. *There is no need to select events based on this token.*

- **`E[LE1,LE0] {2} -`** "Lost events" are those events that are detected but cannot be assigned a PHA because the processor is occupied with another event. They are not included in data file and so *there is no need to select events based on this token.*

- **`T[0:15;1] {4} -`** Not an E-token, but four bits devoted to the Science Major Frame Counter, equivalent to the column `IDFNo` in Archive Mode. *There is no need to select events based on this token.*

The cluster position, encoded as a single integer, occupies the `ClstrPosition` column. The values it can assume are:

```
   1.5-degree rocking     3.0-degree rocking

   1 or 65   on-target    8 or 72   on-target
   2 or 66   +1.5 deg     4 or 68   +3.0 deg
  32 or 96   -1.5 deg    16 or 80   -3.0 deg
```

In common with other RXTE science event files, Event mode files have two additional extensions containing good time intervals (GTI). Both are called **`GTI`**.

Time and energy resolution

The time resolution for Event configurations is the resolution of the time stamps. This is not necessarily the same as the number in the name of the configuration, which is an approximation. For example, in the `E_2ms_256_X05` configuration, the step size is really 1/2**9 seconds, i.e. 1.953125 milliseconds.

The configuration name gives the number of channel bands. For current HEXTE Event configurations there are just two possibilities: the full, 256 channels (e.g. `E_2ms_256_X05`), or no PHA information at all (e.g. `E_8us_0_X06`)

Reduction requirements and options

Light curves and spectra may be extracted from HEXTE Event list data using **seextrct** Apart from adjusting screening criteria, your primary reduction options include:

- Selecting by applying a bitmask, in particular:
  - Detector IDs (depends on configuration - some do not have Detector ID)
- Binning the events into a light curve
- Binning the events into a spectrum (depends on configuration - some have only one channel)

Note that both light curves and spectra must be corrected for deadtime using **hxtdead**. See the RXTE

Cookbook recipe Reduction and Analysis of HEXTE Data for further details on working with HEXTE Archive data.

HEXTE Configurations: Histogram Bin

HEXTE Configurations: Multiscalar Bin

HEXTE Configurations: Burst List

Please proceed to the *Screening* chapter. Or return to the *Table of Contents*.