Reduction and Analysis of HEXTE Data

Recipes from the RXTE Cook Book

This recipe describes how to reduce HEXTE archive or event mode data using the HEXTE tools **hxtback** and **hxtdead** released with FTOOLS v4.1. These tools now apply to both archive and event mode data but still require housekeeping files which are not included in realtime data. For this reason, there remains a section on how to do a simple, first order correction to the background for realtime data.

Introductory notes

- **Files:** As received by the guest observer, RXTE data are organized by observation and observation segment. All of the hexte files necessary for these basic steps are in the lowest-level directory called hexte. The HEXTE clusters appear as separate instruments in the data stream, with file prefixes as in the table below.

  Each file name starts with the letter "F" and is followed by "S" for science or by "H" for housekeeping. Next comes a two-digit hex number labeling the data contents, and finally two 7-digit hex numbers giving the start and stop times. Data of each type can appear in more than one file, but this is not usual.

Data Type	Cluster A ("Cl0")	Cluster B("Cl1")
Science data	FS50...	FS56...
Standard Modes (Archive) data	FS52...	FS58...
Calibration data	FS54...	FS55...
16s Housekeeping	FH53...	FH59...
128s Housekeeping	FHfd...	FHfe...

  In addition to these, the user will require the RXTE spacecraft attitude data which can be found both in the XTE Filter File, and in the raw attitude file (FH0e...).

- **Modes:** The Science data files (FS50.., FS56..) contain HEXTE data in the telemetry format selected by the user, either Science Event data (SE), or Science Array (Binned) SA data (which includes Spectral Bin or Temporal Bin modes).

Can't remember which Science Mode was used? Use the Ftool 'fkeyprint' to look at the value of the DATAMODE keyword. Names beginning with "E_" are SE, names beginning with "B_" are binned (SA) data, either Spectral Bin or Temporal Bin. Note that cluster A and B may have been configured (by choice!) in different Science Modes, so check both FS50.. and FS56.. files if you are uncertain.

For a more complete picture of the observing modes (now including the HEXTE rocking and lower energy bounds) users should also consult the appropriate OBSCAT for their observation.

The Standard Modes files contain *two* data products produced automatically for all observations: Archive Spectral Bin (64-bin spectra produced every 16s), and Archive Temporal Bin (4-band light curves with 1s bins).

More information on the Science Modes and the Standard Modes data products may be found in the HEXTE chapters of the proposal documentation.

- **Configurations:** The default configuration for HEXTE's rocking motion before UT 1998 Jan 9 00:00 was 16 second intervals of on-source pointing alternated with 16 seconds of slews and dwell for the off-source pointings. After this date, the default was changed to 32 second intervals. If you are unsure of your configuration, you can simply look at the GTI extension after the tool hxtback has been run. See below.

- **Changes:** One of the detectors (2) on Cluster 1 has lost its spectral capabilities. (For more information, see the HEXTE page on the subject.) This does not affect analysis of light curves; the detector retains its photon counting capabilities. For spectral analysis, however, its data are incorrect. In fact, this detector dumps all events into the first three PHA channels. When extracting light curves, you should in any case exclude those channels below the LLD (i.e. channels < 15) which will also exclude all the detector 2 events. Likewise, when you look at the full spectrum, your analysis should ignore these channels.

  As of UT 1998 Jan 9 00:00, a lower energy bound of 10 keV was implemented as the default. For more information about the HEXTE status, please see the HEXTE status report at http://mamacass.ucsd.edu:8080/hexte/status/hexte_status_980109.html.

Separating background from source+background in raw FITS files

If the HEXTE cluster was configured for source/background beamswitching observation (the default is a 32 second "rocking" configuration), users must separate the on- and off-source data before accumulating spectra and/or light curves. This step is the same for both archive and event modes.

- The script **hxtback** will produce one, two or three files for the input Science file. These consist of the original data selected by rocking position. All the data which is source-looking will appear in one file whose name begins with the original data file name followed by "_src". If two-sided rocking was selected (as in the default configuration), two background files are created with "_p" and "_m" suffixes, for "plus" and "minus" positions respectively. Alternatively, users may elect to keep all the background data in a single file (if you are not concerned about any possible nearby source or other asymmetry in the background pointings), by using the -b option, in which case the output file is appended "_bkg". Note that one may add the two final background spectra back together later using **mathpha**, after the dead-time corrections has been performed (see below). In addition to separating the on- and off-source Science Events, **hxtback** also produces a good-time interval (GTI) extension which specifies in full detail the time intervals on/off-source. This information is essential for the extractor programs to calculate the correct raw exposure time, which is later corrected to live time by **hxtdead**. You may also look at this to determine the time interval of the rocking which in turn will tell you how to bin the light curve.

- The calling sequence is

  ```
  hxtback -h
  ```

  for a full list of options. For our Cluster 0(A) example:

  ```
  hxtback -b -i FS50_xxx
  ```

  You will see output which includes something like the following:

  ```
  running fdump to get the GTI Extension header . . .
  cluster string: ClstrPosition ==  1 || ClstrPosition == 65 || ClstrPosition
  ==  8 || ClstrPosition == 72
  fselect for cluster position all source...
  ```

  where the tool has determined the values of ClstrPosition corresponding to an on-source pointing and run fselect with that selection expression; it will use another expression for the background pointings.

- Run this tool for each of your FITS data files. It may take quite a while for it to go through all the data.

Extracting light curves and spectra

What you need to know about binsizes: read even for SPECTRAL analysis !

The deadtime correction algorithm uses the GTI extensions of the extracted light curves and spectra. These extensions will depend on the chosen binsize, even for spectra, since the extractor's algorithm for creating them is the same regardless of which printmode you choose. The individual good time intervals cannot be smaller than the specified binsize, as each bin must be completely within good time, by definition. This means that, if you choose a binsize which is greater than the rocking interval, you loose the information about the on source versus the off source time intervals. This in turn causes an incorrect deadtime calculation. Users should use a binsize equal to the rocking interval so that the GTI extensions are appropriate and hxtdead will have the information it needs. After the correction is made, light curves can be rebinned using **lcurve** so that the background can be subtracted.

For archive mode: This step is very similar to extracting PCA Standard2 data using **saextrct**.

- If you have production data, you will want to apply the deadtime correction to the light curves and spectra. The current tools do not accept more than one science file at a time, so you should extract products from individual files. In other words, give the extractor only one file at a time.

  If, however, you have realtime data and will be unable to apply the deadtime correction anyway, you may make a list of the source (or background) FITS files from which to extract one light curve and spectrum, and enter the name of the list preceded by an '@' character.

- For the "GTI files to be OR'd", you must answer "APPLY" so that the resulting exposure correctly accounts for the rocking motion.

- One difference from PCA Standard2 data is that the default GOOD columns to extract does not apply. You must make your own column list consisting of the following text (each line followed by a return and with no blank lines before or after):

  ```
  SpecDet0
  SpecDet1
  SpecDet2
  SpecDet3
  ```

  and specify the name of this text file, prepended by '@', at the "COLUMNS to be accumulated" prompt.

- As discussed above, give a binsize equal to the rocking interval of your data.

- For the best results extracting a lightcurve, you should select only the channels with the highest signal to noise; for most sources, a range like 15-61 would be good. (This is above the LLD threshold and below where the background begins to dominate for a typical spectrum.) You should first extract a full spectrum and compare it to the background to determine which channels would be best for your particular source.

- You can run this from the command line or in a script; use "plist saextrct" to see the names of the parameters (there are many, but only "infile" and "outroot" will change):

  ```
  saextrct infile=FS52_xxx_src outroot=FS52_xxx_src gtiorfile=APPLY  binsz=12
  ```

  along with the long (too long to put here!) list of other parameters.

For event modes:

- As for Archive mode above, the number of files to extract at one time depends on whether or not you will apply the deadtime correction. In general, for each resulting FITS file from the above step, use **seextrct** to extract individual light curves and spectra which can then be corrected.

- Again, you must APPLY the GTIOR file.

- As discussed above, limit the channel range from which to extract a light curve to something like 15-61.

- Again, you may run this from the command line or in a script:

```
seextrct infile=FS50_xxx_src outroot=FS50_xxx_src gtiorfile=APPLY  binsz=12
```

along with the long (too long to put here!) list of other parameters.

Deadtime Correction

(Now available for both binned (Archive) and event modes, for processed data only, however; see Notes below for using realtime data.)

For more information about the HEXTE deadtime, please see http://mamacass.ucsd.edu:8080/hexte/status/hexte_deadtime.html.

hxtdead corrects either light curves or spectra for the clock time durations. This is an essential step in the reduction because the cluster's motion while rocking is treated as dead time in the off-source data, and background subtraction will be grossly in error without it. In addition to the file to be corrected, the hxtdead programs require data from the original FITS file and also a housekeeping file and coefficients file. They calculate live time corrections and apply them to the .pha or .lc file.

In both cases, hxtdead applies an algorithm developed by the HEXTE team to calculate the live-time based on 3 quantities: the live time counter in the FITS Science data file, FS5{0268}, and the so-called ULD and XULD particle rates in the 16-second Housekeeping file, FH5{39}. The coefficients file, hxtdead_97jul2_pwa.fits for Cluster A(0) or hxtdead_97jul2_pwb.fits for Cluster B(1), contains some HEXTE instrument settings which determine the conversion factors used by this algorithm. These files are in the latest version of the HEXTE area of CALDB. See the CALDB Management Page for how to update your current CALDB. Alternatively, you may simply get these individual files from the CALDB part of the anonymous ftp are at ftp://legacy.gsfc.nasa.gov/caldb/data/xte/hexte/bcf/deadtime/ and give the appropriate file at the prompt in stead of "CALDB".

Run **hxtdead** on both the source and background data files; this calculates the correct EXPOSURE keyword for the PHA files, so at the end of this stage you will have for each FITS data file: one source file and one or two background files, with appropriate keywords set.

```
%  hxtdead
    Running HXTDEAD version 0.0.1
   =============================================

   Calibration file:[]caldb
   File containing status apid values (FH5{39}):[] FH53_xxx
   File containing events list/archive data (FS5{0268}):[] FS50_xxx_src
   .pha/.lc file to be modified:[] FS50_xxx_src.pha
   Current  EXPOSURE = 1584.000000
   Adjusted EXPOSURE = 907.844299
```

To correct a light curve is essentially the same, but the output is much longer, as it displays the original and corrected rate fore each time bin.

Again, as an example of running this on the command line:

```
% hxtedead calvalf=caldb engvalf=FH53_xxx eventarcf=FS50_xxx_src phalcf=FS50_xxx_
```

Note: A common warning when running the tool is a message like the following:

```
apModPeriod undfined for index i = 455
uld or xuld undfined for indices i = 455 j = 0
...
Current  EXPOSURE = 784.000000
Adjusted EXPOSURE = 366.632904
Detector 0: Uld  data interpolated for   1 IDFs: 7796942 - 7796942
Detector 0: Xuld data interpolated for   1 IDFs: 7796942 - 7796942
...
```

The tool needs the housekeeping data to cover the entire time range of the science data, which is expected. Due to the different telemetry formats and rates, however, this isn't always the case. Occasionally, the science data will have an extra bin extending beyond the housekeeping, and hxtdead will simply interpolate the values in the housekeeping. This introduces only a negligible error and should in no way affect your analysis.

Another, less common warning which may appear is:

```
Error: Analysing SA type data.
       XFF Revision # < 5.3.1
       Continuing with analysis until error processing can be established.
```

The tool may run to completion but with incorrect results. This is due to a problem in early processing of HEXTE data which was fixed with XFF version 5.3.1. If you are working with data from original processing that was taken before mid December 1996, you may see this message. If so, you should give hxtdead not the _src or _bkg file but the original science data file.

Combining light curves and spectra

Since the event mode data has to be extracted one FITS file at a time and deadtime corrected separately, this describes how to combine the results.

- For combining the individual spectra, use the tool **mathpha** (the values of CORRSCAL, AREASCAL, and BACKSCAL will be incorrect if not set directly on the command line):

  ```
  % mathpha corrscal=0 backscal=1 areascal=1 nc=0
  Expression to be evaluated[]  FS50_xxx_src.pha+FS50_yyy_src.pha+FS50_zzz_s
  Units algebraic expression to be performed in (C,R,F or Help)[C]
  O/p PHA filename[]  src.pha
  Exposure time flag/value ({value},{file},CALC,NULL or Help)[] CALC
   ......... processing file: FS50_xxx_src.pha
   ......... processing file: FS50_yyy_src.pha
   ......... processing file: FS50_zzz_src.pha
   ...  ... performing algebra in units of COUNTS
   ... written the PHA data Extension
   ** mathpha 4.2.0 completed successfully
  ```

  Warning: this tool will not operate on files whose names include the "-" character, so if you name them after the original FITS files which include this between the start and stop times, mathpha will try to interpret it as a minus sign.

After you have combined the various individual spectra to make one source file and one background file, you are ready to XSPEC. (Note: do not attempt to combine spectra from clusters 0 and 1 in this way; the two must be analyzed as different instruments.)

- For combining the light curves, you can use **lcurve**, which, given 1 for the number of time series, takes a list of input light curves and appends them. It will also rebin them so that the background can then be subtracted in **lcmath**. See the fhelp for details on both of these tools.

Form the appropriate RMF:

The HEXTE response matrices are available via anonymous FTP at ftp://legacy.gsfc.nasa.gov/xte/calib_data/. The current version is *hexte_97mar20c_resp.tar.gz*.

- If you have 256-channel event list data, you may use the appropriate 256-channel HEXTE .rmf file and the corresponding .arf file found here. For Cluster 0(A) spectrum this is hexte_97mar20c_pwa.rmf/arf; for Cluster 1(B), use hexte_97mar20c_pwb013.rmf/arf for data since March 6, 1996 (when detector 2 went out), and hexte_97mar20c_pwb.rmf/arf for data before that time.

- For any modes with spectra binned differently (e.g. array data, often in the form of 64 channel spectra), users must first rebin the .RMF file to match the spectral binning of their data. You will first use the ftool **rddescr** which reads the PHA file and produces a text file with the channel-binning information. This can then be used to rebin the full-sampling 256-channel RMF using the tool **rbnrmf** thus:

```
% rddescr phafil=FS50_xxx_src.pha chanfil=FS50_xxx.bins
% rbnrmf binfile=FS50_xxx.bins infile=hexte_97mar20c_pwa.rmf outfile=FS50_xx
% fparkey add=yes value="FS50_xxx_src.rmf" fitsfile=FS50_xxx_src.pha keyword
```

The final command writes the name of the RMF into the PHA file for use with XSPEC (eventually these commands will be combined into a script).

Notes on the background:

- **Check the background spectra:**
If you did not use the -b option in HXTBACK, you may try using either the _p or _m background files. The spectra and/or light curves of these files should be the same, to within the error, unless a contaminating source appears in one of them. One easy way to check the two backgrounds against each other is to enter both as two data sets in XSPEC; if you plot them both this way, you should see that they lie exactly on top of one another. If there is any difference, this could indicate another source in the field. (To find out the exact pointing of the off-source rockings, use the web tool

HEXTErock.) Likewise, you can check the background against the on-source spectrum. They should look the same at the highest energies (where there are presumably no source counts). If there is any offset, this could be an indication that there is some mis-match in the way the two were extracted or that the deadtime correction is not right.

Assuming that the two background spectra look OK, you can use mathpha to add them together before performing a spectral analysis on the source.

- **Scaling the background for realtime data:**
  Though realtime data do not include the necessary housekeeping information for the deadtime correction, they can still be used for some basic analysis. You can at least make the simple correction for the exposure difference introduced by the clusters slewing from source to background pointings. It takes 2 seconds to slew from one pointing to the other, and this time is deadtime in the background data. So, if you bin the source and background lightcurves as described above, you must take into account the fact that there is 4 seconds less exposure for the background per dwell.

  For 16 second rocking, for instance, you should scale the background while subtracting in **lcmath** by entering a factor of 1.33 for the background light curve. (I.e. us the tool to multiply the count rate by 4/3, the ratio of 16 seconds on source to 12 seconds background, where the difference is the two slews, each of 2 seconds.) For the spectra, the total exposure should be corrected by the inverse of this amount. Simply take the value of the EXPOSURE keyword for the background PHA file, obtained using **fkeyprint**, and change it in the header using **fparkey** to 0.75 times the original exposure. (The fhelp for these tools describes the simple usage.)

If you have a question about RXTE, please send email to one of our help desks. This page is maintained by the RXTE GOF and was last modified on Monday, 17-Aug-1998 14:58:28 EDT.

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