The HXMT Data Reduction Guide

for hxmtsoftv2.05

HXMT Science Data Center [1]

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Chapter 1

Introduction

1.1 Scope

This document is meant as a guide and reference for users who want to extract scientific products with HXMT data.

1.2 Organization of this Guide

- Chapter 2 describes the HXMT instrument.
- Chapter 3 describes the HXMT data products.
- Chapter 4 describes the overview of data analysis software.
- Chapter 5, 6, and 7 describe the data analysis methods of HE, ME and LE, respectively.
- Chapter 8 describes the barycenter correction tools (`hxbary`), and other useful tools including the usage of pipeline tool (`hpipeline`) and an example of real data analysis.
- Appendix A gives a description of how to install `HXMTDAS` package.

Chapter 2

HXMT Instruments

The Hard X-ray Modulation Telescope (HXMT) is a large X-ray astronomical satellite with a broad energy band in 1–250 keV. It was successfully launched on June 15th, 2017 in China. It is a low earth orbit telescope with altitude of 550 km and inclination of 43 degrees. In order to fulfill the requirements of the broad band spectral and fast variability observations, three payloads are configured onboard HXMT, which are, High Energy X-ray telescope (HE) using 18 NaI(Tl)/CsI(Na) scintillation detectors for 20–250 keV band, Medium Energy X-ray telescope (ME) using 1728 Si-PIN detectors for 5–30 keV band, and Low Energy X-ray telescope (LE) using 96 SCD detectors for 1–15 keV band. The three payloads are integrated on a same supporting structure to achieve the same pointing direction, thus they can simultaneously observe the same source. They all have collimators to confine different kinds of field of view (FOV). Figure 2.1 shows the three main payloads onboard Insight-HXMT and their FOVs.

2.1 High Energy X-ray telescope

Similar to BeppoSAX/PDS and RXTE/HEXTE, HE adopts an array of NaI(Tl)/CsI(Na) PHOSWICHs as the main detectors as shown in the Figure 2.2. The diameter of each PHOSWICH is 190 mm. The thickness of NaI(Tl) and CsI(Na) is about 3.5 mm and 40 mm. The working temperature of PHOSWICHS is actively controlled in $18 \pm 2°$C. The incident X-ray with most of its energy deposited in NaI(Tl) is regarded as a NaI(Tl) event. CsI(Na) is used as an active shielding detector to reject the background events from backside and events with partial energy loss in the NaI(Tl). The scintillation photons generated within the two crystals can be collected by the same photomultiplier tube (PMT). Signals from the PMT (Hamamatsu R877–01) are pulse shaped to distinguish NaI(Tl) events and CsI(Na) events due to their different decay time. The energy loss, time of arrival and the pulse width with each detected event are measured, digitized and telemetered to the ground. The CsI(Na) can be used as a gamma ray burst (GRB) monitor. The detected energy range in normal mode is about 50–800 keV and is changed to 250 keV–3 MeV in GRB mode for CsI(Na) if the high voltage of PMT is decreased.

The collimators of HE define 15 narrow FOV ($5.7° \times 1.1°$), 2 wide FOV ($5.7° \times 5.7°$) and a blind FOV which was covered with 2 mm thick tantalum. They also have different orientations with a step of 60 degrees, as shown in Figure 2.1. The FOV and orientation of each detector are shown in Table 2.1.

For each PHOSWICH detector, a radioactive source ^{241}Am with an activity of 200 Bq is embedded into a plastic scintillator (BC–448M) and viewed by a separate Multi-Pixel Photon Counter. They all mounted in the collimator and used as an automatic gain control (AGC) detector. A coincident measurement between the AGC detector (5.5 MeV alpha particle) and PHOSWICH detector (59.5 keV X-ray) will be labeled as a calibration event. The calibration events are saved like norm events, just have a different flag to discriminate. The spectrum of calibration events is shown

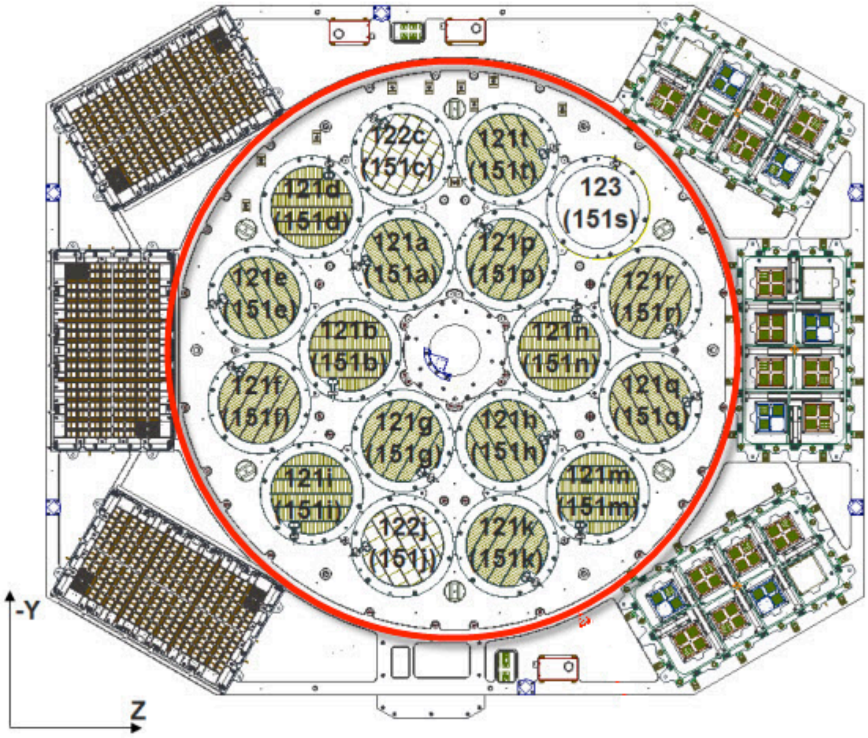

Figure 2.1: Three main payloads onboard Insight–HXMT. In the red circle, there are 18 NaI(Tl)/CsI(Na) scintillation detectors for HE. The left side is three ME boxes. The right side is three LE boxes. They all have different FOVs.

Detector ID	Field of View (FoV)	orientation
0	$5.7° \times 1.1°$	$-60°$
1	$5.7° \times 1.1°$	$0°$
2	$5.7° \times 5.7°$	$+60°$
3	$5.7° \times 1.1°$	$0°$
4	$5.7° \times 1.1°$	$-60°$
5	$5.7° \times 1.1°$	$+60°$
6	$5.7° \times 1.1°$	$+60°$
7	$5.7° \times 1.1°$	$-60°$
8	$5.7° \times 1.1°$	$0°$
9	$5.7° \times 5.7°$	$-60°$
10	$5.7° \times 1.1°$	$+60°$
11	$5.7° \times 1.1°$	$0°$
12	$5.7° \times 1.1°$	$0°$
13	$5.7° \times 1.1°$	$+60°$
14	$5.7° \times 1.1°$	$-60°$
15	$5.7° \times 1.1°$	$+60°$
16	blind FoV	
17	$5.7° \times 1.1°$	$-60°$

Table 2.1: The collimators of HE define 15 narrow FOV($5.7° \times 1.1°$), 2 wide FOV ($5.7° \times 5.7°$) and a blind FOV which was covered with 2 mm tantalum. They are distinguished by different detector IDs. They also have different orientations with a step of 60 degrees.

is Figure 2.3. In-flight performance shows that the line centroids of 59.5 keV are stable to better than 0.01 channels on a one day timescale. The response of NaI(Tl) is not uniform in its large surface so the calibration events are just used as the gain control and are not suitable to calibrate the gain of NaI(Tl) detectors in-orbit. In the analysis of X-ray spectrum, the radioactive events should be discarded.

Besides the active shielding of CsI(Na), HE also adopts the 18 plastic scintillators (6 on the top and 12 in the later sides of PHOSWICH detectors) as the anti-coincidence detectors(ACD). The ACD are always used to reject the particle background.

2.2 Medium Energy X-ray telescope

ME consists of 3 detector boxes as shown in Figure 2.4. Each box has 576 Si-PIN detector pixels read out by 18 ASIC (Application Specified Integrated Circuit). Each ASIC is responsible for the readout of 32 pixels. The working temperature of Si-PIN detectors in orbit is from $-40°$C to $-10°$C.

For each detector box, the collimators of ME confine 15 ASICs as narrow FOV ($1° \times 4°$), 2 ASIC as wide FOV($4° \times 4°$) and one blind FOV. The layout of the FOVs in one detector box is also shown in Figure 2.4. Two in-orbit calibration radioactive sources (^{241}Am) are installed in the corner of two ASICs and each source illuminates four pixels. The FOV of each detector is shown in Table 2.2.

Si-PIN detectors are fixed on the ceramic chip by silver glue. When the energy of incident X-ray photon is greater than 25.5 keV (K-edge of Ag), they have some probability of penetrating the Si-PIN and react with silver. Ag emission lines will be generated due to the photoelectric effect with electrons in K-shell of Ag and detected by the Si-PIN detectors. Figure 2.5 showed that emission lines of Ag appeared in the detected energy spectrum when energy of incident X-ray photon is larger than 25.5 keV in the ground calibration experiments.

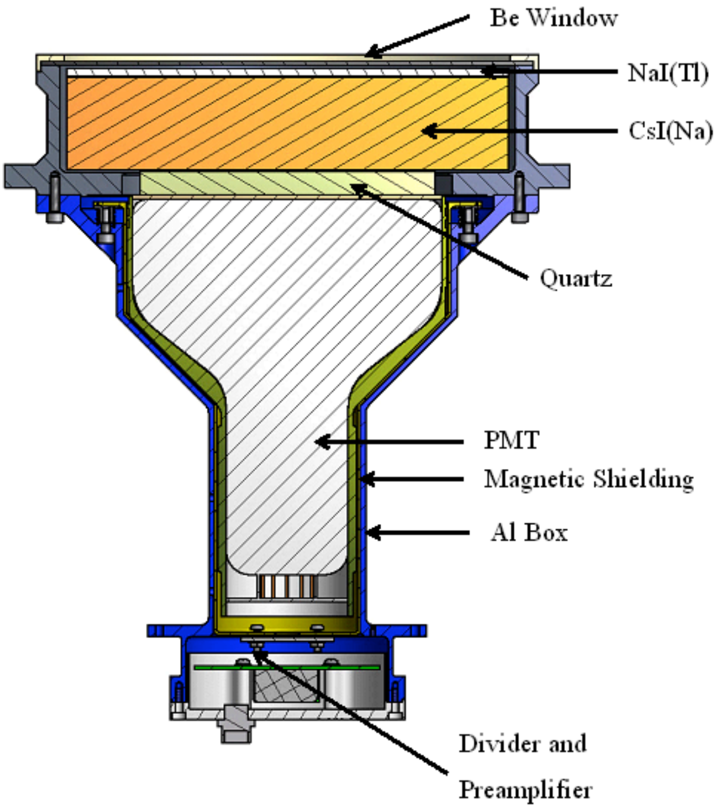

Figure 2.2: One detector module for HE.

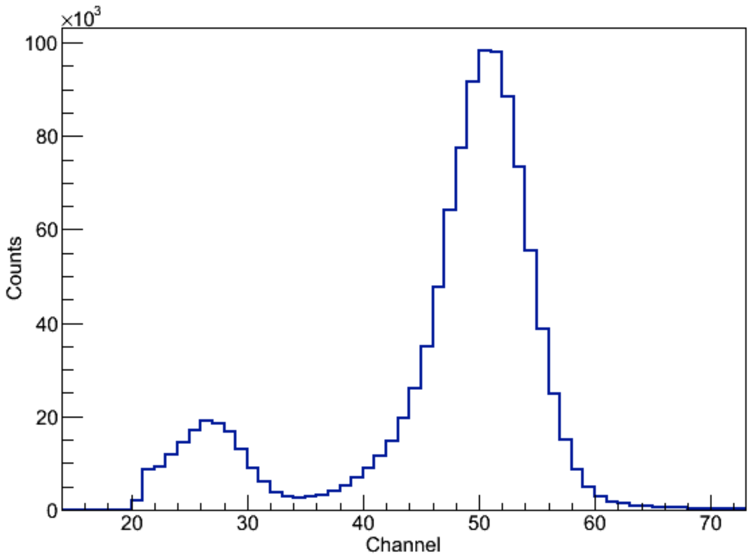

Figure 2.3: Calibration spectrum of ^{241}Am. The data were accumulated over one day. The 59.5 keV line was corresponded to the 50th Channel.

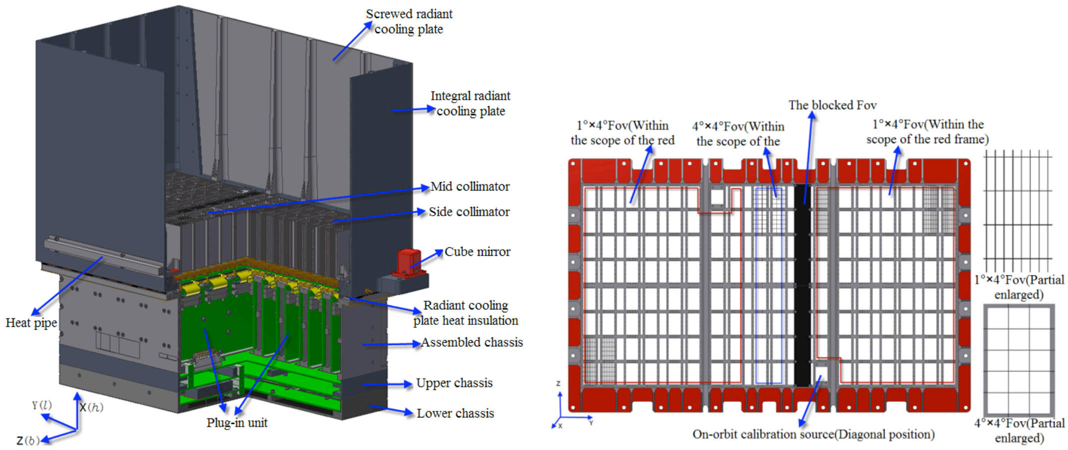

Figure 2.4: Left: One detector box of ME. Right: Layout of FOVs in one detector box.

Field of View(FoV)	Detector ID	ASIC ID
$1^\circ \times 4^\circ$	0-255	0-7
	352-575	11-17
	576-831	18-25
	928-1151	29-35
	1152-1407	36-43
	1504-1727	47-53
$4^\circ \times 4^\circ$	256-319	8-9
	832-895	26-27
	1408-1471	44-45
blind FoV	320-351	10
	896-927	28
	1472-1503	46
Calibration source	192	6
	352	11
	768	24
	928	29
	1344	42
	1504	47

Table 2.2: The FoVs of ME and the corresponding detector IDs.

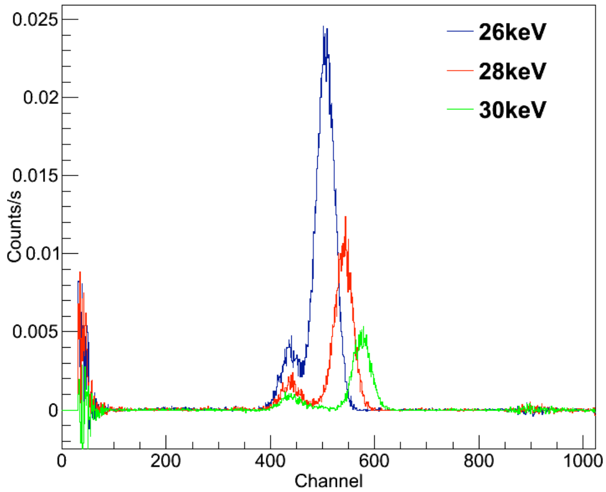

Figure 2.5: The emission lines of Ag generated in the detected spectrum of Si-PIN detectors when the energy of incident X-ray is larger than 25.5 keV(K-edge of Ag).

2.3 Low Energy X-ray telescope

LE also consists of three detector boxes and each box contains 32 CCD236 which is a kind of Swept Charge Devices (SCD). CCD236 is a second-generation SCD, which has been developed by e2v company. Each CCD236 is built with a sensitive area of about 4 cm^2 and has four quadrants. In each quadrant, the L-shaped electrodes guide the charge towards the diagonal firstly and then to a common readout amplifier in the central region. In the continuous readout mode, the maximum readout time is about 1 ms with a guaranteed energy resolution. Figure 2.6 shows the detector box of LE and photograph of four pieces of CCD236. The working temperature in-orbit for CCD236 is about from $-75°$C to $-40°$C.

For each detector box of LE, collimators define four kinds of FOVs as shown in Table 2.3. Twenty CCD236 have narrow FOVs with $1.6° \times 6°$. Six CCD236 have wide FOVs with $4° \times 6°$. Two CCD236 have blind FOVs and one of them has carried a ^{55}Fe radioactive source. Four CCD236 have a very large FOV with about $50 - 60° \times 2 - 6°$.

For events with energy above the onboard threshold, the energy and the readout time of each detected event are measured, digitized and telemetered to the ground. Besides this, LE also has the forced trigger events, which record the amplitude of the noise or the pedestal offset for each CCD detector every 32 ms. The forced trigger events are also saved as normal events, but with a different type.

The spreading of the charge cloud over several pixels may cause split events. These split events may be read out in adjacent readout periods. In order to reduce the effect of the charged particles, the single events without split are selected to generate the spectrum and light curve of LE.

Detector ID	Field of View(FOV)
0/32/64	$1.6° \times 6°$
1/33/65	$4° \times 6°$
2/34/66	$1.6° \times 6°$
3/35/67	$1.6° \times 6°$
4/36/68	$1.6° \times 6°$
5/37/69	$4° \times 6°$
6/38/70	$1.6° \times 6°$
7/39/71	$1.6° \times 6°$
8/40/72	$1.6° \times 6°$
9/41/73	$1.6° \times 6°$
10/42/74	$1.6° \times 6°$
11/43/75	$4° \times 6°$
12/44/76	$1.6° \times 6°$
13/45/77	blind FOV
14/46/78	$1.6° \times 6°$
15/47/79	$4° \times 6°$
16/48/80	$50 \sim 60° \times 2 \sim 6°$
17/49/81	$50 \sim 60° \times 2 \sim 6°$
18/50/82	$50 \sim 60° \times 2 \sim 6°$
19/51/83	$50 \sim 60° \times 2 \sim 6°$
20/52/84	$1.6° \times 6°$
21/53/85	blind FOV
22/54/86	$1.6° \times 6°$
23/55/87	$1.6° \times 6°$
24/56/88	$1.6° \times 6°$
25/57/89	$1.6° \times 6°$
26/58/90	$1.6° \times 6°$
27/59/91	$4° \times 6°$
28/60/92	$1.6° \times 6°$
29/61/93	$1.6° \times 6°$
30/62/94	$1.6° \times 6°$
31/63/95	$4° \times 6°$

Table 2.3: The FoVs of LE and the corresponding detector IDs.

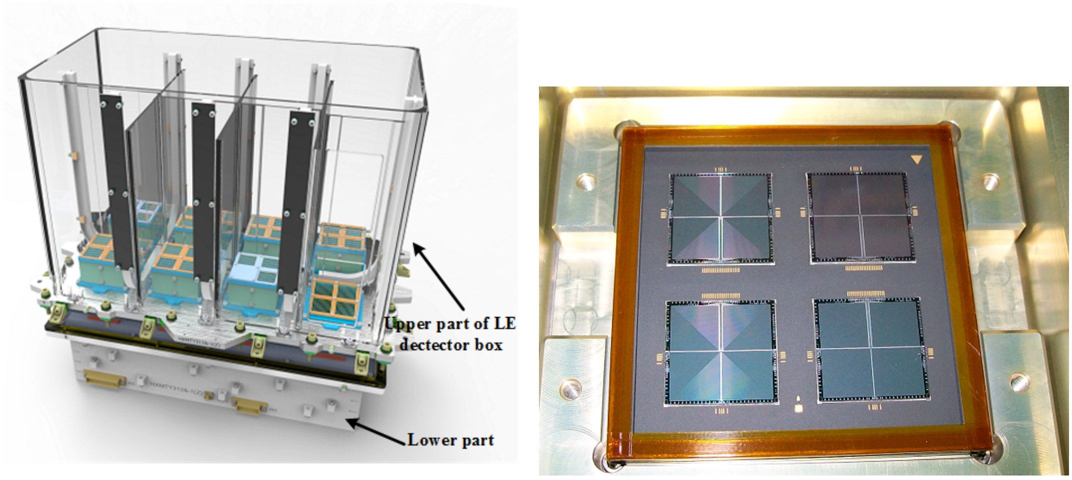

Figure 2.6: Left: one detector box of LE. Right: four pieces of CCD236.

Chapter 3

HXMT Data Products

3.1 Definitions of Proposal ID, Observation ID and Exposure ID

The observation data of Insight-HXMT is organized by Proposal-Observation-Exposure. Proposal ID is the unique ID of the approved proposal, which is assigned after the annual proposal collection. The proposal ID is named like "Paattmmm", where "aa" is the sequence of the annual proposal collection, "tt" is the type of proposal, "mmm" is the given sequence of the proposal.

One proposal may consist of several observations. One observation is the continuous time for a specific target. The observation ID is unique identification of an observation. The observation ID is composed of its proposal ID and the sequence number (3 digits, start from 001). For example P0102005003, "P0102005" is the proposal ID and "003" is the sequence number, it means this observation is the 3^{rd} observation of proposal P0102005.

Usually one observation lasts several hours and the data volume exceeds several GBs. To reduce the single file size, an observation is artificially split into multiple segments (named exposure), which is only a time segmentation in an observation without the traditional exposure concept of camera or CCD image instrument. The duration of an exposure is usually about three hours, except that few exposures will last longer. Exposure ID is used to name the directory of exposure data, which is composed of exposure sequence, observation date and some spare numbers. For example, in exposure ID P010200500308-20171106-03-04, P010200500308 indicates it is the 8^{th} exposure of the observation P0102005003, the exposure is begin from 20171106. There is also a short format Exposure ID used for filename. It only reserves part of exposure sequence, for example P010200500308.

3.2 The Directory Structure of Level 1 Data Product

For Scientific user, data analysis starts from Level 1 (L1) data product. Files of L1 data are arranged in a hierarchical directory tree with the cue of Observation ID - Exposure ID. The root directory of every product is named by the Observation ID. There are three types of catalogues: List Files, Exposures Directory and Auxiliary Data for whole observation.

- List Files:
  Two List File are provided in root of 1L product. "FileList.FITS" contains all files information of archived observation, include the name, path, size, type of file and md5 checksum and so on. "ExpoList.XML" gives exposures list in this observation.

- Auxiliary Data Directory:
  Two Auxiliary Data Directories are designed in root directory. "ACS" directory stores atti-

```
Observation ID
         |----FileList.FITS
         |----ExpoList.XML
         |----ACS
         |----AUX
         |----Exposure ID 1
         |----Exposure ID 2
              ......
         |----Exposure ID n
```

Figure 3.1: Directory of Observation ID.

```
|----Exposure ID
           |----ACS
           |----AUX
           |----HE
           |----LE
           |----ME
```

Figure 3.2: Directory of Exposure ID.

tude and orbit data. "AUX" is used for auxiliary data originated from ground segment, such as EHK and so on. These "ACS" and "AUX" catalogues cover for whole observation period, distinguished from the same directory in exposure directory, which only covered exposure period.

- Exposures Directory:
  Each exposure has a separate directory to store the scientific and the engineering data collected in the exposure period. "ACS" and "AUX" contain the same data as homonymic catalogs in root directory. "HE", "ME" and "LE" directories store Events and Engineering Data from HE, ME and LE telescope, respectively.

3.3 Level 1 Data Product

Data files of Level 1 Product are named as following format:
"HXMT_exposure-id_type_FFFFFF_Vn_L1P.FITS"
The filename is composed with seven segments, "HXMT", "exposure-id", "type", "FFFFFF", "Vn", "L1P", and "FITS". "HXMT", "FFFFFF" , "L1P", and "FITS" are fixed, and the rest vary according to different exposure ID, file types, and file version. The capital letters are fixed, and the lowercase letters are variable according to different file types and exposures.

- HXMT - Fixed Prefix for all data files.
- exposure-id - Short format Exposure ID.
- type - Abbreviated name of file type.
- FFFFFF - Reserved segment for future, filled with FF now.
- Vn - File Version. V is fixed prefix, n is the character from 1-9, a-z.

Abbreviated Type Name	Data Content
HE-Evt	HE_Events
HE-RadEvt	HE_Radioactive_Events
HE-ShltEvt	HE_Sheltered_Detector_Events
HE-InsStat	HE_Instrument_Status
HE-TH	HE_Temperature
HE-Cnts	HE_Counts
HE-DTime	HE_DeadTime
HE-HV	HE_High_Voltage
HE-PM	HE_Particle_Monitor
ME-Evt	ME_Events
ME-RadEvt	ME_Radioactive_Events
ME-ShltEvt	ME_Sheltered_Detector_Events
ME-CirPara	ME_Circuit_Parameter
ME-InsStat	ME_Instrument_Status
ME-TH	ME_Temperature
ME-Cnts	ME_Counts
LE-Evt	LE_Events
LE-RadEvt	LE_Radioactive_Events
LE-ShltEvt	LE_Sheltered_Detector_Events
LE-WFOVEvt	LE_Wide_FOV_Events
LE-ForcedEvt	LE_Forced_Trigger_Events
LE-CirPara	LE_Circuit_Parameter
LE-InsStat	LE_Instrument_Status
LE-TH	LE_Temperature
LE-Cnts	LE_Counts
Att	Attitude
Orbit	Orbit
EHK	Extend Housekeeping Data

Table 3.1: The types of the file.

- L1P - Fixed part. L1 indicates it is a Level 1 data file. P is the abbreviation of Pointing Observation Mode.
- FITS - Fixed file extension name, indicating this is a FITS format file.

This is an example of data files in an exposure directory as shown in Figure 3.3. All types of the file are displayed in the following Table 3.1.

```
P010129900101-20170827-01-01/
     |-- ACS
     |    |-- HXMT_P010129900101_Att_FFFFFF_V1_L1P.FITS
     |    `-- HXMT_P010129900101_Orbit_FFFFFF_V1_L1P.FITS
     |-- AUX
     |    `-- HXMT_P010129900101_EHK_FFFFFF_V1_L1P.FITS
     |-- HE
     |    |-- HXMT_P010129900101_HE-Cnts_FFFFFF_V1_L1P.FITS
     |    |-- HXMT_P010129900101_HE-DTime_FFFFFF_V1_L1P.FITS
     |    |-- HXMT_P010129900101_HE-Evt_FFFFFF_V1_L1P.FITS
     |    |-- HXMT_P010129900101_HE-HV_FFFFFF_V1_L1P.FITS
     |    |-- HXMT_P010129900101_HE-InsStat_FFFFFF_V1_L1P.FITS
     |    |-- HXMT_P010129900101_HE-PM_FFFFFF_V1_L1P.FITS
     |    |-- HXMT_P010129900101_HE-RadEvt_FFFFFF_V1_L1P.FITS
     |    |-- HXMT_P010129900101_HE-ShltEvt_FFFFFF_V1_L1P.FITS
     |    `-- HXMT_P010129900101_HE-TH_FFFFFF_V1_L1P.FITS
     |-- LE
     |    |-- HXMT_P010129900101_LE-CirPara_FFFFFF_V1_L1P.FITS
     |    |-- HXMT_P010129900101_LE-Cnts_FFFFFF_V1_L1P.FITS
     |    |-- HXMT_P010129900101_LE-Evt_FFFFFF_V1_L1P.FITS
     |    |-- HXMT_P010129900101_LE-ForceEvt_FFFFFF_V1_L1P.FITS
     |    |-- HXMT_P010129900101_LE-InsStat_FFFFFF_V1_L1P.FITS
     |    |-- HXMT_P010129900101_LE-RadEvt_FFFFFF_V1_L1P.FITS
     |    |-- HXMT_P010129900101_LE-ShltEvt_FFFFFF_V1_L1P.FITS
     |    |-- HXMT_P010129900101_LE-TH_FFFFFF_V1_L1P.FITS
     |    `-- HXMT_P010129900101_LE-WFOVEvt_FFFFFF_V1_L1P.FITS
     `-- ME
          |-- HXMT_P010129900101_ME-CirPara_FFFFFF_V1_L1P.FITS
          |-- HXMT_P010129900101_ME-Cnts_FFFFFF_V1_L1P.FITS
          |-- HXMT_P010129900101_ME-Evt_FFFFFF_V1_L1P.FITS
          |-- HXMT_P010129900101_ME-InsStat_FFFFFF_V1_L1P.FITS
          |-- HXMT_P010129900101_ME-RadEvt_FFFFFF_V1_L1P.FITS
          |-- HXMT_P010129900101_ME-ShltEvt_FFFFFF_V1_L1P.FITS
          `-- HXMT_P010129900101_ME-TH_FFFFFF_V1_L1P.FITS
```

Figure 3.3: An example of data files in an exposure directory.

Chapter 4

HXMT Data Analysis Overview

4.1 HXMTDAS overview

The Insight-HXMT Data Analysis Software package (HXMTDAS) is to achieve the HXMT data analysis processing and extract scientific products, such as energy spectra, light curves, Redistribution Matrix Files (RMF) and background files. It provides several tasks with each task is to accomplish a step of data analysis. These tasks are written in *ftools* style and are fully compatible with the HEASoft.

The processing procedures of HXMTDAS package is organized into three distinct stages for the calibration, the screening and the extraction of high-level scientific products. The input is a observation (call exposure ID) from the HXMT level 1 (1L) data products and has FITS format. It has two run styles:

- Command Line style:

```
hepical evtfile=HXMT_P010130600202_HE-Evt_FFFFFF_V1_1RP.FITS
outfile=he_pi.fits evtnum=5 timedel=0.00008
```

- User interface style:

```
hepical evtnum=5 timedel=0.00008
hepical : ##############################################
hepical : HXMT HE task, hepical is running
Name of the input 1-L Event FITS file[] HXMT_P010130600202_HE-Evt_FFFFFF_V1_1RP.FITS
Name of the output calibrated Event FITS file[] he_pi.fits
hepical : HXMT HE task, hepical is running successfully!
hepical : ##############################################
```

Since the input parameters are important to these tasks, some common parameters are listed as follows:

- evtfile [filename], name of the input 1L/reconstructed/screened Event FITS file.
- outfile [filename/string], name of the output FITS file/output prefix for spectra/light curves.
- baddetfile [filename], name of the Bad Detector FITS file or NONE for none; userdetid [string], detectors selection of each payload, some regulations: a set of detectors which are delimited by comma or blank character with each other will constitute a spectrum/light curve; more spectra/light curves is delimited by semicolon (";"); "-"(hyphen) means "to"; it can be set to a file (e.g., @+filename).

- starttime/stoptime [real], starting/stop time for summation (DEFAULT = 0).
- minPI/maxPI [integer], minimum/maximum PI to consider (DEFAULT = 0).

Calibration

Telecope	Task	Description
HE	*hepical*	remove spike events and calculate PI column
ME	*mepical*	calculate PI column
	megrade	calculate event grade and deadtime of each FPGA
LE	*lepical*	calculate PI column and remove forced trigger events
	lerecon	reconstruct two split events and assign event grade

At this stage, the values of Pulse Invariant (PI) are calculated from the raw values of Pulse Height Amplitude (PHA) of each event, accounting for temporal changes in gain and energy offset.

Users are advised to download the latest HXMT CALDB. If the parameter *gainfile* of these tasks is set to CALDB (*gainfile*=CALDB), these tasks will use the gain files from CALDB. Otherwise, the parameter can be directly set to the path of gain file.

The HE task *hepical* can be used to find the spike events with the default parameters *timedel*=0.00008 *evtnum*=5 *lowchan*=0 and *highchan*=255. If users who don't care low energy band can set *lowchan*=35 (and then remove the low band at screening). The meaning of these parameters is below:

- lowchan: low channel considered to remove spike events.
- highchan: high channel considered to remove spike events.
- timedel: time interval between two neighbor events for removing spike events.
- evtnum: continuous events number which two neighbor events satisfied *timedel* between *lowchan* and *highchan*.

The task *megrade* calculates the grade column for the input event file and writes the values in the output file. At the same time, higher grade events will be automatically removed from the event list. This task can also calculate the deadtime for each FPGA, which are required for *mespecgen* and *melcgen*. Other parameter *binsize* (DEFAULT = 1s) is used to set the time interval of each deadtime calculation.

The task *lepical* calculates the peak position of PHA distribution of forced trigger events with integral time of *maxtimedel* (DEFAULT = 60 s). The task *lerecon* reconstructs two-split event, and assigns grade (0: ALL; 1: Single Event; 2: Two-Split Event).

For these tasks, the GTI extension(s) present in the input file will be copied to the output file without changes.

There is a simple correlation between PI and energy (E, in keV):

- HE: PI=256*(E-15)/370
- ME: PI=1024*(E-3)/60
- LE: PI=1536*(E-0.1)/13

Screening

Telescope	Task name	Description
HE	*hegtigen*	generate a FITS GTI (good time interval) file
	hescreen	use GTI together with other criteria to screen the data
ME	*megtigen*	generate a FITS GTI file
	megticorr	generate a new GTI file to eliminate some bad time intervals from above GTI file
	mescreen	use GTI together with other criteria to screen the data
LE	*legtigen*	generate a FITS GTI file
	legticorr	generate a new GTI file to eliminate some bad time intervals from above GTI file
	lescreen	use GTI together with other criteria to screen the data

The Good Time Intervals (GTIs) are calculated according to two sets of parameters, one related to the extended housekeeping (EHK) file, the other one related to temperature file (default criteria). For HE, particle flux file could be used (if users don't want to use, please set *pmfile* to 'NONE'). The criteria associated to *expr* parameter (when '*defaultexpr*' parameter set to 'NONE') for each payload is listed below:

```
HE: ELV>10&&COR>8&&SAA_FLAG==0&&ANG_DIST<0.04&&T_SAA>300&&TN_SAA>300
ME: ELV>10&&COR>8&&SAA_FLAG==0&&ANG_DIST<0.04&&T_SAA>300&&TN_SAA>300
LE: ELV>10&&DYE_ELV>30&&COR>8&&SAA_FLAG==0&&ANG_DIST<0.04&&T_SAA>300&&TN_SAA>300
```

We recommend users set *defaultexpr* to NONE and use *expr* parameter. If these GTI tasks report the following error:
please set parameter '*expr*' when '*defaultexpr*=NONE'
please use these tasks with the *expr* parameter, for example,

```
hegtigen expr="ELV>10&&COR>8&&SAA_FLAG==0&&ANG_DIST<0.04&&T_SAA>300&&TN_SAA>300"
```

Sometimes, there are still some bad time intervals in GTI files. The tasks of *megticorr* and *legticorr* are used to eliminate these intervals and new GTI files are generated for ME and LE, respectively.

The screening criteria used to generate the cleaned event file are listed as follows:

- Removal of the bad time intervals (using the GTI file (*gtifile*) and GTIs in event file);
- Removal of the bad detectors (*baddetfile* parameter);
- Removal of the bad events (events with higher grade);

For HE, *anticoincidence* can be used (set to 'yes') to remove particle background; *minpulsewidth* (DEFAULT = 54) and *maxpulsewidth* (DEFAULT = 70) are the minimum and maximum pulse width for NaI, respectively.

Extracting high-level Products

Telescope	Task	Description
HE	*hespecgen*	extract spectra
	helcgen	extract light curves
	herspgen	generate response file
	hebkgmap	generate background file
ME	*mespecgen*	extract spectra
	melcgen	extract light curves
	merspgen	generate response file
	mebkgmap	generate background file
LE	*lespecgen*	extract spectra
	lelcgen	extract light curves
	lerspgen	generate response file
	lebkgmap	generate background file

At this stage, the high-level products are extracted from the screened event file. The products include the energy spectra, response file (RSP), light curves and background files.

The exposure time is the summation of all deadtime corrected GTIs.

To extract a light curve, the bin size (*binsize*) of the light curves must be set. Sometimes, the start or end of the GTIs may fall within a bin size and the column named *fracexp* in the light curve will give the value as the proportion of the bin shortening for each bin. The deadtime correction (set parameter *deadcorr*=yes) is done bin by bin using the deadtime file (the parameter *deadfile*). If the parameter of *aligncorr* set to yes and the parameter of *attfile* set to attitude file, the psf (point spread function) correction can be done bin by bin.

hebkgmap, *mebkgmap* and *lebkgmap* are used to generate background files for HE, ME and LE, respectively.

Other tools

- hxmtscreen
  There are some different time intervals for different detectors of one telescope. For example, the GTIs of 18 detectors of HE may be different with each other. This task is used to filter these event files generated by *hescreen* according to their common GTIs among all detectors. The output event file only includes a common GTI extension. The parameter *usergtifile* can be set to "NONE" or a text file (each line has a format of 'start-time stop-time') and the common GTI will consider the GTIs in text file. The task can also be used for ME and LE.

- hxbary
  Do barycenter correction for HE, ME and LE. The time is corrected from TT to TDB (accuracy $< 1\,\mu s$) and written to a new column named TDB.

- hxbary2
  Do barycenter correction for HE, ME and LE. The time column is replaced by TDB time.

Chapter 5

HE Data Analysis

This chapter contains the details of the current status of the HE data analysis.

The processing procedures include three major steps: calibration (stage 1), screening (stage 2) and extraction of high-level scientific products (stage 3). For stage 1, the EVT file is processed to produce a calibrated EVT file; for stage 2, the calibrated EVT file is filtered by applying cleaning criteria to produce a cleaned EVT file; for stage 3, the high-level scientific products are generated. The following sections describe the analysis steps that are presented in Fig. 5.1.

5.1 Calibration

5.1.1 hepical

This task mainly remove spike events and calculate PI values of HE event. The CsI events are removed in this task by default.

The spike events are false signal and caused by electronic system. Generally, the light curve of spike is a 'burst', which is not from the sources. Usually, it only happens in one detector in a very short time interval.

PARAMETER

The parameters of this task are listed below:

- evtfile [file name]
  Name of the input 1-L event FITS file.
- outfile [file name]
  Name of output calibrated event FITS file.
- gainfile [file name]
  Name of the input gain FITS file.
  If set to CALDB, use the file in the Calibration Database(DEFAULT=CALDB).
- seed [int]
  Input seed for random number generator.
- lowchan [int]
  Low channel considered to remove events led by electronic instrument (DEFAULT = 0).
- highchan [int]
  High channel considered to remove events led by electronic instrument (DEFAULT = 255).

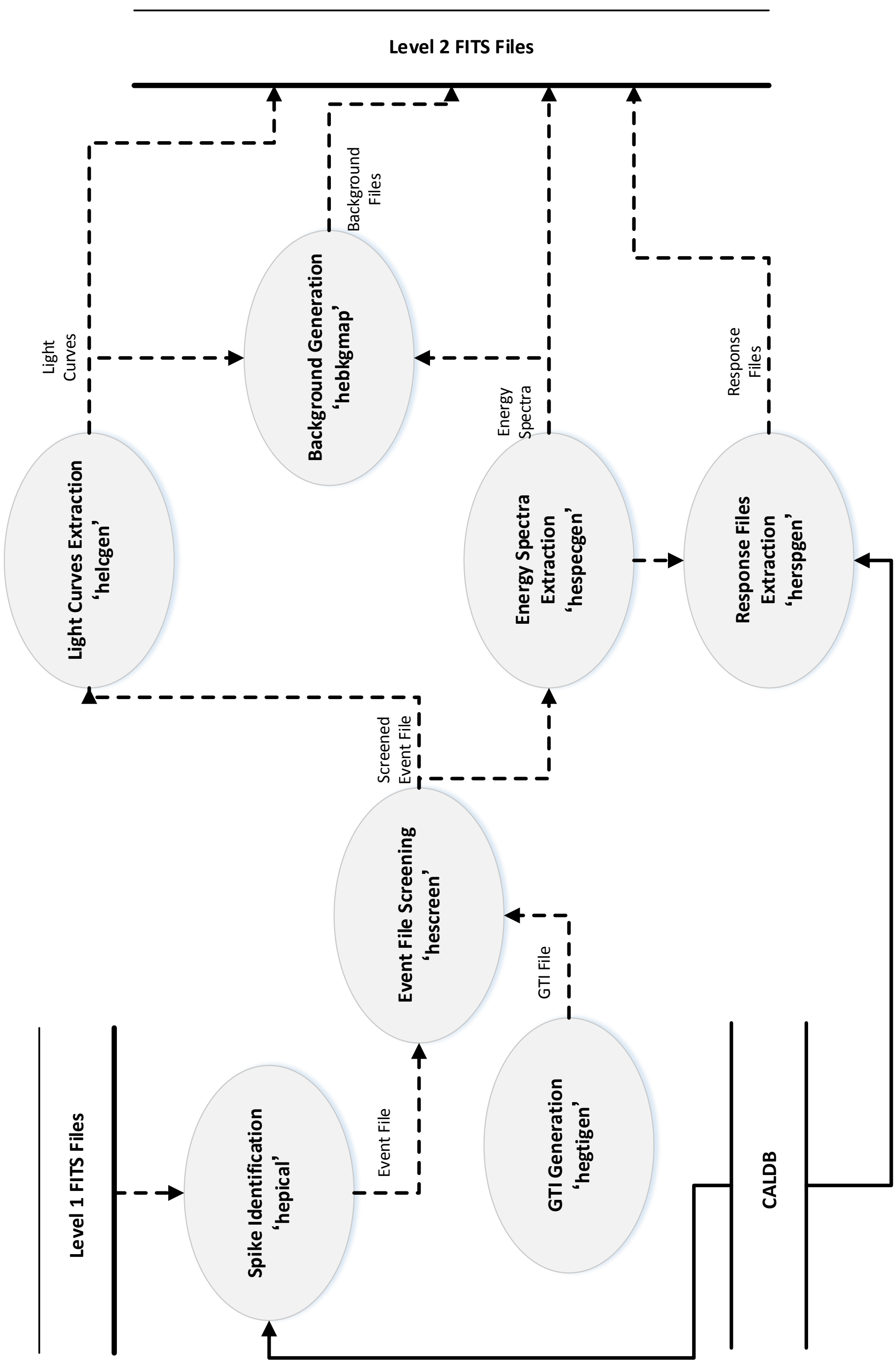

Figure 5.1: HE data reduction flow diagram.

- timedel [real]
  Time interval between tow neighbor events for removing spike events (DEFAULT=0.00008).

- evtnum [int]
  Continuous events number which two neighbor events satisfied *timedel* between *lowchan* and *highchan* to consider (DEFAULT = 5).

- glitchfile [file name]
  Name of the output file of spike events (DEFAULT = NONE).

- clobber [boolean]
  If *clobber=yes* and outfile=filename, the file with the same name will be overwritten if it exists (DEFAULT=yes).

- history [boolean]
  If *history=yes* the parameter values and other information are written in HISTORY keywords (DEFAULT=yes).

- chatter[integer]
  Chatter Level (min=0, max=5) (DEFAULT=2). It is used to control the output message.

USAGE

- General usage

```
hepical evtfile=HXMT_P010129300302_HE-Evt_FFFFFF_V1_L1P.FITS  outfile=he_pi.FITS
```

The structure (Event extension and GTIs extension) of HXMT_P010129300302_HE-Evt_FFFFFF_V1_L1P.FITSS will copy to the new files. And a column named PI is added in the new event file.

- If users want to get the spike events, please set *glitchfile*.

```
hepical glitchfile=he_spike.FITS
```

The default parameters to remove spike events are *lowchan=0 highchan=255 timedel=0.00008* and *evtnum=5*. Figure. 5.2 shows the comparison between the raw light curve and the spike light curve removed by this tool (*binsize=0.1s*).

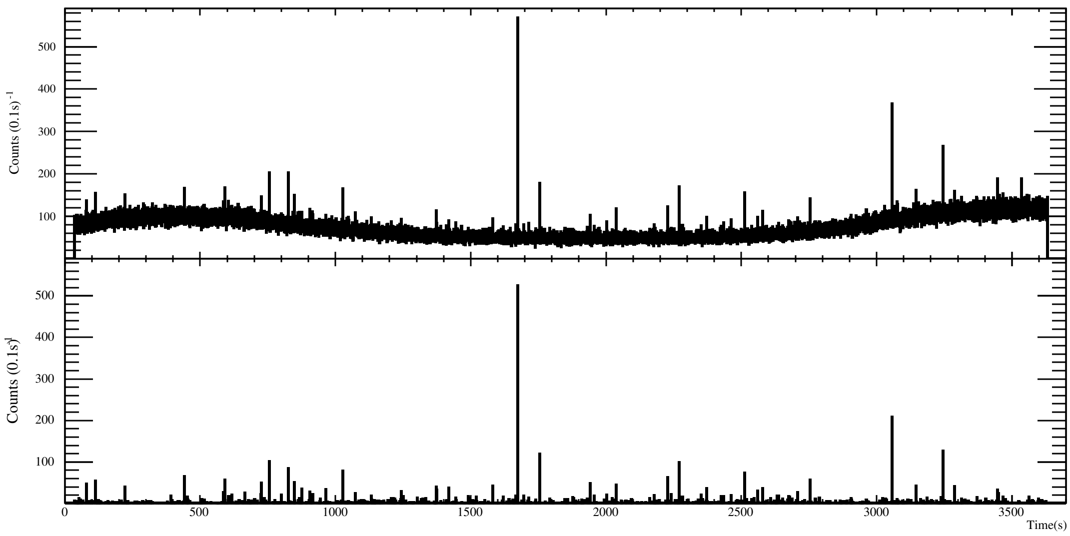

Figure 5.2: The comparison between the raw light curve (upper panel) and the spike light curve (lower panel) with *binsize=0.1s* and *Det_ID=16*.

- This tool needs CALDB environment. The default *gainfile* is set to 'CALDB'. Users can also assign the gain file, by:

```
hepical gainfile=/file/path/to/hxmt_he_gain_20171030_v1.fits
```

5.2 Screening

5.2.1 hegtigen

Generate a GTI FITS file.

PARAMETER

The parameters of this task are listed below:

- hvfile [file name]
  Name of the input 1-L High Voltage FITS file.
- tempfile [file name]
  Name of the input 1-L Temperature FITS file.
- ehkfile [file name]
  Name of the input 1-L EHK FITS file.
- outfile [file name]
  Name of output GTI FITS file.
- rangefile [file name]
  Name of the input parameter configure FITS file. Default is $HEADAS/refdata/herangefile.fits.

- ascendfile [file name]
  Name of the input fits for high bkg. Default is $HEADAS/refdata/HE_D0_C26-255_Ascend_PHA_Map.txt or NONE.
- descendfile [file name]
  Name of the input fits for high bkg. Default is $HEADAS/refdata/HE_D0_C26-255_Descend_PHA_Map.txt or NONE.
- defaultexpr [string]
  EHK Selection Expression: 'YES' to use parameter *herangefile*/ 'NO' for user setting/ *NONE* to use parameter *expr* and only create a GTI extension.
- ELV [real]
  Pointing direction above Earth($> 10^\circ$) or $<0^\circ$ for default.
- DYE_ELV [real]
  Pointing direction above bright Earth($> 10^\circ$) or $<0^\circ$ for default.
- SAA_FLAG [bool]
  Exclude the data in SAA.
- T_SAA [real]
  Time since SAA passage($> 300\,$s) or $< 0\,$s for default.
- TN_SAA [real]
  Time to next SAA passage($> 300\,$s) or $< 0\,$s for default.
- COR [real]
  Min Cut-off Rigidity value($> 8\,$GV) or < 0 for default.
- MOON_ANGLE[real]
  The Moon Angle is bigger than($> 1^\circ$) or $< 0^\circ$ for default.
- SUN_ANGLE [real]
  The Sun Angle is bigger than($> 70^\circ$) or $< 0^\circ$ for default.
- ANG_DIST [real]
  The offset angle from the pointing direction.
- pmfile [file name]
  Name of the input Particle Monitor FITS file.
- pmexpr [string]
  Selection Expression for Particle Monitor File (DEFAULT = NONE).
- expr [string]
  Selection Expression for EHK file (DEFAULT=NONE), if *defaultexpr*=NONE, *expr* must be set.
- prefr [real]
  Pre-Time Interval factor [0,1], default is 0.5.
- postfr [real]
  Post-Time Interval factor [0,1], default is 0.5.
- clobber [boolean]
  If clobber=yes and outfile=filename, the file with the same name will be overwritten if it exists (DEFAULT=yes).

- history [boolean]
  If history=yes the parameter values and other information are written in HISTORY keywords (DEFAULT=yes).

- chatter [integer]
  Chatter Level (min=0, max=5) (DEFAULT=2).

USAGE

- General usage

```
hegtigen hvfile=HXMT_P010129300302_HE-HV_FFFFFF_V1_L1P.FITS
tempfile=HXMT_P010129300302_HE-TH_FFFFFF_V1_L1P.FITS
ehkfile=HXMT_P010129300302_EHK_FFFFFF_V1_L1P.FITS
outfile=he_gti.FITS defaultexpr=NONE
expr="ELV>10&&COR>8&&SAA_FLAG==0&&ANG_DIST<0.04&&T_SAA>300&&TN_SAA>300"
```

  Currently, we recommend users set the parameter *defaultexpr* to *NONE*, not to *YES/NO*.

- If users want to use particle monitor, users should set *pmfile* and *pmexpr* correctly. For example:

```
hegtigen hvfile=HXMT_P010129300302_HE-HV_FFFFFF_V1_L1P.FITS
tempfile=HXMT_P010129300302_HE-TH_FFFFFF_V1_L1P.FITS
ehkfile=HXMT_P010129300302_EHK_FFFFFF_V1_L1P.FITS
outfile=he_gti.FITS defaultexpr=NONE
expr="ELV>10&&COR>8&&SAA_FLAG==0&&ANG_DIST<0.04&&T_SAA>300&&TN_SAA>300"
pmfile=HXMT_P010129300302_HE-PM_FFFFFF_V1_L1P.FITS
pmexpr="Cnt_PM_0<100&&Cnt_PM_1<100&&Cnt_PM_2<100"
```

- If users want to set their own criteria for high voltage or temperature, users can modify the *herangefile.fits* and set the *rangefile* parameter. For example:

```
hegtigen rangefile=./rangefile.fits
```

  The default value of *herangefile.fits* is $HEADAS/refdata/herangefile.fits.

- History keywords in GTI file (*GTIDesc* extension):
  Users can ignore these keywords such as 'HISTORY P8 ELV = 5', 'HISTORY P10 COR=5', etc, when the parameter *defaultexpr=NONE*, and users only concern the *expr* keyword (*HISTORY P18 expr=*"$ELV > 10\&\&ANG\_DIST < 0.1\&\&SAA\_FLAG == 0$").

- This version has removed some regions where the background can not be estimated very well, so the GTIs maybe less than these in previous version(2.0/2.01). If users don't care the background estimation, users can set the parameter *ascendfile* and *descendfile* to *NONE*, and will get more GTIs. For example:

```
hegtigen defaultexpr=NONE
expr="ELV>10&&COR>8&&SAA_FLAG==0&&ANG_DIST<0.04&&T_SAA>300&&TN_SAA>300
ascendfile=NONE descendfile=NONE
hvfile=HXMT_P010129300302_HE-HV_FFFFFF_V1_L1P.FITS
tempfile=HXMT_P010129300302_HE-TH_FFFFFF_V1_L1P.FITS
ehkfile=HXMT_P010129300302_EHK_FFFFFF_V1_L1P.FITS
outfile=he_gti.FITS
```

5.2.2 hescreen

Selection some of the photons with special criteria in event file.

PARAMETER

The parameters of this task are listed below:

- evtfile [file name]
  Name of the calibrated event FITS file.
- outfile [file name]
  Name of output screened event FITS file.
- gtifile [file name]
  Name of the input GTI FITS file.
- baddetfile [file name]
  Name of the input bad detector configure file. Always set to '$HEADAS/refdata/hedetectorstatus.fits'.
- userdetid [string]
  Detector ID (0-17) Selection (ID List).
- anticoincidence [bool]
  The logical anticoincidence selection used? (*yes/no*) (DEFAULT = *yes*).
- eventtype [int]
  Type of Event: 0 for all; 1 for X-ray; 2 for calibration source (DEFAULT=1)
- starttime [real]
  Start time for filtering (DEFAULT = 0).
- stoptime [real]
  Stop time for filtering (DEFAULT = 0).
- minPI [int]
  Minimum PI for filtering.
- maxPI [int]
  Maximum PI for filtering.
- minpulsewidth [int]
  Minimum Pulse Shape Discriminator for NaI and CsI (DEFAULT = 54).
- maxpulsewidth [int]
  Maximum Pulse Shape Discriminator for NaI and CsI (DEFAULT = 70).
- clobber [boolean]
  If *clobber=yes* and *outfile=filename*, the file with the same name will be overwritten if it exists (DEFAULT=yes).
- history [boolean]
  If 'history=yes' the parameter values and other information are written in HISTORY keywords (DEFAULT=yes).
- chatter [integer]
  Chatter Level (min=0, max=5) (DEFAULT=2).

USAGE

- General usage

```
hescreen evtfile=he_pi.FITS gtifile=he_gti.FITS  outfile=he_screen.FITS
userdetid="0-17"
```

- If users don't want to use logical anticoincidence array, users can set *anticoincidence* to *no* (DEFAULT=*yes*). We recommend users set this parameter *yes*. Because the background generation module need *anticoincidence=yes*.
- The parameters of *minpulsewidth* and *maxpulsewidth* can be set to any values (DEFAULT=54, 70), but for background generation, only the default values are considered.
- In order to estimate the background, the blind detector should be selected in this stage.

Example

In Figure 5.3, the upper panel shows the light curve of event file (ObsID: P010129800201) after performing *hepical*. The bottom panel is the light curve after performing *hescreen*. The "0-15,17" detectors are selected. And the NaI photons which have pulsewidth between 54 to 70 are selected as well.

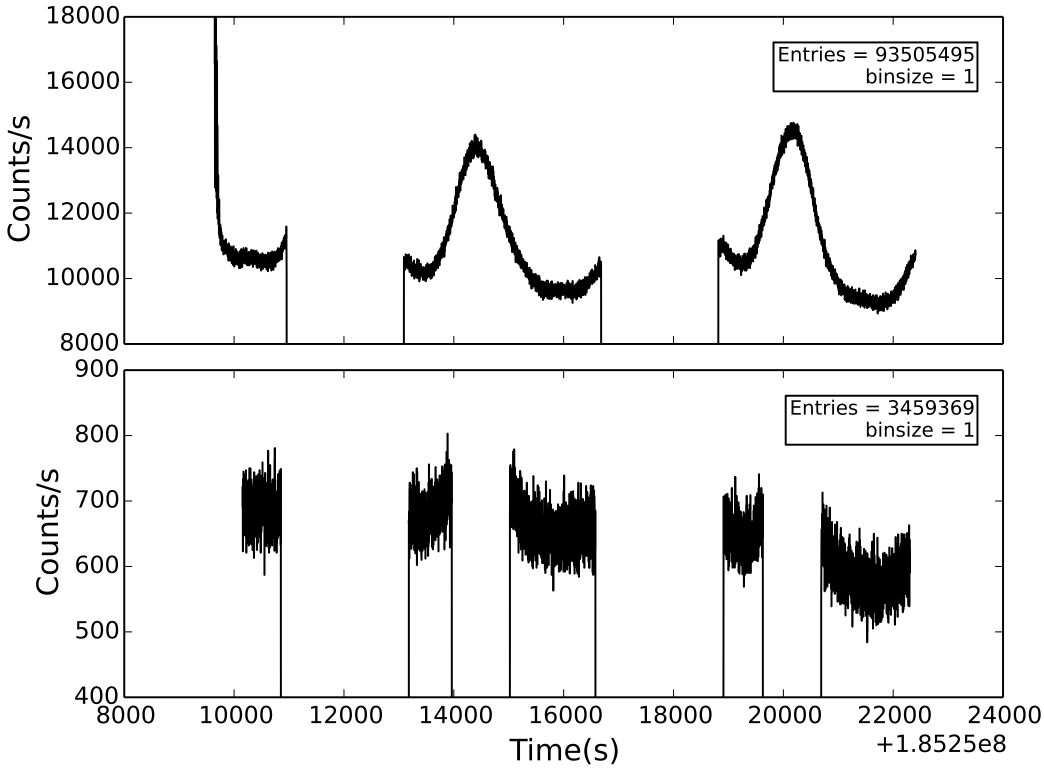

Figure 5.3: The top panel is the light curve of event file after *hepical* and the bottom panel is the light curve after *hescreen*.

5.3 Extracting High Level Products

5.3.1 hespecgen

This task is used to extract spectra of HE telescope.

PARAMETER

The parameters of this task are listed below:

- evtfile [file name]
  Name of the screened event FITS file.
- outfile [file name]
  Name of the output prefix to PHA FITS file.
- deadfile [file name]
  Name of the input 1-L dead time FITS file.
- userdetid [string]
  Detector ID (0–17) Selection (ID List), such "0-17; 0 1 2 3; 4,5,6,7; 8-10,11"
- eventtype [int]
  Type of Event: 0 for for; 1 for X-ray; 2 for calibration source (DEFAULT = 1).
- starttime [real]
  Start time for filtering (DEFAULT = 0).
- stoptime [real]
  Stop time for filtering (DEFAULT = 0).
- minPI [int]
  Minimum PI for filtering.
- maxPI [int]
  Maximum PI for filtering.
- clobber [boolean]
  If *clobber=yes* and *outfile=filename*, the file with the same name will be overwritten if it exists (DEFAULT=*yes*).
- history [boolean]
  If *history=yes* the parameter values and other information are written in HISTORY keywords (DEFAULT=*yes*).
- chatter [integer]
  Chatter Level (min=0, max=5) (DEFAULT=2).

USAGE

- General usage

```
hespecgen evtfile=he_screen.FITS
deadfile=HXMT_P010129300302_HE-DTime_FFFFFF_V1_L1P.FITS
outfile=spec userdetid="0-15,17"
```

5.3.2 helcgen

This task is used to extract light curve of HE telescope.

PARAMETER

The parameters of this task are listed below:

- evtfile [file name]
  Name of the screened event FITS file.
- outfile [file name]
  Name of the output prefix to PHA FITS file.
- deadfile [file name]
  Name of the input dead time FITS file.
- binsize [real]
  Bin size (seconds) for light curve.
- userdetid [string]
  Detector ID (0–17) selection (ID List), such "0-15,17".
- eventtype [int]
  Type of Event: 0 for all; 1 for X-ray; 2 for calibration source (DEFAULT = 1).
- starttime [real]
  Start time for filtering (DEFAULT = 0)
- stoptime [real]
  Stop time for filtering (DEFAULT = 0)
- minPI [int]
  Minimum PI for filtering.
- maxPI [int]
  Maximum PI for filtering.
- deadcorr [bool]
  Correct light curve used dead time (yes/no) (DEFAULT = no).
- aligncorr [bool]
  Correct light curve used time-dependent PSF (alignment) correction, at the same time, users should set *attfile*.
- attfile[file name]
  Name of the input 1-L Attitude FITS file (PSF correction, set *aligncorr=yes*).
- (clobber=no) [boolean]
  If *clobber=yes* and *outfile=filename*, the file with the same name will be overwritten if it exists.
- (history=yes) [boolean]
  If *history=yes* the parameter values and other information are written in HISTORY keywords.
- (chatter = 2) [integer]
  Chatter Level (min=0, max=5)

USAGE

- General usage

```
helcgen evtfile=he_screen.FITS
deadfile=HXMT_P010129300302_HE-DTime_FFFFFF_V1_L1P.FITS
outfile=spec userdetid="0-15,17" binsize=1 minPI=9 maxPI=59
```

- To get a better background estimation, the PI of light curve of non-blind detectors is suggested to be in the range from 9 to 59.

5.3.3 herspgen

This task is used to generate the response file of spectrum.

PARAMETER

The parameters of this task are listed below:

- phafile [file name]
  Name of the input PHA FITS file.
- outfile [file name]
  Name of the output RSP FITS file.
- attfile [file name]
  Name of the input 1-L Attitude FITS file.
- ra [real]
  Source R.A. (degrees), from 0° to 360° (DEFAULT = -1).
- dec[real]
  Source Decl. (degrees), form $-90°$ to 90° (DEFAULT = -91).
- (clobber=no) [boolean]
  If *clobber=yes* and *outfile=filename*, the file with the same name will be overwritten if it exists.
- (history=yes) [boolean]
  If *history=yes* the parameter values and other information are written in HISTORY keywords.
- (chatter = 2) [integer]
  Chatter level (min=0, max=5).

USAGE

- General usage

```
herspgen phafile=spec_g0_0-17.pha
attfile=ACS/HXMT_P010129300302_Att_FFFFFF_V1_1RP.FITS
outfile=he_rsp.fits ra=-1 dec=-91
```

- If users set ra and dec to -1 and -91, respectively, the task will read their values from keywords of spectrum file.
- If users set ra and dec, the task will generate the response file for this direction.

```
herspgen phafile=spec_g0_0-17.pha
attfile=ACS/HXMT_P010129300302_Att_FFFFFF_V1_1RP.FITS
outfile=he_rsp.fits ra=86.3 dec=22.0
```

- This version can not generate response file for blind detector.

5.3.4 hebkgmap

The background light curve and spectrum are generated for all non-blind detectors by *hebkgmap*

USAGE

Run "hebkgmap -h" or "fhelp hebkgmap" for usage. The format of using the *hebkgmap* command is shown in the following:

- *Method 1*: hebkgmap lc/spec he_screen.FITS ehkfile.fits gtifile.fits deadtime.fits lcname/specname chmin chmax outnam_prefix

- *Method 2*: Using interactive method in prompt.

- *Method 3*: hebkgmap sflag=lc/spec evtfile=he_screen.FITS ehkfile=ehkfile.fits gtifile=gtifile.fits dtname=deadtime.fits srcdat=lcname/specname chmin=chmin chmax=chmax outnam=outnam_prefix

Parameters

Parameters input for method 1:

- lc/spec: [char]
  lc for background light curve and *spec* for background spectrum.
- hescreen.FITS: [file name]
  The event file that includes the events of the blind detectors (DetID=16).
- ehkfile.fits: [file name]
  The EHK file for the observation.
- gtifile.fits: [file name]
  GTI file for HE.
- deadtime.fits: [file name]
  The dead time file for HE.
- lcname/specname: [file name]
  ASCII file, in which the name of the light curves or the spectra to analysis should be written.
- chmin: [int]
  Minimum PI for light curves.
- chmax: [int]
  Maximum PI for light curves.
- outnam_prefix: [char]
  The output prefix for the light curves or spectra.

Parameters input for method 3:

- sflag: [char]
  lc for background light curve and *spec* for background spectrum.
- evtfile [file name]
  The event file that includes the events for the blind detector (DetID=16).
- ehkfile: [file name]
  EHK file for the observation.
- gtifile: [file name]
  GTI file for HE.
- dtname: [file name]
  The dead time file for HE.
- srcdat: [file name]
  ASCII file, in which the name of the light curves or the spectra to analysis should be written.
- chmin: [int]
  The minimum PI for light curves.
- chmax: [int]
  The maximum PI for light curves.
- outnam_prefix: [char]
  The output prefix for light curves or spectra.

Example

Here we present the general case for creating background files of light curves and spectra.
(1) Generate background spectra
If spectrum of HE has been generated, *spec_g0_0-17.pha*, then saves this name to an ASCII file named *specname.txt*. The content of ASCII file *specname.txt* look like this:

```
spec_g0_0-17.pha
```

You may perform the command

```
hebkgmap spec he_screen.FITS ehkfile.fits gtifile.fits  deadtime.fits specname.txt
0 255 he_specbkg
```

(2) Generate background lightcurve
If lightcurve of HE has been generated and its name is *he_g0_0-17.lc*, then write the name of light curve file to an ASCII file named *lcname.txt*. The content of ASCII *lcname.txt* should be like this:

```
he_g0_0-17.lc
```

The channel range selected for the lightcurve is 9 to 59 (roughly refers to 28–100 keV). Now you may perform the command

```
hebkgmap lc hescreen.FITS ehkfile.fits gtifile.fits deadtime.fits
lcname.txt  9 59 he_lcbkg
```

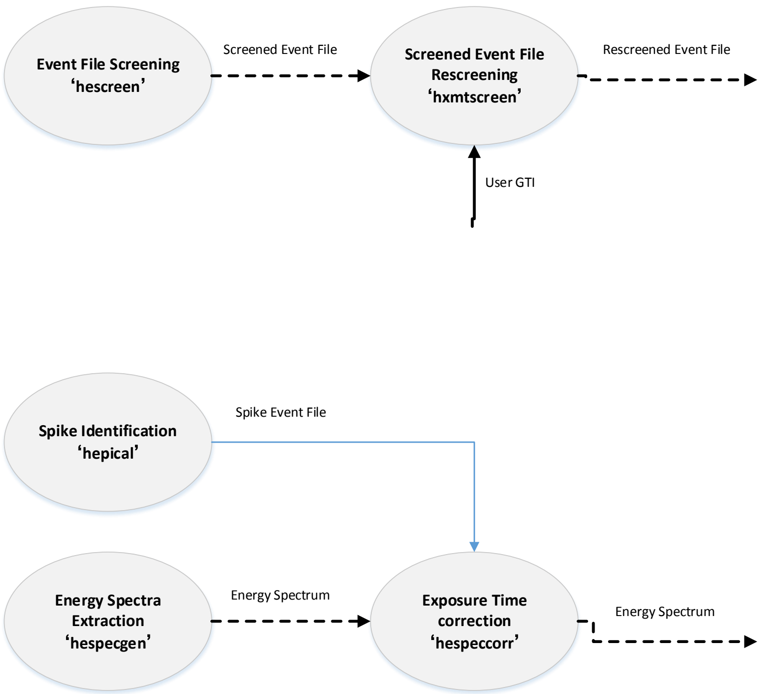

Figure 5.4: *hxmtscreen* data reduction.

5.4 Special Processing

hxmtscreen is used to re-screen the screened event file and *hespeccorr* is used to correct exposure time(see Figure 5.4).

5.4.1 hxmtscreen

For a combined events files, there are more than one detector and each detector has its own good time intervals. But, sometimes, users want to extract spectra/light curves at same time intervals for different detectors. This task is used to re-screen the screened event files and a common GTIs will be given.

PARAMETER

The parameters of this task are listed below:

- evtfile [file name]
  Name of the input screened Event FITS file.
- outfile [file name]
  Name of the output new screened Event FITS file.
- usergtifile [file name]
  Name of the input User GTI file (txt format).
- userdetid [string]
  Detector ID Selection (ID List).
- clobber [integer]
  If 'clobber'=yes and outfile=filename, the file with the same name will be overwritten if it exists.
- (history=yes) [boolean]
  If 'history=yes' the parameter values and other information are written in HISTORY keywords.
- (chatter = 2) [integer]
  Chatter Level (min=0, max=5)

USAGE

- General usage

```
hxmtscreen evtfile=he_screen.FITS outfile=he_screen2.FITS
userdetid="0-17" usergtifile=NONE
```

- If users set *usergtifile* to *NONE*, this task will only consider the GTI extensions from *evtfile*. The format of user GTI file(parameter of *usergtifile*) is a ASCII format file, and each line includes a good time interval, such as
  t1 t2
  t3 t4
- This task can be used to re-screen the HE/ME/LE screened file.

5.4.2 hespeccorr[1]

The spike events have influence on exposure time. *hespeccorr* is used to correct the exposure time of the spectrum by removing time intervals of spike events. The corrected exposure time is very small, so this task can be skipped.

PARAMETER

The parameters of this task are listed below:

- phafile [file name]
  Name of the input PHA FITS file.
- glitchfile [file name]
  Name of the input HE Glitch-Event FITS file.
- deadfile [file name]
  Name of the input Dead time FITS file.
- clobber [integer] If 'clobber'=yes and outfile=filename, the file with the same name will be overwritten if it exists.
- (history=yes) [boolean]
  If 'history=yes' the parameter values and other information are written in HISTORY keywords.
- (chatter = 2) [integer]
  Chatter Level (min=0, max=5)

USAGE

- General usage

```
hespeccorr phafile=he_g0_0.pha glitchfile=glitch.fits \
deadfile=HXMT_P010129300302_HE-DTime_FFFFFF_V1_L1P.FITS
```

  This task will correct the exposure time of $phafile$.

- $glitchfile$ is created by *hepical*!
- This task is used to estimate exposure time when *hepical lowchan* = 0 *highchan* = 255.
- After correction, the exposure time (P010130600202-20170828-01-01) is modified from 3055.327 to 3054.969(s).

[1] This task usually skipped in the data analysis processes, due to the small difference in the exposure time before and after correction

Chapter 6

ME Data Analysis

The processing procedures include three major steps: calibration (stage 1), screening (stage 2) and extraction of high-level scientific products (stage 3). For stage 1, the event file is processed to produce a calibrated event file; for stage 2, the calibrated event file is filtered by applying cleaning criteria to produce a cleaned event file; for stage 3, the high-level scientific products are generated.

Fig. 6.1 shows the ME data reduction.

6.1 Calibration

6.1.1 mepical

This task is used to calculate PI values of ME event.

PARAMETER

The parameters of this task are listed below:

- evtfile [file name]
  Name of the input 1-L event FITS file.
- tempfile [file name]
  Name of the input 1-L temperature FITS file.
- outfile [file name]
  Name of output event FITS file.
- gainfile [file name]
  Name of the input gain FITS file. If set to CALDB, use the file in the Calibration Database.
- seed [int]
  Input seed for random number generator
- (clobber=no) [boolean]
  If *clobber=yes* and *outfile=filename*, the file with the same name will be overwritten if it exists.
- (history=yes) [boolean]
  If *history=yes* the parameter values and other information are written in HISTORY keywords.
- (chatter = 2) [integer]
  Chatter level (min=0, max=5).

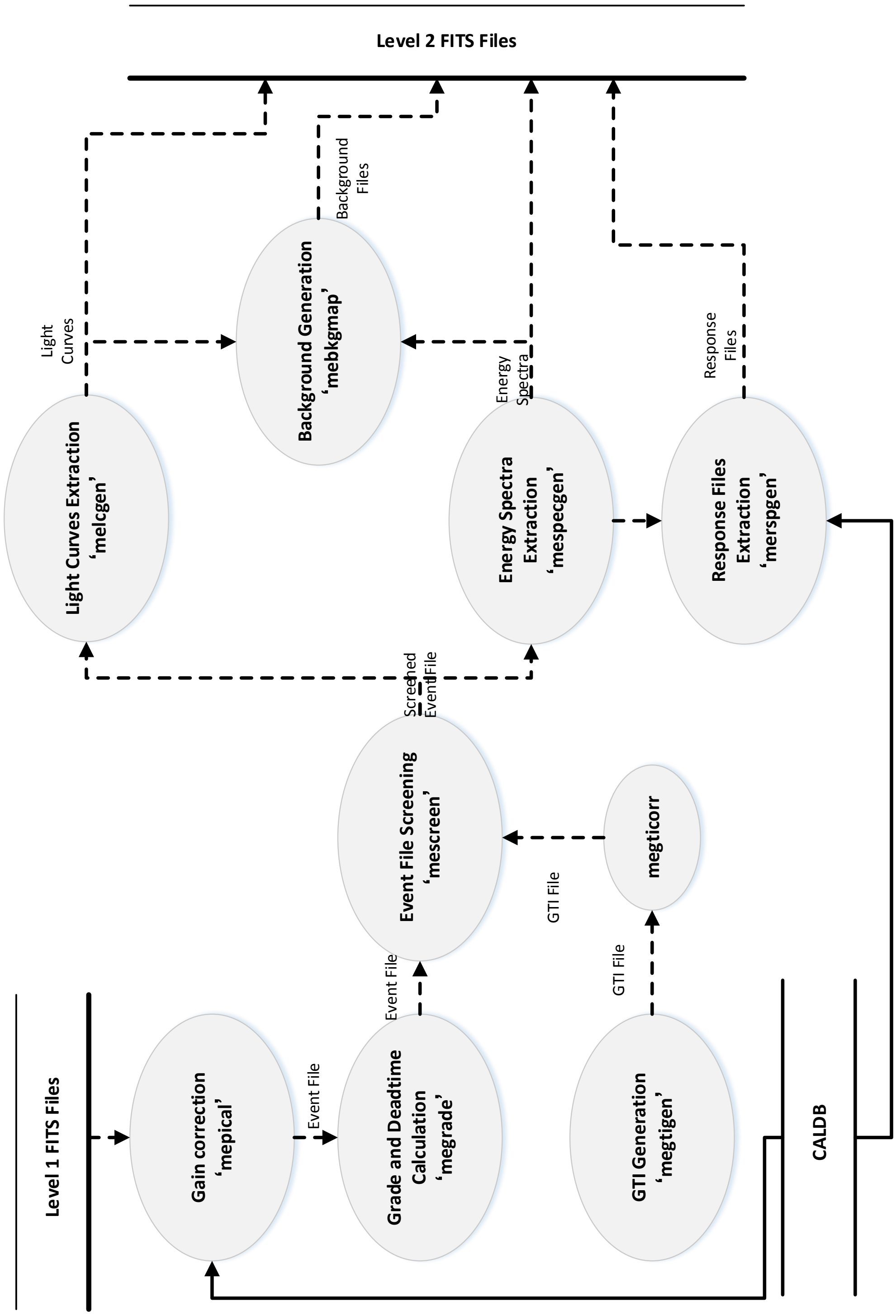

Figure 6.1: ME data reduction.

USAGE

- General Usage

```
mepical evtfile=HXMT_P010130600202_ME-Evt_FFFFFF_V1_1RP.FITS
tempfile=HXMT_P010130600202_ME-TH_FFFFFF_V1_1RP.FITS outfile=me_pi.FITS
```

6.1.2 megrade

This task is used to calculate grade values of ME calibrated event and calculate dead time of each FPGA.

PARAMETER

The parameters of this task are listed below:

- evtfile [file name]
  Name of the input calibrated event FITS file.
- outfile [file name]
  Name of output event FITS file.
- deadfile [file name]
  Name of output dead FITS file. If set to NONE, this file can't be created.
- binsize [real]
  Time interval to create dead FITS file.
- (clobber=no) [boolean]
  If *clobber=yes* and *outfile=filename*, the file with the same name will be overwritten if it exists.
- (history=yes) [boolean]
  If *history=yes* the parameter values and other information are written in HISTORY keywords.
- (chatter = 2) [integer]
  Chatter level (min=0, max=5).

USAGE

- General Usage

```
megrade evtfile=me_pi.FITS outfile=me_grade.FITS deadfile=dead.FITS
```

- If users want to get dead time less than 1 second, users can set the parameter of *binsize* $\leq$ 1 (such as 0.1).
- The *binsize* of this task should be less than the *binsize of melcgen* in order to get accurate deadtime correction.

6.2 Screening

6.2.1 megtigen

This task is used to generate a FITS GTI file.

PARAMETER

The parameters of this task are listed below:

- tempfile [file name]
  Name of the input 1-L Temperature FITS file.
- ehkfile [file name]
  Name of the input 1-L EHK FITS file.
- outfile [file name]
  Name of output event FITS file.
- rangefile [file name]
  Name of the input parameter configure FITS file. Always set to '$HEADAS/refdata/merangefile.fits'.
- defaultexpr [string]
  EHK Selection Expression: YES to use parameter *merangefile/ NO* for user setting/ NONE to use parameter *expr* and only create a GTI (for EHK) extension.
- ELV [real]
  Pointing direction above Earth($> 10^\circ$) or $<0^\circ$ for default.
- DYE_ELV [real]
  Pointing direction above bright Earth($>10^\circ$) or $<0^\circ$ for default.
- SAA_FLAG [bool]
  Exclude the data in SAA.
- T_SAA [real]
  Time since SAA passage($> 300\,\mathrm{s}$) or $< 0\,\mathrm{s}$ for default.
- TN_SAA [real]
  Time to next SAA passage($> 300\,\mathrm{s}$) or$< 0\,\mathrm{s}$ for default.
- COR [real]
  Min Cut-off Rigidity value($> 8\,\mathrm{GV}$) or $< 0\,\mathrm{s}$ for default.
- MOON_ANGLE [real]
  The Moon Angle is bigger than($> 6^\circ$) or $< 0^\circ$ for default.
- SUN_ANGLE [real]
  The Sun Angle is bigger than($> 70^\circ$) or $< 0^\circ$ for default.
- ANG_DIST [real]
  The offset angle from the pointing direction $< 0.04^\circ$ or $\leq 0^\circ$ for default.
- expr [string]
  Selection Expression for EHK file (DEFAULT=NONE), if defaultexpr=NONE, expr must be set.
- prefr [real]
  Pre-Time Interval factor [0,1].
- postfr [real]
  Post-Time Interval factor [0,1].
- (clobber=no) [boolean]
  If *clobber=yes* and *outfile=filename*, the file with the same name will be overwritten if it exists.

- (history=yes) [boolean]
  If *history=yes* the parameter values and other information are written in HISTORY keywords.

- (chatter = 2) [integer]
  Chatter level (min=0, max=5).

USAGE

- General Usage

```
megtigen defaultexpr='NONE' expr="$ELV>10&&COR>8&&SAA_FLAG==0&&
ANG_DIST<0.04&&T_SAA>300&&TN_SAA>300"
tempfile=HXMT_P010130600202_ME-TH_FFFFFF_V1_1RP.FITS
ehkfile=HXMT_P010130600202_EHK_FFFFFF_V1_1RP.FITS outfile=me_gti.FITS
```

- History keywords in GTI file (GTIDesc extension)
  Users can ignore these keywords such as 'HISTORY P8 ELV=5', when the parameter $defaultexpr = NONE$, and users only concern the *expr* keyword for event selection.

6.2.2 megticorr

megticorr is an auxiliary task to recalculate GTI of ME according to the GTI file generated by *megtigen* and a new GTI file is produced. While *megticorr* could also be used to select the good pixels of ME and generate a good pixel file, which will be used in *mescreen* and *mebkgmap*.

USAGE

(1) GTI update

```
megticorr evtfile oldgtiname newgtiname
```

- 'evtfile' is the event file name generated by *megrade*.
- 'oldgtiname' is the GTI name generated by *megtigen*.
- 'newgtiname' is the out file name for the updated GTI.

(2) GTI update and pixel selection

```
megticorr megradename oldgtiname newgtiname $HEADAS/refdata/medetectorstatus.fits
newmedetectorstatus.fits
```

- 'evtfile' is the event file name generated by *megrade*.
- 'oldgtiname' is the GTI name generated by *megtigen*.
- 'newgtiname' is the out file name for the updated GTI.
- '$HEADAS/refdata/medetectorstatus.fits' is the file name of old pixel status of ME.
- 'newmedetectorstatus.fits' is output file name for the updated pixel status.

6.2.3 mescreen

Use GTI together with other criteria to screen the ME data.

PARAMETER

The parameters of this task are listed below:

- evtfile [file name]
  Name of the calibrated event FITS file.

- outfile [file name]
  Name of output screened event FITS file.

- gtifile [file name]
  Name of the input gti FITS file.

- baddetfile [file name]
  Name of the input bad detector configure file. Always set to '$HEADAS/refdata/medetectorstatus.fits'.

- userdetid [string]
  Detector ID (0–53) Selection (ID List).

- starttime [real]
  Starting time for filtering (DEFAULT = 0).

- stoptime [real]
  Ending time for filtering (DEFAULT = 0).

- minPI [int]
  Minimum PI for filtering.

- maxPI [int]
  Maximum PI for filtering.

- (clobber=no) [boolean]
  If *clobber=yes* and *outfile=filename*, the file with the same name will be overwritten if it exists.

- (history=yes) [boolean]
  If *history=yes* the parameter values and other information are written in HISTORY keywords.

- (chatter = 2) [integer]
  Chatter level (min=0, max=5).

USAGE

- General Usage

```
mescreen evtfile=me_grade.fits gtifile=me_gti.fits outfile=me_screen.fits
userdetid="0-53" baddetfile=newmedetectorstatus.fits
```

- the events of the bad detectors will be removed in this task. In the old version, the default file of bad detector file is $HEADAS/refdata/medetectorstatus.fits. In this version, the bad detector file can be generated from *megticorr* module.

- Currently, the blind FoV detectors must be included in this stage and these detectors will be used by the background modules.

6.3 Extraction of high-level products

6.3.1 mespecgen

This task is used to extract spectra from the screened event file.

PARAMETER

The parameters of this task are listed below:

- evtfile [file name]
  Name of the screened event FITS file.
- outfile [file name]
  Name of the output prefix to PHA FITS file.
- deadfile [file name]
  Name of the input dead time FITS file (created in megrade task).
- userdetid [string]
  Detector ID (0–53) Selection (ID List), such "0-53"
- starttime [real]
  Start time for filtering (DEFAULT = 0)
- stoptime [real]
  Stop time for filtering (DEFAULT = 0)
- minPI [int]
  Minimum PI for filtering.
- maxPI [int]
  Maximum PI for filtering.
- (clobber=no) [boolean]
  If *clobber=yes* and *outfile=filename*, the file with the same name will be overwritten if it exists.
- (history=yes) [boolean]
  If *history=yes* the parameter values and other information are written in HISTORY keywords.
- (chatter = 2) [integer]
  Chatter level (min=0, max=5).

USAGE

- General Usage

```
mespecgen evtfile=me_screen.fits deadfile=dead.fits userdetid="0 1 2 3 4 5 6 7
11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 29 30 31 32 33 34 35 36 37 38 39
40 41 42 43 47 48 49 50 51 52 53;10 28 46" outfile=pha
```

- Currently, only small FoV detectors can be used to generate spectra. The detector ID list for small FoV is: 0 1 2 3 4 5 6 7 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 47 48 49 50 51 52 53.

6.3.2 melcgen

This task is used to extract light curves from the screened event files.

PARAMETER

The parameters of this task are listed below:

- evtfile [file name]
  Name of the screened event FITS file.
- outfile [file name]
  Name of the output prefix to PHA FITS file.
- deadfile [file name]
  Name of the input dead time FITS file.
- binsize [real]
  Bin size (second) of the light curve.
- userdetid [string]
  Detector ID (0–53) Selection (ID List), such "0-17; 0 1 2 3; 4,5,6,7; 8-10,11"
- starttime [real]
  Start time for filtering (DEFAULT = 0)
- stoptime [real]
  Stop time for filtering (DEFAULT = 0)
- minPI [int]
  Minimum PI for filtering.
- maxPI [int]
  Maximum PI for filtering.
- deadcorr [bool]
  Correct light curve used dead time (yes/no) (DEFAULT = no).
- aligncorr [bool]
  Correct light curve used time-dependent PSF(alignment) correction, at the same time, users should set *attfile*.
- attfile[file name]
  Name of the input 1-L Attitude FITS file (psf correction, set aligncorr=yes)
- (clobber=no) [boolean]
  If *clobber=yes* and *outfile=filename*, the file with the same name will be overwritten if it exists.
- (history=yes) [boolean]
  If *history=yes* the parameter values and other information are written in HISTORY keywords.
- (chatter = 2) [integer]
  Chatter level (min=0, max=5).

USAGE

- General Usage

```
melcgen evtfile=me_screen.fits deadfile=dead.fits userdetid="0 1 2 3 4 5 6 7 11 12
13 14 15 16 17 18 19 20 21 22 23 24 25 29 30 31 32 33 34 35 36 37 38 39 40 41 42
43 47 48 49 50 51 52 53" outfile=lg binsize=1
```

- In order to get accurate background, only small FoV detectors can be used to generate light curves. The detector ID list for small FoV is: 0 1 2 3 4 5 6 7 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 47 48 49 50 51 52 53.

6.3.3 merspgen

This task is used to generate the response file of spectrum.

PARAMETER

The parameters of this task are listed below:

- phafile [file name]
  Name of the input PHA FITS file.
- outfile [file name]
  Name of the output RSP FITS file.
- attfile [file name]
  Name of the input 1-L Attitude FITS file.
- ra [real]
  Source R.A. (degrees), from $0°$ to $360°$.
- dec[real]
  Source Decl. (degrees), form $-90°$ to $90°$.
- (clobber=no) [boolean]
  If *clobber=yes* and *outfile=filename*, the file with the same name will be overwritten if it exists.
- (history=yes) [boolean]
  If *history=yes* the parameter values and other information are written in HISTORY keywords.
- (chatter = 2) [integer]
  Chatter level (min=0, max=5).

USAGE

- General usage

```
merspgen phafile=spec_g0_0.fits
attfile=ACS/HXMT_P010129300302_Att_FFFFFF_V1_1RP.FITS outfile=le_rsp.fits ra=-1 dec=-91
```

- If users set $ra = -1$ and $dec = -91$, the task will read their values from the keywords of spectrum file.

6.3.4 mebkgmap

The background of ME for small FoV is generated by *mebkgmap*. The background spectrum and light curve are generated from the screened event file, which is generated by *mescreen* and includes all events of blind detectors.

USAGE

Like *hebkgmap*, you can execute "mebkgmap -h" for help. The format looks like this:

- Method 1: mebkgmap lc/spec screen.FITS ehkfile.fits gtifile.fits deadtime.fits tempname lcname/specname chmin chmax outnam_prefix baddetfile
- Method 2: Using interactive method in prompt.
- Method 3: mebkgmap sflag=lc/spec evtfile=screen.FITS ehkfile=ehkfile.fits gtifile=gtifile.fits dtname=deadtime.fits tempname=tempname srcdat=lcname/specname chmin=chmin chmax=chmax outnam=outnam_prefix baddetfile=baddetfile

PARAMETER

Parameters input for method 1:

- lc/spec: [char]
  lc for background light curve and *spec* for background spectrum. The background spectra or light curves for each detector box can be generated. *spec-box0*, *spec-box1*, *spec-box2*, *spec-box01*, *spec-box02*, *spec-box12* represent the background spectra for Box-0, Box-1, Box-2, Box-0 and Box-1, Box-0 and Box-2, Box-1 and Box-2, respectively. *lc-box0*, *lc-1*, *lc-2*, *lc-01*, *lc-02*, *lc-12* represent the background light curve for Box-0, Box-1, Box-2, Box-0 and Box-1, Box-0 and Box-2, Box-1 and Box-2, respectively.
- mescreen.FITS: [fits file]
  The event file that includes the events for blind detectors (DetID=10, 28, 46).
- ehkfile.fits: [file name]
  EHK file for the observation.
- gtifile.fits: [file name]
  GTI file for ME.
- deadtime.fits: [file name]
  the dead time file for ME.
- tempfile.fits: [file name]
  the temperature file for ME.
- lcname/specname: [file name]
  ASCII file, in which the name of the light curves or the spectra to analysis should be written.
- chmin: [int]
  the minimum PI for light curves.
- chmax: [int]
  the maximum PI for light curves.
- outnam_prefix: [char]
  the output prefix for light curves or spectra.

- baddetfile: [file name]
  the file name of ME detector status including the information of bad pixels.

Parameters input for method 3:

- sflag: [char]
  lc for background light curve and *spec* for background spectrum. The background spectra or light curves for each detector box can be generated. *spec-box0*, *spec-box1*, *spec-box2*, *spec-box01*, *spec-box02*, *spec-box12* represent the background spectra for Box-0, Box-1, Box-2, Box-01, Box-02 and Box-12, respectively. *lc-box0*, *lc-1*, *lc-2*, *lc-01*, *lc-02*, *lc-12* represent the background light curve for Box-0, Box-1, Box-2, Box-01, Box-0 and Box-2, Box-1 and Box-2, respectively.
- evtfile [file name]
  the event file that includes the events for blind detectors (DetID=10, 28, 46).
- ehkfile: [file name]
  EHK file for the observation.
- gtifile: [file name]
  GTI file for ME.
- dtname: [file name]
  the dead time file for ME.
- tempname: [file name]
  the temperature file for ME.
- srcdat: [file name]
  ASCII file, in which the name of the light curves or the spectra to analysis should be written.
- chmin: [int]
  the minimum channel for light curves.
- chmax: [int]
  the maximum channel for light curves.
- outnam_prefix: [char]
  the output prefix for light curves or spectra.
- baddetfile: [file name]
  the file name of ME detector status including the information of bad pixels.

Example

Here we present the general case for creating background files of light curves and spectra.
(1) Generate background spectrum
If small FoV spectrum of ME has been generated and its name *mespec.pha*, then save these names to *specname.txt*. The content of ASCII file *specname.txt* should be like this:

```
mespec.pha
```

Now you can execute the command

```
mebkgmap spec mescreen.FITS ehkfile.fits gtifile.fits deadtime.fits tempfile.fits
specname.txt 0 1023 me_specbkg
```

If the file including bad pixel information generated by *megti* is 'newdet.fits' , the background spectrum could be generated by

```
mebkgmap spec mescreen.FITS ehkfile.fits gtifile.fits deadtime.fits tempfile.fits
specname.txt 0 1023 me_specbkg newdet.fits
```

(2) Generate background lightcurve

If lightcurve of ME has been generated and its name is *me.lc*. Save this name to *lccname.txt*. The channel range for the lightcurve is 119 to 290 (roughly refers to 10–20 keV).

```
mebkgmap lc mescreen.FITS ehkfile.fits gtifile.fits deadtime.fits tempfile.fits
lcname.txt 119 290 me_lcbkg
```

If the file including bad pixel information generated by *megti* is 'newdet.fits', the background light curve could be generated by

```
mebkgmap lc mescreen.FITS ehkfile.fits gtifile.fits deadtime.fits tempfile.fits
lcname.txt 119 290 me_lcbkg newdet.fits
```

Chapter 7

LE Data Analysis

The LE processing procedures include three major steps: calibration (stage 1), screening (stage 2) and extraction of high-level scientific products (stage 3). Figure 7.1 shows the LE data reduction.

7.1 Calibration

7.1.1 lepical

This task is used to calculate the main peak from the PHA distribution of the forced trigger events in a specified time interval and then subtract the mean peak from the raw PHA of the physical events in this time interval. And then the PI values are calculated based on the temperature and the gain files from CALDB.

PARAMETER

The parameters of this task are listed below:

- evtfile [file name]
  Name of the input 1-L event file.

- outfile [file name]
  Name of output event file.

- tempfile [file name]
  Name of the input 1-L temperature file.

- gainfile [file name]
  Name of the input gain file. If set to CALDB, use the file in the Calibration Database.

- pedestalfile [file name]
  Name of the output peak of pedestal events (equivalent to forced trigger events). (DEFAULT=NONE).

- maxtimedel [real]
  Accumulate time interval (s) for calculation noise.

- clobber [boolean]
  If *clobber=yes* and *outfile=filename*, the file with the same name will be overwritten if it exists (DEFAULT=yes).

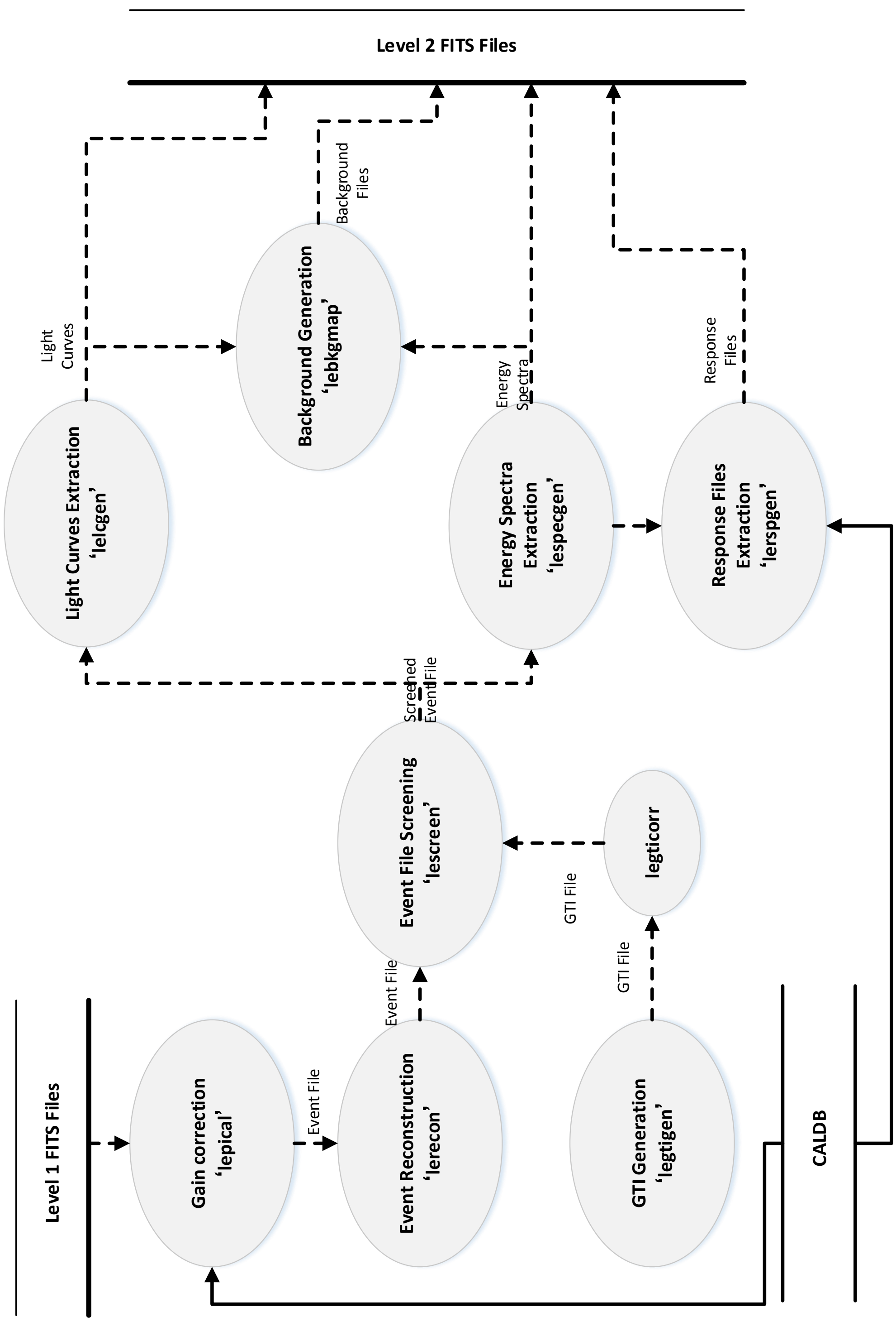

Figure 7.1: LE data reduction.

- history [boolean]
  If *history=yes* the parameter values and other information are written in HISTORY keywords(DEFAULT=yes).

- chatter [integer]
  Chatter level (min=0, max=5) (DEFAULT=2). It is used to control the output message.

USAGE

- General usage

```
lepical evtfile=HXMT_P010129900101_LE-Evt_FFFFFF_V1_L1P.FITS
tempfile=HXMT_P010129900101_LE-TH_FFFFFF_V1_L1P.FITS
outfile=le_pi.FITS
```

- If users want to see the pedestal events, users can set *pedestalfile* not to NONE.
  hepical pedestalfile=le_pedestal.FITS
  The output file includes columns of *Time*, *Peak*, *Width*, and their errors.

7.1.2 lerecon

This task is used to reconstruct two split events, and assign grade.

PARAMETER

The parameters of this task are listed below:

- evtfile [file name]
  Name of the input 1-L event file.

- outfile [file name]
  Name of output event file.

- instatusfile[file name]
  Name of the input 1-L detector status file.

- hzscale [interger]
  A scale to calculate split events, e.g., two events with time interval less than 10 µs×hzscale will be reconstructed to one event (two-split event) (DEFAULT=1).

- clobber [boolean]
  If *clobber=yes* and *outfile=filename*, the file with the same name will be overwritten if it exists (DEFAULT=yes).

- history [boolean]
  If *history=yes* the parameter values and other information are written in HISTORY keywords (DEFAULT=yes).

- chatter [integer]
  Chatter level (min=0, max=5) (DEFAULT=2).

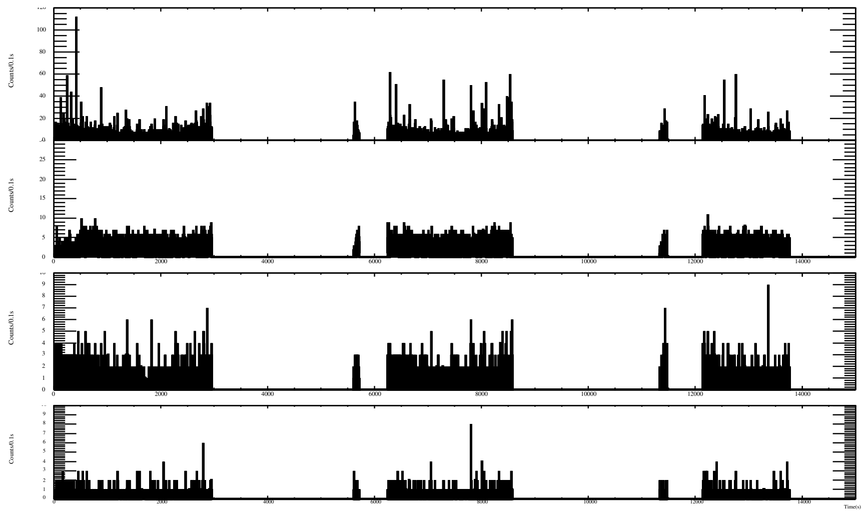

Figure 7.2: The reconstructed events for CCD 0: raw light curve, single events light curve (*GRADE*=0), split events light curve (*GRADE*=1) and more split events light curve (*GRADE*=2).

USAGE

- General usage

```
lerecon evtfile=le_pi.FITS instatusfile=HXMT_P010129900101_LE-InsStat_FFFFFF_V1_L1P.FITS
outfile=le_recon.FITS
```

There are three grades: 0 means normal events (single events), 1 means split events (two split events) and 2 means more split events (> 2). Figure 7.2 shows the raw events light curve (*binsize=0.1*) and the light curves for *GRADE*=0, 1, 2, respectively. The light curve of raw events has some spikes which is due to continuous split events. Figure 7.3 shows the ratio of two-split/more-split events of small CCDs of board 0 to covered CCDs of board 0. The more-split events number is linear with particle background.

- the *hzrescal* parameter
  The light curve of two-split events (shown in Figure 7.2) has some spikes which maybe due to more-split event has event missing (pixel energy deposit below threshold). In order to reduce their cases, users can enlarge *hzrecal*. Figure 7.4 shows the reconstructed events for CCD 0 with *hzscale*=5. The spike number is significantly decreased and the number of single events is reduced by 1.3%.

  CasA observations are used to check the two-split event and Figure 7.5 shows the energy spectra of single events, no reconstructed two split events, and the reconstructed two-split events.

7.2 Screening

7.2.1 legtigen

This task is used to generate a GTI file in FITS format.

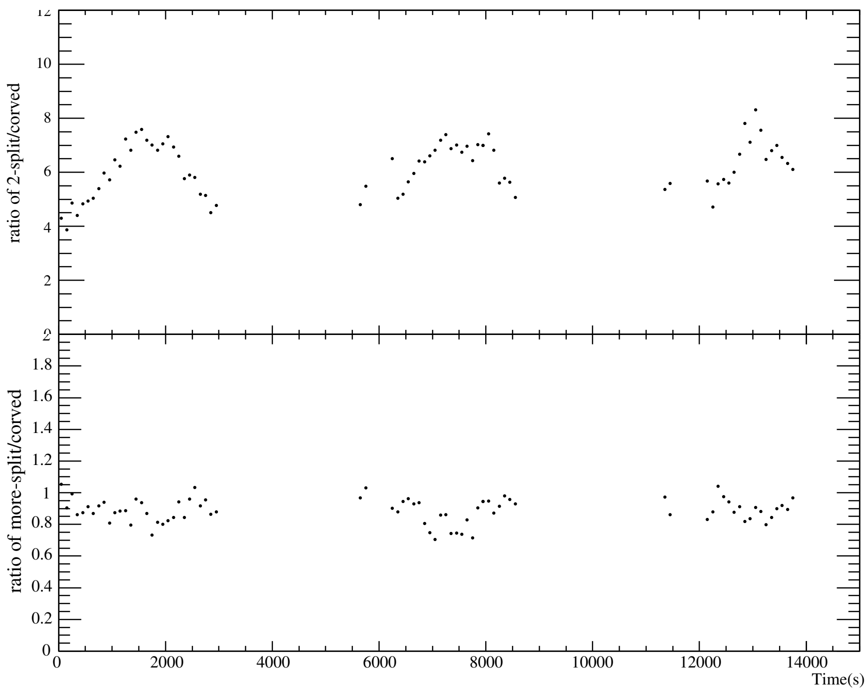

Figure 7.3: The ratio of two-split/more-split events(*binsize*=100) of small CCDs to covered CCDs for board 0.

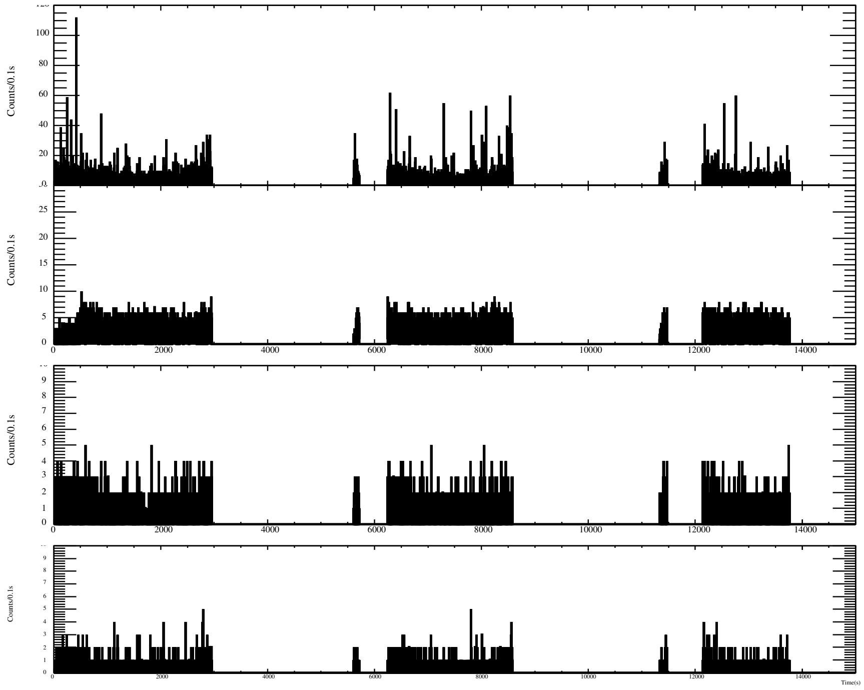

Figure 7.4: The reconstructed events for CCD 0 with *hzscal*=5: raw light curve, single events light curve (*GRADE*=0), split events light curve (*GRADE*=1) and more split events light curve (*GRADE*=2).

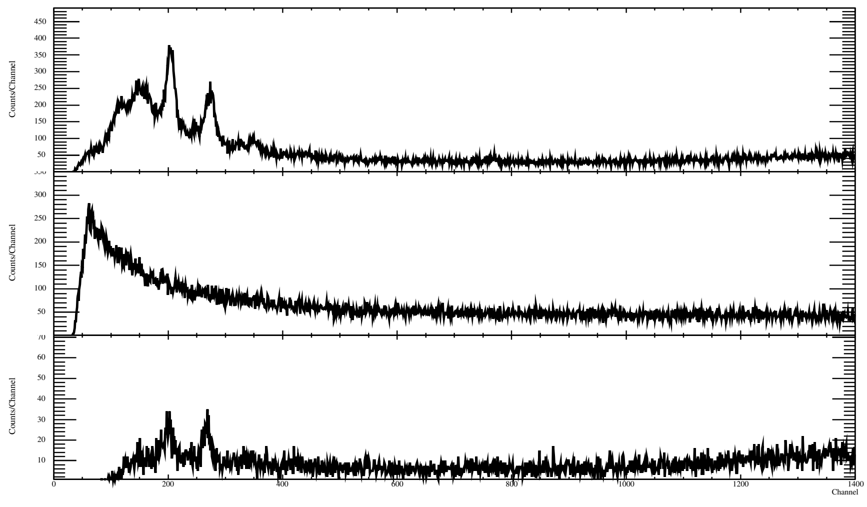

Figure 7.5: The energy spectra of single events (*GRADE*=0), no reconstructed two split events, and the reconstructed two-split events (*GRADE*=2).

PARAMETER

The parameters of this task are listed below:

- evtfile [file name]
  Name of the input 1-L event file.
- instatusfile[file name]
  Name of the input 1-L detector status file.
- tempfile [file name]
  Name of the input 1-L temperature file.
- ehkfile [file name]
  Name of the input 1-L EHK file.
- outfile [file name]
  Name of output event file.
- rangefile [file name]
  Name of the input parameter configure file. Always set to '$HEADAS/refdata/lerangefile.fits'.
- defaultexpr [string]
  EHK selection expression: YES to use parameter *lerangefile*; NO for user setting; NONE to use parameter *expr* and only create a GTI extension. (DEFAULT=NONE).
- ELV [real]
  Pointing direction above Earth($> 10°$) or $< 0°$ for default.
- DYE_ELV [real]
  Pointing direction above bright Earth($> 30°$) or $< 0°$ for default.
- SAA_FLAG [bool]
  Exclude the data in SAA.
- T_SAA [real]
  Time since SAA passage($> 300\,s$) or $< 0\,s$ for default.
- TN_SAA [real]
  Time to next SAA passage($> 300\,s$) or $< 0\,s$ for default.
- COR [real]
  Min Cut-off Rigidity value($> 8\,GV$) or $< 0\,GV$ for default.
- MOON_ANGLE[real]
  The Moon Angle is bigger than($> 6°$) or $< 0°$ for default.
- SUN_ANGLE [real]
  The Sun Angle is bigger than(70°) or $< 0°$ for default.
- ANG_DIST [real]
  The offset angle from the pointing direction($< 0.04°$) or $\leq 0°$ for default.
- expr [string]
  Selection expression for EHK file (DEFAULT=NONE), if *defaultexpr=NONE*, expr must be set.
- prefr [real]
  Pre-time interval factor [0,1].

- postfr [real]
  Post-time interval factor [0,1].
- (clobber=no) [boolean]
  If *clobber=yes* and *outfile=filename*, the file with the same name will be overwritten if it exists.
- (history=yes) [boolean]
  If *history=yes* the parameter values and other information are written in HISTORY keywords.
- (chatter = 2) [integer]
  Chatter level (min=0, max=5).

USAGE

- General usage

```
legtigen defaultexpr=NONE
expr="ELV>10&&DYE_ELV>30&&COR>8&&ANG_DIST<0.04&&SAA_FLAG==0&&T_SAA>300&&TN_SAA>300"
evtfile=NONE instatusfile=HXMT_P010130600202_LE-InsStat_FFFFFF_V1_1RP.FITS
tempfile=HXMT_P010130600202_LE-TH_FFFFFF_V1_1RP.FITS
ehkfile=../AUX/HXMT_P010130600202_EHK_FFFFFF_V1_1RP.FITS
outfile=le_gti.fits
```

- parameter of *evtfile*
  If this parameter is not set to NONE (or is set to a wrong file), the trigger event rate will be considered to calculate the good time intervals. But in 1L data, the time of data overflow has been abandoned.
- Now, we recommend users set the *defaultexpr* to NONE and use *expr* as selection expression of GTIs.
- Since the legticorr module can modify the output of this task, the *evtfile* can be set to NONE.

7.2.2 legticorr

legticorr is an auxiliary software to select GTI of LE according to the GTI file generated by *legtigen*.

USAGE

```
legticorr evtfile oldgtiname newgtiname
```

- evtfile: the event file name generated by *lerecon*.
- oldgtiname: the GTI name generated by *legtigen*.
- newgtiname: the out file name for the updated GTI.

7.2.3 lescreen

Use GTI together with other criteria to screen the LE data.

PARAMETER

The parameters of this task are listed below:

- evtfile [file name]
  Name of the calibrated event file.
- outfile [file name]
  Name of output screened event file.
- gtifile [file name]
  Name of the input GTI file.
- baddetfile [file name]
  Name of the input bad detector configure file. Always set to '$HEADAS/refdata/ledetectorstatus.fits'.
- userdetid [string]
  Detector ID (0–95) Selection (ID List).
- eventtype [int]
  Type of Event: 0 for all; 1 for single event; 2 for two-split event.
- starttime [real]
  Start time for filtering (DEFAULT = 0).
- stoptime [real]
  Stop time for filtering (DEFAULT = 0).
- minPI [int]
  Minimum PI for filtering.
- maxPI [int]
  Maximum PI for filtering.
- (clobber=no) [boolean]
  If *clobber=yes* and *outfile=filename*, the file with the same name will be overwritten if it exists.
- (history=yes) [boolean]
  If *history=yes* the parameter values and other information are written in HISTORY keywords.
- (chatter = 2) [integer]
  Chatter level (min=0, max=5).

USAGE

- General usage

  ```
  lescreen evtfile=le_recon.fits gtifile=le_gti.fits
  userdetid="0-95" eventtype=1 outfile=le_screen.fits
  ```

- In order to get accurate background, only small FoV detectors are used to do analysis. The detector ID list for small FoV is: 0 2-4 6-10 12 14 20 22-26 28-30 32 34-36 38-42 44 46 52 54-58 60-62 64 66-68 70-74 76 78 84 86-90 92-94.
- Currently, the blind FoV detectors must be included in this stage and these detectors will be used by background modules. The blind FoV detector ID list is: 13,45,77.
- So, the parameter of *userdetid* should be set to 0 2-4 6-10 12 14 20 22-26 28 30 32 34-36 38-42 44 46 52 54-58 60-62 64 66-68 70-74 76 78 84 86 88-90 92-94; 13,45,77.
- The recommended GTI file is the GTI file updated by *legticorr* module.

7.3 High level products extraction

7.3.1 lespecgen

This task is used to extract spectra.

PARAMETER

The parameters of this task are listed below:

- evtfile [file name]
  Name of the screened event file.
- outfile [file name]
  Name of the output prefix to PHA file.
- userdetid [string]
  Detector ID (0–95) Selection (ID List), such as "0-31; 0 1 2 3; 4,5,6,7; 8-10,11"
- eventtype [int]
  Type of event: 0 for all; 1 for single event; 2 for two-split event.
- starttime [real]
  Start time for filtering (DEFAULT = 0)
- stoptime [real]
  Stop time for filtering (DEFAULT = 0)
- minPI [int]
  Minimum PI for filtering.
- maxPI [int]
  Maximum PI for filtering.
- (clobber=no) [boolean]
  If *clobber=yes* and *outfile=filename*, the file with the same name will be overwritten if it exists.
- (history=yes) [boolean]
  If *history=yes* the parameter values and other information are written in HISTORY keywords.
- (chatter = 2) [integer]
  Chatter level (min=0, max=5).

USAGE

- General usage

```
lespecgen evtfile=le_screen.fits userdetid="0 2-4 6-10 12 14 20 22-26
28-30 32 34-36 38-42 44 46 52 54-58 60-62 64 66-68 70-74
76 78 84 86-90 92-94" outfile=pha eventtype=1
```

The above selected detectors are all small FoV detectors of LE. Although some of these detectors are no longer working, you do not need to exclude them in *userdetid*, the program considers the status of these bad detectors.

7.3.2 lelcgen

This task is used to extract light curves.

PARAMETER

The parameters of this task are listed below:

- evtfile [file name]
  Name of the screened event file.

- outfile [file name]
  Name of the output prefix to PHA file.

- binsize [real]
  Bin size (seconds) of light curve.

- userdetid [string]
  Detector ID (0–95) Selection (ID List), such as "0-95; 0 1 2 3; 4,5,6,7; 8-10,11"

- eventtype [int]
  Type of Event: 0 for all; 1 for single event; 2 for two-split event.

- starttime [real]
  Start time for filtering (DEFAULT = 0)

- stoptime [real]
  Stop time for filtering (DEFAULT = 0)

- minPI [int]
  Minimum PI for filtering.

- maxPI [int]
  Maximum PI for filtering.

- aligncorr [bool]
  Correct light curve used time-dependent PSF (alignment) correction, at the same time, users should set 'attfile'

- attfile[file name]
  Name of the input 1-L attitude file (PSF correction, set *aligncorr*=yes)

- (clobber=no) [boolean]
  If *clobber=yes* and *outfile=filename*, the file with the same name will be overwritten if it exists.

- (history=yes) [boolean]
  If *history=yes* the parameter values and other information are written in HISTORY keywords.

- (chatter = 2) [integer]
  Chatter level (min=0, max=5).

USAGE

- General usage

```
lelcgen evtfile=le_screen.fits outfile=lg binsize=1
userdetid="0 2-4 6-10 12 14 20 22-26 28-30 32 34-36 38-42 \
44 46 52 54-58 60-62 64 66-68 70-74 76 78 84 86-90 92-94"
```

  The above selected detectors are all small FoV detectors of LE. Although some of these detectors are no longer working, you do not need to exclude them in *userdetid*, the program considers the status of these bad detectors.

7.3.3 lerspgen

This task is used to generate the response file of spectrum.

PARAMETER

The parameters of this task are listed below:

- phafile [file name]
  Name of the input PHA file.
- outfile [file name]
  Name of the output RSP file.
- attfile [file name]
  Name of the input 1-L attitude file.
- tempfile[file name]
  Name of the input 1-L temperature file.
- ra [real]
  Source R.A. (degrees), from 0° to 360°.
- dec[real]
  Source Decl. (degrees), form −90° to 90°.
- (clobber=no) [boolean]
  If *clobber=yes* and *outfile=filename*, the file with the same name will be overwritten if it exists.
- (history=yes) [boolean]
  If *history=yes* the parameter values and other information are written in HISTORY keywords.
- (chatter = 2) [integer]
  Chatter level (min=0, max=5).

USAGE

- General usage

```
lerspgen phafile=spec_g0_0.fits
temp=HXMT_P010130600202_LE-TH_FFFFFF_V1_1RP.FITS
attfile=ACSHXMT_P010129300302_Att_FFFFFF_V1_1RP.FITS
outfile=le_rsp.fits ra=-1 dec=-91
```

- If users set *ra* and *dec* to −1 and −91, respectively, the task will read their real values from spectrum file.

7.3.4 lebkgmap

The background of LE for small FoV is generated by *lebkgmap*. The background spectrum and light curve are generated from screened event file, which is generated by *lescreen* and includes all events of blind detectors.

Uasge

Run "lebkgmap -h" for help. The format of using *lebkgmap* is:

- Method 1: lebkgmap lc/spec screen.fits gtifile.fits lcname/specname chmin chmax outnam_prefix
- Method 2: Using interactive method in prompt.
- Method 3: lebkgmap sflag=lc/spec evtfile=screen.FITS gtifile=gtifile.fits srcdat=lcname/specname chmin=chmin chmax=chmax outnam=outnam_prefix

Parameters

Parameters input for method 1:

- lc/spec: [char]
  lc for background light curve and *spec* for background spectrum. The background spectra or light curves for each detector box can be generated. *spec-box0*, *spec-box1*, *spec-box2*, *spec-box01*, *spec-box02*, *spec-box12* represent the background spectra for Box-0, Box-1, Box-2, Box-0 and Box-1, Box-0 and Box-2, Box-1 and Box-2, respectively. *lc-box0*, *lc-1*, *lc-2*, *lc-01*, *lc-02*, *lc-12* represent the background light curve for Box-0, Box-1, Box-2, Box-0 and Box-1, Box-0 and Box-2, Box-1 and Box-2, respectively.
- lescreen.FITS: [fits file]
  The event file that includes the events for all blind detectors (DetID=13,21,45,53,77,85).
- gtifile.fits: [fits file]
  GTI file for LE.
- lcname/specname: [file name]
  ASCII file, in which the name of the light curves or the spectra to analysis should be written.
- chmin: [int]
  The minimum channel for light curves.
- chmax: [int]
  The maximum channel for light curves.
- outnam_prefix: [char]
  The output prefix for light curves or spectra.

Parameters input for method 3:

- sflag: [char]
  lc for background light curve and *spec* for background spectrum. The background spectra and light curves for each detector box can be generated. *spec-box0*, *spec-box1*, *spec-box2*, *spec-box01*, *spec-box02*, *spec-box12* represent the background spectra for Box-0, Box-1, Box-2, Box-0 and Box-1, Box-0 and Box-2, Box-1 and Box-2, respectively. *lc-box0*, *lc-1*, *lc-2*, *lc-01*, *lc-02*, *lc-12* represent the background light curve for Box-0, Box-1, Box-2, Box-01, Box-02 and Box-12, respectively.

- evtfile [file name]
  The event file that includes the events for blind detectors (DetID=13,21,45,53,77,85).
- gtifile: [file name]
  GTI file for LE.
- srcdat: [file name]
  ASCII file, in which the name of the light curves or the spectra to analysis should be written.
- chmin: [int]
  The minimum channel for light curves.
- chmax: [int]
  The maximum channel for light curves.
- outnam_prefix: [char]
  The output prefix for light curves or spectra.

Example

(1) Generate background spectrum
If small FoV spectrum of LE has been generated and its name *lespec.pha*, then save its name to *specname.txt*. Run the command:

```
lebkgmap spec lescreen.FITS gtifile.fits specname.txt 0 1535 le_specbkg
```

(2) Generate background light curve
If lightcurve of LE has been generated and its name is *le.lc*, save its name to *lcname.txt*. The channel range for the lightcurve is 106 to 1069 (roughly refers to 1.0–10 keV). Run the command:

```
lebkgmap lc lescreen.FITS gtifile.fits lcname.txt  106  1069 lebkg
```

Chapter 8

Barycentric correction tools and other tools

8.1 HXMT hxbary

This task is used to convert the arrival time of a photon from TT (Terrestrial Time) to TDB (Barycentric Dynamic Time). The arrival times of photons are corrected to the solar system barycentric center (SSB), considering the time delay due to the movement of the spacecraft and the earth, the proper motion of the object, and the relativistic effects (Einstein delay, shapiro delay). After barycentering, a new column named "TDB" is added in the last column of the extension, in MET seconds to the reference epoch. Thus, to compute the MJD time from barycentered files, referred to the TDB system, one should use one of the following formulae,
MJD(TDB) = (MJDREFI+MJDREFF)+(TDBTIME+TIMEZERO)/86400.

PARAMETER

The parameters of this task are listed below:

- evtfile [file name]
  Name of the input event FITS file.
- orbitfile [file name]
  Name of the orbit FITS file.
- ra [real]
  Right ascension of the object (in degrees)
- dec [real]
  Declination of the object (in degrees)
- eph [int]
  The choice of the ephemeris: 1 for DE200, 2 for DE405, 3 for DE430, and 4 for DE440
- tdbtdtfile [file name]
  The path of the TDB correction file (DEFAULT=$HEADAS/refdata/TDB.1950.2050) (Fairhead L., & Bretagnon P. 1990, A&A, 229,240)
- iftephfile
  The path of the IF TDB correction file (DEFAULT=$HEADAS/refdata/TIMEEPH_short.te405) (Irwin A. W., & Fukushima T. 1999, A&A, 348, 642)

- eph200file
  The path of the DE200 ephemeris file (DEFAULT=$HEADAS/refdata/DE200.1950.2050)
- eph405file
  The path of the DE405 ephemeris file (DEFAULT=$HEADAS/refdata/DE405.1950.2050)
- history [boolean]
  If *history*=yes the parameter values and other information are written in HISTORY keywords (DEFAULT=yes).
- chatter [int]
  Chatter level

USAGE

```
hxbary evtfile=PATH/to/event.fits orbitfile=PATH/to/orbit.fits
ra=86.2 dec=22.01 eph=2
```

8.2 HXMT hxbary2

This task is used to convert the arrival times of a photons from TT (Terrestrial Time) to TDB (Barycentric Dynamic Time). It is quite similar with *hxbary*, while the extension number and the column number can be specified to do SSB corrections.

PARAMETER

The parameters of this task are listed below:

- evtfile [file name]
  Name of the input event FITS file.
- exten_num [int]
  The extension to be corrected.
- exten_col [int]
  The column number in the extension to be corrected.
- orbitfile [file name]
  Name of the orbit FITS file
- ra [real]
  Right ascension of the object (in degrees)
- dec [real]
  Declination of the object (in degrees)
- eph [int]
  The choice of the ephemeris: 1 for DE200, 2 for DE405, 3 for DE430, and 4 for DE440
- tdbtdtfile [string]
  The path of the TDB correction file (DEFAULT=$HEADAS/refdata/TDB.1950.2050)
- iftephfile
  The path of the IF TDB correction file (DEFAULT=$HEADAS/refdata/TIMEEPH_short.te405)
- eph200file
  The path of the DE200 ephemeris file (DEFAULT=$HEADAS/refdata/DE200.1950.2050)

- eph405file
  The path of the DE405 ephemeris file (DEFAULT=$HEADAS/refdata/DE405.1950.2050)
- Clobber [boolean]
  If *clobber*=yes and *outfile*=filename, the file with the same name will be overwritten if it exists (DEFAULT=yes).
- History [boolean]
  If *history*=yes the parameter values and other information are written in HISTORY keywords (DEFAULT=yes).
- Chatter [int]
  Chatter level.

USAGE

```
hxbary2 evtfile=PATH/event.fits exten_num=1 exten_col=1 orbitfile=PATH/orbit.fits
ra=86.2 dec=22.01 eph=2
```

8.3 hobs_info

Print some information for observations.

USAGE

Run "hobs_info -h" for help. The format of using *hobs_info* is:

```
hobs_info /data_path/
```

Example

```
hobs_info ./P0101299/
```

8.4 hprint_detid

Print the information of detectors of Insight-HXMT.

USAGE

```
hprint_detid
```

8.5 hgti_create

Create GTI file for Insight-HXMT with the same information as the GTI sample.

USAGE

```
hgti_create GTI_sample.fits gti.txt out.fits
```

'GTI_sample.fits' is the GTI file name, which could be generated by legtigen/megtigen/hegtigen. 'gti.txt' is the input file name, which includes two columns START and STOP time. 'out.fits' is the out file name.

Example

```
hgti_create LE_oldgti.fits gti.txt out.fits
hgti_create ME_oldgti.fits gti.txt out.fits
hgti_create HE_oldgti.fits gti.txt out.fits
```

8.6 hspec_merge

Merge spectra and response files for Insight-HXMT.

USAGE

```
hspec_merge spec specfile.dat mpha.fits
hspec_merge resp respfile.dat mrsp.fits weight.txt
```

8.7 hpipeline

The command `hpipeline` generates a shell script contains all the modules of the HXMTDAS to produce cleaned, calibrated events data, and high level data production (spectra, light curves). After the version 1.2.1 of *hpipeline*, a user interface style to execute the command was provided.

USAGE

```
hpipeline -i /DATA_PATH/ExpID/ -o /OUTPUT_PATH/
```

PARAMETERS

To show the detail description of the *hpipeline*, execute '*hpipeline -h*', the result is shown as below:

```
  -i, --input=/DATA_PATH/ExpID/
         Input archieved data directory. The directory is identified by
         Exposure ID (P010129900101-20170727 for example).

  -I [optional], --inputlist=INPUTLIST.txt
         A text file that records multiple input directories, each directory takes one
         line.

  -o, --output=outdir
         Output directory to save all the production.

  -O [optional], --outputlist=OUTPUTLIST.txt
         A text file that records multiple output directories, each directory takes one
         line.

------- OPTIONALS --------

  -b, --bash=bash-script-file.sh
         The pipeline does not directly call the modules, it save all the
         commands and corresponding parameters to a script file. Use -b
         parameter to name this script file.

  -e, --execute
```

```
        directly execute the commands instead of saving the commands to bash scripts.

--stem=[string]
        the stem string of the data products.

--hxbary
        carry out Barycentric correction (add new column named
        TDB to file) --ra and --dec must be assigned.

--hxbary2
        carry out Barycentric correction (modify the column
        Time instead of add new column) --ra and --dec must be assigned.

--ephem=[string]
        The JPL planetary ephemeris for Barycentric
        correction, use ‘JPLEPH.DE200’, ‘JPLEPH.DE405’
        (default), or ‘JPLEPH.DE430’.

-r, --ra=[float]
        right ascension of barycentering correction (unit: degree).

-d, --dec=[float]
        declination of barycentering correction (unit: degree).

-v, --version
        the pipeline is compatible with HXMTDAS version 2.05
        (default), if --version 2.02 , the pipeline is
        compatible with HXMTsoft v2.02.

--gti=[string]
        assign the good time intervals (GTIs) to generate the
        light curve and spectra. The input could be a name of
        file or a list of time intervals in unit of MET (e.g.,
        --git ’178710234,178710244; 178710334,178710444’)

--LE_LC_EMIN=[float]
        lower energy limit for LE light curve (unit: keV)

--LE_LC_EMAX=[float]
        upper energy limit for LE light curve (unit: keV)

--LE_LC_BINSIZE=[int]
        binsize for LE light curve (unit: second)

--ME_LC_EMIN=[float]
        lower energy limit for ME light curve (unit: keV)

--ME_LC_EMAX=[float]
        upper energy limit for ME light curve (unit: keV)

--ME_LC_BINSIZE=[int]
        binsize for ME light curve (unit: second)
```

```
--HE_LC_EMIN=[float]
        lower energy limit for HE light curve (unti: keV)

--HE_LC_EMAX=[float]
        upper energy limit for HE light curve (unti: keV)

--HE_LC_BINSIZE=[int]
        binsize for HE light curve (unit: second)

--HE_ONLY              only generate HE results
--ME_ONLY              only generate ME results
--LE_ONLY              only generate LE results
--IGNORE_HEPICAL       skip hepical processes
--IGNORE_MEPICAL       skip mepical processes
--IGNORE_LEPICAL       skip lepical processes
--header               write BACKFILE and RESPFILE keyword to the header of
                       the spectrum files
-c, --clean            remove the non-scientific files generated in the data
                       processing, keep clean data and products only (default
                       keeps all)
-p, --parallel         setup environmental variables for parallel processing
```

EXAMPLES

This is a typical invocation (the interactive method to use *hpipeline*):

```
$ hpipeline

============================================================
             Running HXMT pipeline (hpipeline)
Task: hpipeline Version: 1.2.4-25  Release Date: 2022.01.05
============================================================

Name of Input Exposure directory: P0101029900101-20170827/
Name of Output directory: out_data/
Stem of FITS input files [P010129900101]:
```

This is a prompt approach to execute the *hpipeline*. Three parameters are required:

- The name of data directory. For example, 'P010129900101-20170827-01-01' is the data of Crab Nebula.
- The output directory.
- The prefix in the name of all products. (e.g., the name of output light curve file will start with 'P010129900101')

The above interactive method has the equivalent command line method to use *hpipeline*.

```
hpipeline -i P010129900101-20170827-01-01 -o out_data/ --stem P010129900101
```

This parses the folder of the input path, and generate spectra and light curves for Crab Nebula.

8.8 Real data example

In this section, we will show an example of practical HXMT data processing, containing spectrum analysis, PDS (power density spectrum) analysis, and pulse profile of pulsar plotting. The data used in example are real data released by the HXMT team[1], so you can use this example as a reference to check if the data processing is running correctly. In this example, we use the *hpipeline* to achieve the following goals:

1. generate the spectra and lightcurves of the three telescopes (HE, ME, and LE)
2. select the energy range (e.g., HE: 27–200 keV, ME: 10–35 keV, LE: 2–10 keV)
3. set the time resolution of the light curves (e.g., HE: 5 s, ME: 1 s, LE: 0.1 s)
4. carry out a barycenteral correction on the photons (convert the arrival time to the arrival time of the center of mass of the solar system)
5. set the environment variables for parallel processing (setup PFILES)

Command and Output results

```
hpipeline -i P0101029900101-20170827/ -o Crab_outdir --hxbary -r 83.63322083 -d 22.014461 \
--HE_LC_EMIN=27 --HE_LC_EMAX=200 --ME_LC_EMIN=10 --ME_LC_EMAX=35 \
--LE_LC_EMIN=1 --LE_LC_EMAX=10 --LE_LC_BINSIZE=0.1 --ME_LC_BINSIZE=1 --HE_LC_BINSIZE=5 \
--clean --parallel
```

After successfully running the command, one can list all the results in the ouput directory Crab_outdir by executing the command:

```
> ls -1tr Crab_outdir/
P010129900101_HE_gti.fits
P010129900101_HE_lc_27.0-200.0keV_5.0s_g0_0-17.lc
P010129900101_HE_lc.txt
P010129900101_HE_lcbkg_27.0-200.0keV_5.0s_all.lc
P010129900101_HE_lcnet_27.0-200.0keV_5.0s_all.lc
P010129900101_HE_spec_g0_0-17.pha
P010129900101_HE_spec_g0_0-17.rsp
P010129900101_HE_specbkg.pha
P010129900101_HE_screen.fits
P010129900101_ME_dtime_1.0s.fits
P010129900101_ME_gti_tmp.fits
P010129900101_ME_gti.fits
P010129900101_ME_status.fits
P010129900101_ME_gti.fits.png
P010129900101_ME_lc_10.0-35.0keV_1.0s_g0_0-53.lc
P010129900101_ME_lc.txt
P010129900101_ME_lcbkg_10.0-35.0keV_1.0s.lc
P010129900101_ME_lcnet_10.0-35.0keV_1.0s.lc
P010129900101_ME_spec_g0_0-53.pha
P010129900101_ME_spec_g0_0-53.rsp
P010129900101_ME_specbkg.pha
P010129900101_ME_screen.fits
```

[1] You can download the data in http://archive.hxmt.cn/proposal. The data used in our example is the Crab Nebula observation with the observation ID 'P0101299001', and the specific exposure ID (files containing few kilo-seconds data) 'P010129900101'.

```
P010129900101_LE_gti_tmp.fits
P010129900101_LE_gti.fits
P010129900101_LE_gti.fits.png
P010129900101_LE_lc_2.0-10.0keV_0.1s_g0_0-94.lc
P010129900101_LE_lc.txt
P010129900101_LE_lcbkg_2.0-10.0keV_0.1s.lc
P010129900101_LE_lcnet_2.0-10.0keV_0.1s.lc
P010129900101_LE_spec_g0_0-94.pha
P010129900101_LE_spec_g0_0-94.rsp
P010129900101_LE_specbkg.pha
```

Here are all products generated in the output directory. The prefix "P010129900101" is the stem of output name (you can use the parameter *–stem* to assign the stem you prefer). The second section of string (e.g., "_HE_") represents the instrument.

8.8.1 light curves

We use the *fplot* tool in FTOOLS to plot the generated net light curves. Executing the following command to plot the light curve:

```
> fplot offset=yes
Name of FITS file and [ext#][ ] P010129900101_LE_lcnet_2.0-10.0keV_0.1s.lc
Name of X Axis Parameter[error][ ] TIME
Name of Y Axis Parameter[error] up to 8 allowed[ ] RATE{ERROR}
Lists of rows[-]
Device: /XWindow, /XTerm, /TK, /PS, etc[/xw]
Any legal PLT command[ ]
```

The background subtracted (using *lcmath* to subtract background) light curve are shown in figure 8.1. You can generate the ME, and HE light curve as well.

```
> fplot offset=yes
Name of FITS file and [ext#][] P010129900101_ME_lcnet_10.0-35.0keV_1.0s.lc
Name of X Axis Parameter[error][] TIME
Name of Y Axis Parameter[error] up to 8 allowed[] RATE{ERROR}
Lists of rows[-]
Device: /XWindow, /XTerm, /TK, /PS, etc[/xw]
Any legal PLT command[ ]
```

```
> fplot offset=yes
Name of FITS file and [ext#][] P010129900101_HE_lcnet_27.0-200.0keV_5.0s_all.lc
Name of X Axis Parameter[error][] TIME
Name of Y Axis Parameter[error] up to 8 allowed[] RATE{ERROR}
Lists of rows[-]
Device: /XWindow, /XTerm, /TK, /PS, etc[/xw]
Any legal PLT command[ ]
```

The figure 8.2 and figure 8.3 are light curves of ME and HE respectively. In figure 8.3, there are some points at the edge of the GTIs deviate from the average count rate. But don't worry, let us introduce the algorithm that you can reconstruct the correct net light curve. In the source light curve file *P010129900101_HE_lc_27.0-200.0keV_5.0s_g0_0-17.lc*, there are columns *DEADC* and *FRACEXP* that required to calculate the corrected count rate: $R = C/\mathrm{FRACEXP}/\mathrm{DEADC}$, where R is the corrected rate, C is the counts recorded in file. By dividing *FRACEXP* and *DEADC* the rate is corrected by the dead time effect and the correction at the edge of GTI. For the background data *P010129900101_HE_lcbkg_27.0-200.0keV_5.0s_all.lc*, the similar correction could be conduct $R = R/\mathrm{FRACEXP}$ as well. See figure 8.4 for the results.

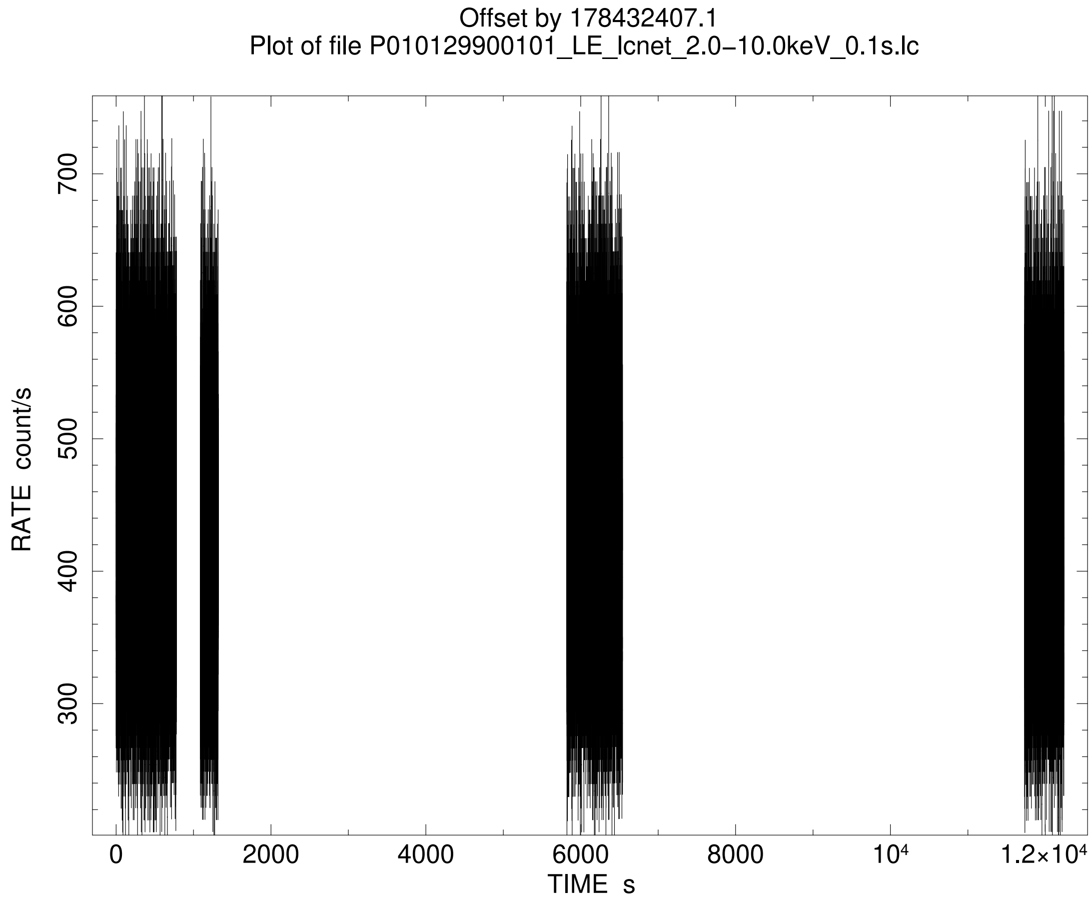

Figure 8.1: Net light curve of LE in 2–10 keV with time resolution of 0.1 seconds.

8.8.2 spectrum

Now we can use `Xspec` tool in `HEASOFT` to fit and plot the spectrum by executing 'XSPEC' to initial the Xspec environment.

```
> xspec

                XSPEC version: 12.10.1f
        Build Date/Time: Tue Oct 29 18:32:17 2019

XSPEC12>
```

Now we are going to

- load the spectrum data
- load background spectrum
- load the response matrix of each instrument
- apply the powerlaw model to the data

and plot the spectra of generated products, by executing the following xspec commands

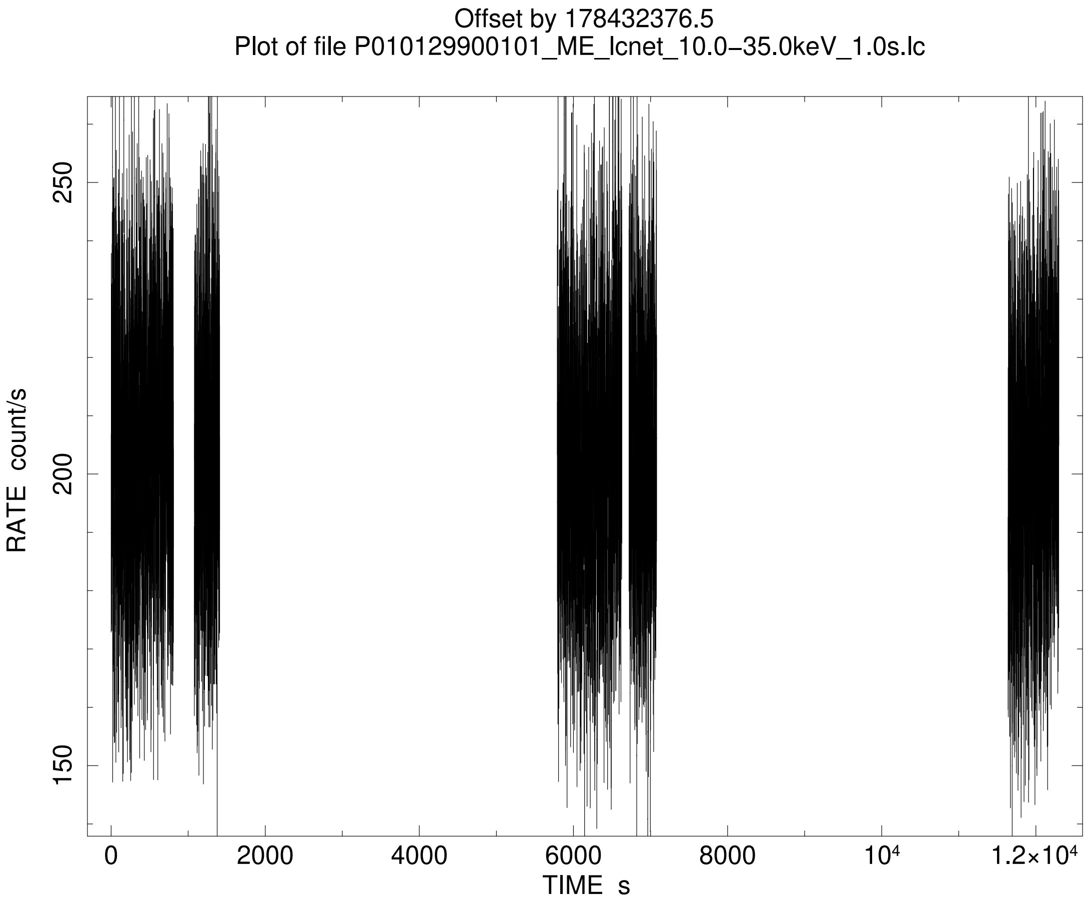

Figure 8.2: Net light curve of ME in 10–35 keV with time resolution of 1 seconds.

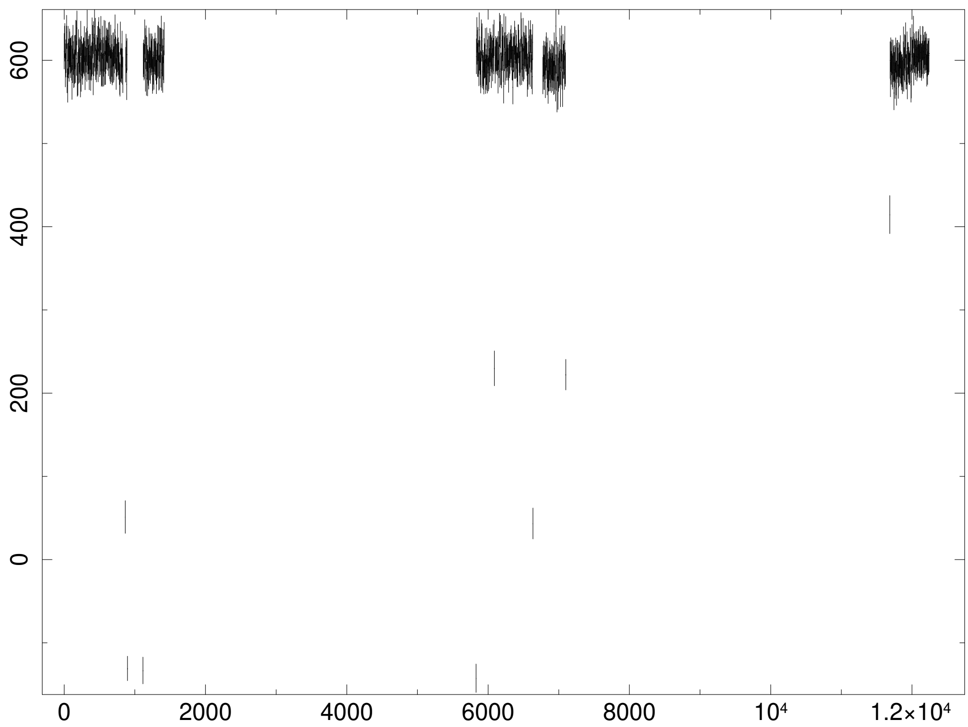

Figure 8.3: Net light curve of HE in 27–200 keV with time resolution 5 seconds. The net light curve was generated by HEASOFT tool *lcmath*, which is not perfectly applicable to the case of HE. If you have those outliers in net light curve, you must recalculate the net light curve from other light curve file for source light curve and background light curve (see content for detail).

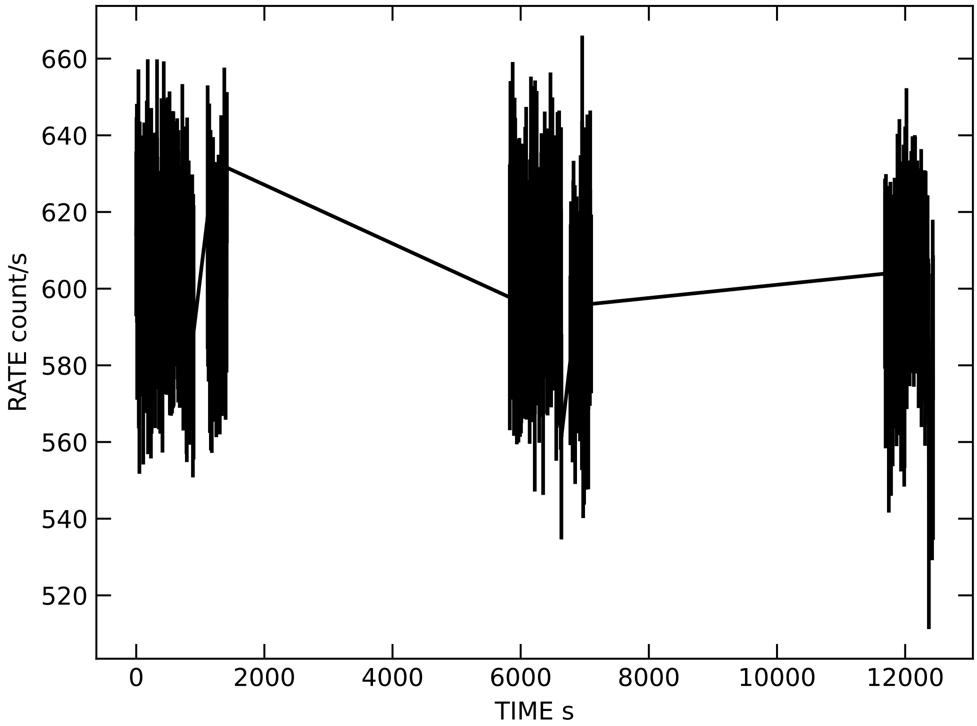

Figure 8.4: The corrected HE light curve.

```
XSPEC12> data 1:1 P010129900101_LE_spec_g0_0-94.pha
XSPEC12> data 2:2 P010129900101_ME_spec_g0_0-53.pha
XSPEC12> data 3:3 P010129900101_HE_spec_g0_0-17.pha
XSPEC12> back 1:1 P010129900101_LE_specbkg.pha 2:2 P010129900101_ME_specbkg.pha
3:3 P010129900101_HE_specbkg.pha
XSPEC12> resp 1 P010129900101_LE_spec_g0_0-94.rsp 2 P010129900101_ME_spec_g0_0-53.rsp
3 P010129900101_HE_spec_g0_0-17.rsp
XSPEC12> ign 1:1 **-2. 10.-** 2:2 **-8. 35.-** 3:3 **-27. 250.-**
XSPEC12> model wabs*powerlaw

Input parameter value, delta, min, bot, top, and max values for ...
              1      0.001(      0.01)          0          0     100000      1e+06
1:data group 1::wabs:nH>/*

========================================================================
Model wabs<1>*powerlaw<2> Source No.: 1   Active/On
Model Model Component  Parameter  Unit     Value
 par  comp
                           Data group: 1
   1    1   wabs       nH         10^22    1.00000      +/-  0.0
   2    2   powerlaw   PhoIndex            1.00000      +/-  0.0
   3    2   powerlaw   norm                1.00000      +/-  0.0
                           Data group: 2
   4    1   wabs       nH         10^22    1.00000      = p1
   5    2   powerlaw   PhoIndex            1.00000      = p2
   6    2   powerlaw   norm                1.00000      = p3
                           Data group: 3
   7    1   wabs       nH         10^22    1.00000      = p1
   8    2   powerlaw   PhoIndex            1.00000      = p2
   9    2   powerlaw   norm                1.00000      = p3
________________________________________________________________________


Fit statistic : Chi-Squared =   2.574161e+07 using 1557 PHA bins.

Test statistic : Chi-Squared =   2.574161e+07 using 1557 PHA bins.
 Reduced chi-squared =       16564.74 for   1554 degrees of freedom
 Null hypothesis probability =   0.000000e+00
 Current data and model not fit yet.
```

Now the data are all set, we can now fit and plot the spectra by doing

```
XSPEC12> fit
XSEPC12> setpl en
XSPEC12> cpd /xw
XSEPC12> pl euf del
XSPEC12> fit
                                   Parameters
Chi-Squared  |beta|/N    Lvl          1:nH     2:PhoIndex        3:norm
1602.29      0.0602204     0      0.364519       2.11533       8.80574
========================================
 Variances and Principal Axes
```

```
                 1         2         3
 1.1410E-07| -0.0153  -0.9989   0.0445
 3.5696E-05|  0.9431  -0.0292  -0.3313
 8.2289E-04| -0.3323  -0.0369  -0.9425
----------------------------------------

====================================
  Covariance Matrix
        1           2           3
   1.226e-04   9.112e-06   2.465e-04
   9.112e-06   1.266e-06   2.897e-05
   2.465e-04   2.897e-05   7.348e-04
------------------------------------

========================================================================
Model wabs<1>*powerlaw<2> Source No.: 1   Active/On
Model Model Component  Parameter  Unit     Value
 par  comp
                           Data group: 1
   1    1   wabs       nH         10^22    0.364519     +/-  1.10727E-02
   2    2   powerlaw   PhoIndex            2.11533      +/-  1.12502E-03
   3    2   powerlaw   norm                8.80574      +/-  2.71078E-02
                           Data group: 2
   4    1   wabs       nH         10^22    0.364519     = p1
   5    2   powerlaw   PhoIndex            2.11533      = p2
   6    2   powerlaw   norm                8.80574      = p3
                           Data group: 3
   7    1   wabs       nH         10^22    0.364519     = p1
   8    2   powerlaw   PhoIndex            2.11533      = p2
   9    2   powerlaw   norm                8.80574      = p3
________________________________________________________________________


Fit statistic : Chi-Squared =        1602.29 using 1557 PHA bins.

Test statistic : Chi-Squared =        1602.29 using 1557 PHA bins.
 Reduced chi-squared =        1.03107 for   1554 degrees of freedom
 Null hypothesis probability =   1.923550e-01
```

8.8.3 Timing

In this section, we will show you the periodic search for the Crab pulsar and the pulse profile accordingly. First, we execute the *fsearch* command to search the best period of the crab pulsar.

```
> efsearch

efsearch 1.1 (xronos6.0)

Ser. 1 filename +options (or @file of filenames +options)[P010129900101_LE_screen.fits vx10]
Name of the window file ('-' for default window)[-]
Epoch[57979.4259421]
```

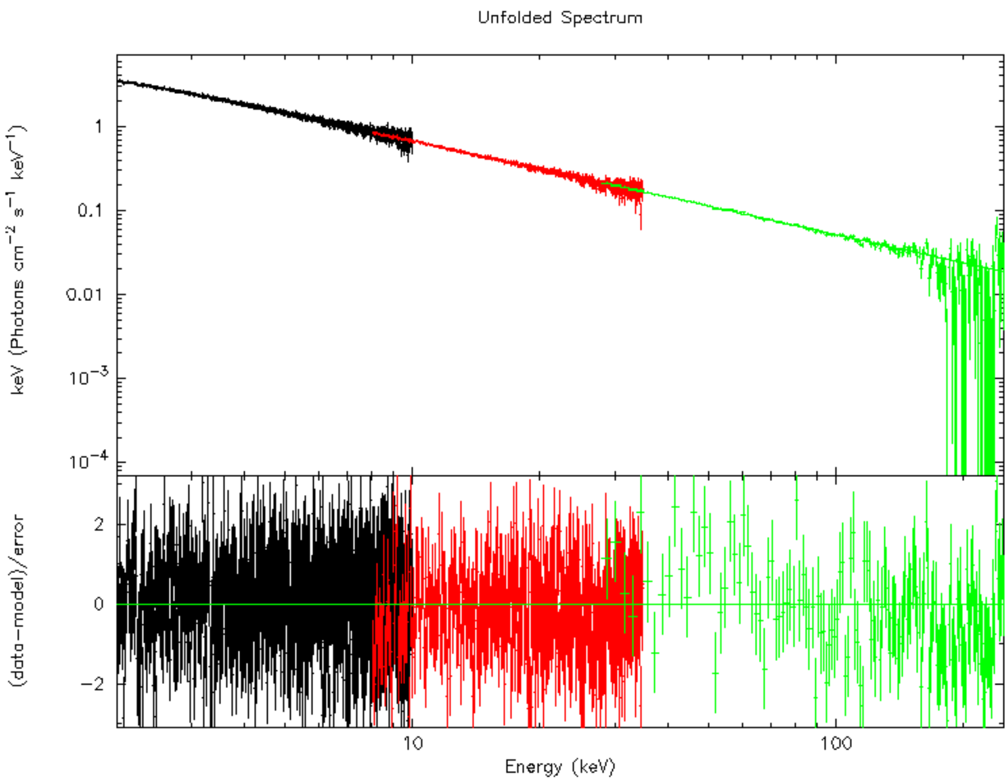

Figure 8.5: The spectra of the Crab nebula plotted by Xspec.

```
Period[0.033742037621868] 0.03373889939683
Phasebins/Period {value or neg. power of 2}[8] 100
Number of Newbins/Interval[] INDEF
Resolution for period search {value or neg. power of 2}[] INDEF
Number of periods to search[] INDEF
Name of output file[fplot]
Do you want to plot your results?[yes]
Enter PGPLOT device[/XW]
```

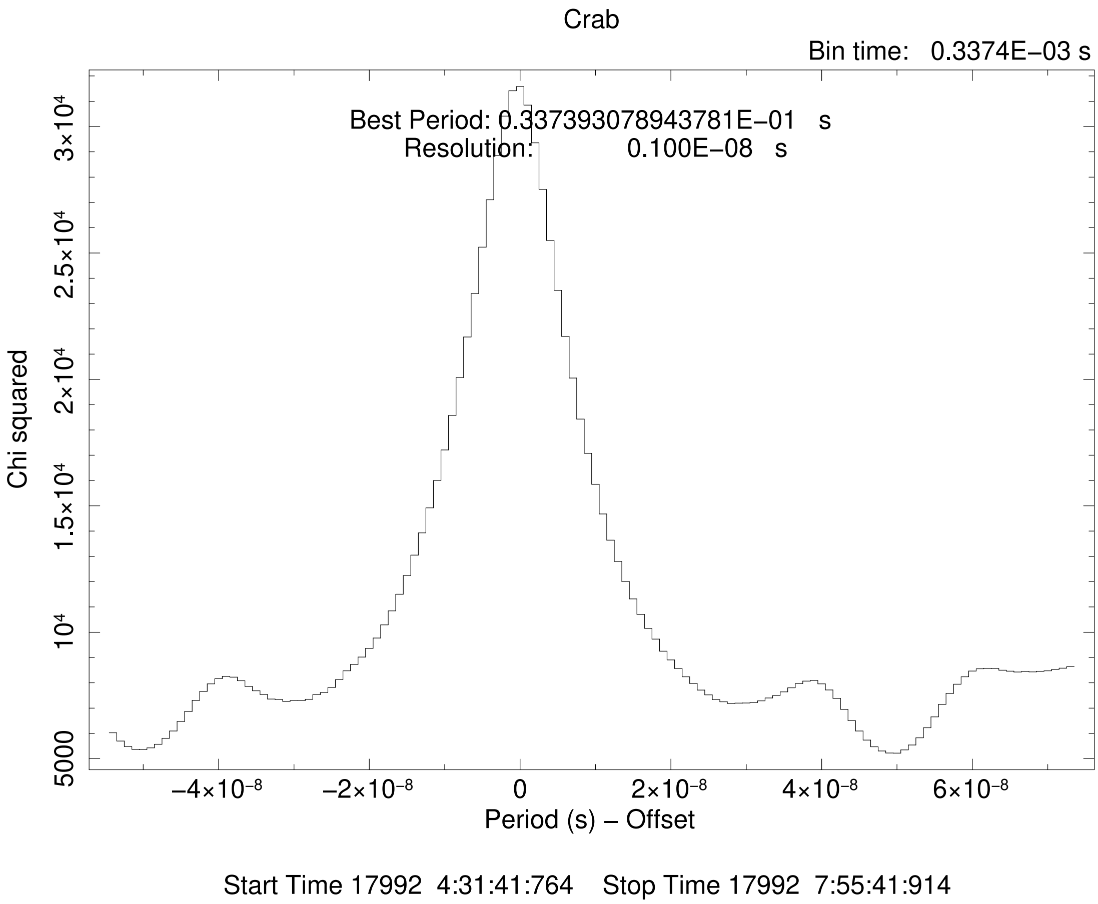

Figure 8.6: Periodic search with Pearson Chisquare test on the Crab pulsar observation of HXMT/LE.

The above command is the standard chisquare search on the Crab pulsar signals. The period 0.03373889939683 seconds is the period reported by Jodrell Bank Radio observatory[2], and then in figure 8.6 the best period is significant appeared. With that period obtained, you can now epoch-folding the photons with the period searched using the command *efold* in `HEASOFT`.

```
> efold

efold 1.1 (xronos6.0)
```

[2]http://www.jb.man.ac.uk/ pulsar/crab.html

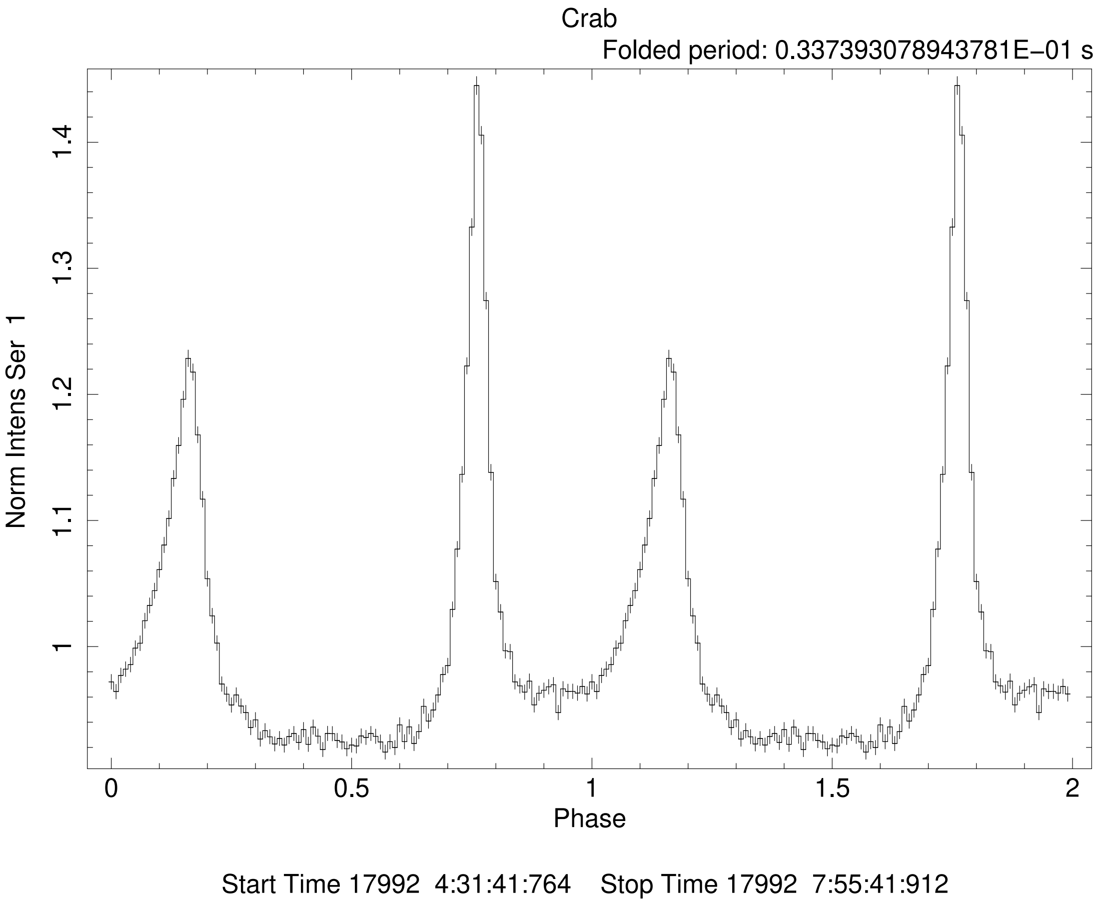

Figure 8.7: The pulse profile folded with period search from *efsearch*.

```
Number of time series for this task[1]
Ser. 1 filename +options (or @file of filenames +options)[P010129900101_LE_screen.fits vx10]
Name of the window file ('-' for default window)[-]
Epoch[59183.654215803464002]
Period[0.337393078943781] 0.0337393078943781
Phasebins/Period {value or neg. power of 2}[100]
Number of Newbins/Interval[36278599]
Number of Intervals/Frame[1]
Name of output file[efold]
Do you want to plot your results?[yes]
Enter PGPLOT device[/XW]
```

In figure 8.7, the pulse profile of the Crab pulsar with double peak in 1–10 keV is revealed. Ta-dha!

At this point, we have shown the results of light curve, spectra fitting, and the periodic search for an example Crab data observed by HXMT. About the tutorial of the HXMT analysis, please contact members in HSDC team if you have any requests or suggestions.

Appendix A

Installation of the HXMTDAS

A.0.1 Compile HXMTDAS source code

(1) Install the HXMTDAS for the first time
After Downloading the HXMT SOURCE CODE, you can execute the following commands to compile the source code.

```
gunzip hxmtsoftv2.05.tar.gz
tar vxf hxmtsoftv2.05.tar
cd hxmtsoftv2.05
cd BUILD_DIR
./configure --prefix=DIR (DIR, install path)
make
make install
```

(2)If you have installed HXMTDAS on your computer.
For example, your source code is located in /home/hxmtsoft directory.
Source your HEADAS environment, eg, source install/x86_64-apple-darwin13.4.0/headas-init.sh
Download the HXMTDAS SOURCE CODE, and then use commands below in sequence:

```
gunzip hxmtsoftv2.05.tar.gz
tar vxf hxmtsoftv2.05.tar
cd hxmtsoftv2.05
cp -r hxmt /home/hxmtsoft/
rm -r hxmt/BUILD_DIR
hmake
hmake install
```

(3)If you want to use the lastest HEAsoft, and install hxmt and HEAsoft at the same time.
step 1:
Download the HEAsoft from HEASARC.
Please make sure the source code must have 'attitude' and 'heacore' components
Use commands gunzip and tar to decompress the package.
step 2:
Download the HXMTDAS.

```
gunzip hxmtsoftv2.05.tar.gz
tar vxf hxmtsoftv2.05.tar
```

step 3:
copy the hxmt component from HEADAS package to HEAsoft package.
step 4:
Change the directory to HEAsoft/BUILD_DIR
open the configure file and modify 'mpfit_required=no' to 'mpfit_required=yes'

```
./configure --prefix=DIR (DIR, installation path)  --with-components=hxmt (for example --with-compon
make
make install
```

A.0.2 Initialization and Setup

for tcsh:

```
setenv HEADAS DIR/PLATFORM
alias hxmtinit 'source \$HEADAS/headas-init.csh'
```

for bash:

```
export HEADAS=DIR/PLATFORM
alias hxmtinit=". $HEADAS/headas-init.sh"
```

In the examples above, (PLATFORM) is a placeholder for the platform- specific string denoting your machine's architecture, for example: i686-pc-linux-gnu-libc2.12.