Analysis of the HXMT High Energy detector calibration data performed at the LARIX–A facility on October 2015

Mauro Orlandini[1], Filippo Frontera[1,2], John B. Stephen[1], Enrico Virgilli[2]

[1] INAF/IASF Bologna, via Gobetti 101, Bologna, Italy
[2] Ferrara University, Physics Department, via Saragat 1, Ferrara, Italy

Abstract: In this report we present the scientific analysis performed on the data acquired during the HXMT High Energy Detector (HED) calibration campaign performed in October 2015 at the LARIX–A facility, located in the Ferrara University scientific-technological campus.

Two HXMT HED units were calibrated in order to determine the channel vs energy relation. For this goal the monochromatic, 5×5 mm X–ray beam was used. This allowed the reconstruction of the average energy response, and the study of its dependence on the the position on the detector crystal (for example, possible border effects).

The analysis shows that the crystal surface responds uniformly to X–ray illumination within $\sim$1%, that the average energy resolution at 30 keV of HED `Z01-23` is 16.5%, that of HED `Z01-24` is 18%, and that the channel vs energy relation is linear in the energy range probed during the calibrations (24–72 keV).

Contents

List of Figures

List of Tables

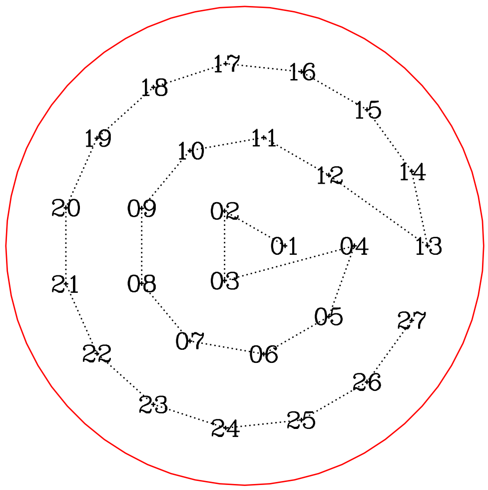


Figure 1: Map of X–ray beam positions onto the HED crystals.

Z01-23	Z01-24
24 26 28	24 26 28
30 32 32.9	30 31 32 32.9
34 36 40	33.9 36 40
50 62 72	50 62 72

Table 1: List of the X–ray beam energies, in keV, used to calibrate the two HEDs.

1 Introduction

The high energy instrument aboard the Chinese Hard X–ray Modulation Telescope (HXMT) [1] consists of 18 cylindrical High Energy Detectors (HEDs), each formed by a phoswich module and its collimator. Each detector unit is a NaI(Tl)/CsI(Na) phoswich scintillation detector with a diameter of 19.6 cm. The thickness of the NaI main detector is 3.5 mm, while that of the CsI shielding is 40 mm. A 5-inch PMT is used to collect the fluorescence of both NaI and CsI crystals.

Two HEDs, coded `Z01-23` and `Z01-24`, were tested at the LARIX–A facility, located in the scientific-technological campus of Ferrara University, at the beginning of October 2015. The setup of the LARIX–A facility during the calibrations will be described in a forthcoming document.

The calibration campaign planned the sweeping of the HED crystals by a monochromatic X–ray beam in 27 different positions, mapped as shown in Fig. 1 (the coordinate positions are given in Appendix A). After fixing the X–ray beam energy (calibrated by means of a Canberra spectrometer), each position was illuminated by the 5×5 mm^2 beam, and the corresponding data acquired by the HED electronics and saved.

This process was repeated for all the 27 points and for the energies tabulated in Table 1 for the two HEDs.

At the end of each measurement a background spectrum was accumulated (obtained by closing the slit in front of the X–ray beam, and leaving the monochromator crystals in the diffraction condition), and used to obtain the net, background subtracted spectrum.

2 Data Analysis

The data format of each energy spectrum accumulated during the calibration campaign was ASCII (extension `.mca`). The file was composed by a header (see an example in Appendix B), and the counts recorded in each of the 512 channels of the detector (one per line). The goal of the calibration campaign was to obtain the channel vs. energy relation.

The first step of the analysis was to convert the ASCII `mca` files into FITS [2]. The reason for this conversion is that we will use the spectral fitting program XSPEC [3], part of the HEAsoft software package[1] to analyze the spectra. XSPEC is the standard tool for spectral analysis in X–ray astrophysics, and takes into account background subtraction, different exposures, error propagation in the data when performing spectral operations, etc.

We wrote a `perl` program that reads the `mca` spectral files, processes their header, adds relevant keywords (see Appendix C), and generates the FITS file by calling the `FTOOLS` program `ascii2pha`.

The naming scheme of the FITS files is the following:

`HXMT_HED_UuEeePpp.fits`	u	Unit number: 1 for `Z01-23`; 2 for `Z01-24`
	ee	Energy (in keV) of the X–ray beam
	pp	Position code, from 01 to 27 (see Fig. 1)

The same program converts also the background `mca` spectral file, that has the same format of the X–ray illuminated spectra (and is named according to the FITS scheme described above, with the `Ppp` part substituted by `BACK`). This information is added to the positional spectra as a `BACKFILE` keyword (see a complete FITS header in Appendix D).

3 Results

Once the FITS is created, we use the XSPEC capability to perform a fit to the data. As a fitting model we use a constant added to a Gaussian function. The program computes the fit, extracts the fitting parameters, computes the errors, and generates the plots. In Fig. 2 we show two typical fits to the data.

We then collected the fit results for all the positions and all the X–ray beam energies. In Fig. 3 we show the best fit Gaussian parameters as a function of the beam positions for the two HEDs for two beam energies (in this case 28 keV for `Z01-23`, and 33.9 keV for `Z01-24`).

From these figures we can see that the centroid energy (and also the energy resolution) is constant within $\sim$1%. The pattern clearly visible in the centroid energy as a function of the beam position is better understood in terms of convolution of the X–ray beaming scheme shown in Fig. 1. A 3D-plot, shown in Fig. 4, shows how the response of the HEDs depends on position onto the detector crystals. Please, keep in mind that this effect is only about $\sim$1%.

Demonstrated that the HED energy resolution does not depend, within $\sim$1%, on the position on the HED crystal, it is now possible to sum the spectra obtained, for a given beam energy, for all the 27 positions. In this way we obtain an energy spectrum for each beam energy, and we can reconstruct the channel vs energy relation, shown in Fig. 5 for the two HEDs.

The linear best fit parameters are shown in the same figure: the value of the correlation Spearman coefficient r excludes any non linearity in the energy range 24–70 keV.

In Fig. 6 we show the energy resolution as a function of energy for the two HEDs. The observed slope is in good agreement with the expected, theoretical value of -0.5. Also the discontinuity at 33 keV, due to the Iodine edge, is clearly visible (and indeed the fits were performed separately for data below and above the edge).

[1] A unified release of the `FTOOLS` and `XANADU` packages, freely available from http://heasarc.gsfc.nasa.gov/docs/software/lheasoft/

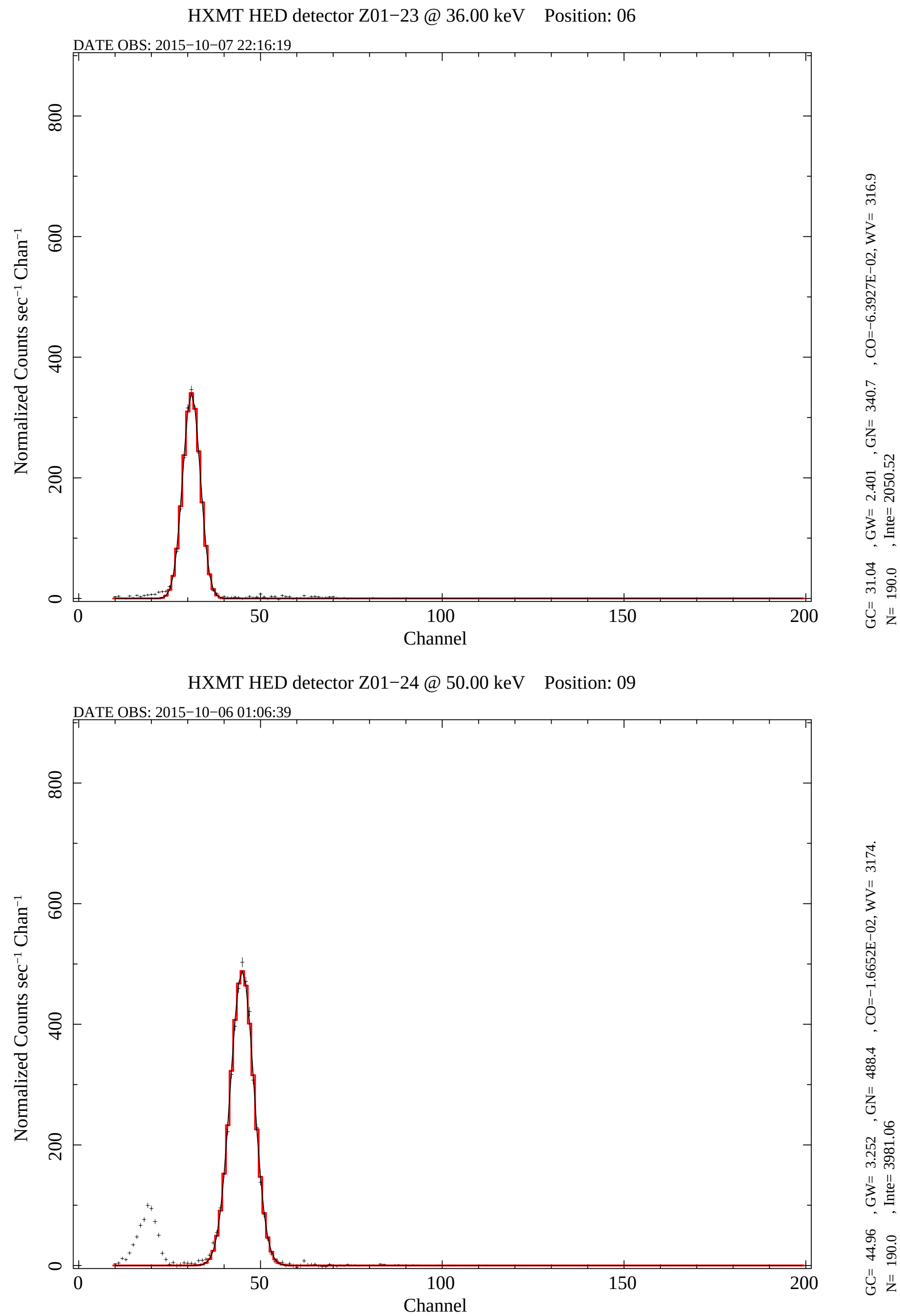


Figure 2: Spectral fits to the background subtracted calibration spectra for two HEDs. *Top:* `Z01-23` spectrum at position 6 and X–ray beam energy 36 keV. *Bottom:* calibration spectrum for unit `Z01-24`, position 9, and beam energy of 50 keV.
The best fit parameters for the fitting model (constant + Gaussian) are shown on the right side of the plot, generated within XSPEC (GC, GW, and GN stand for Gaussian centroid, width, and normalization, respectively. CO stands for the constant value).

Analysis of the HXMT High Energy detector calibration data performed at the LARIX–A facility on October 2015

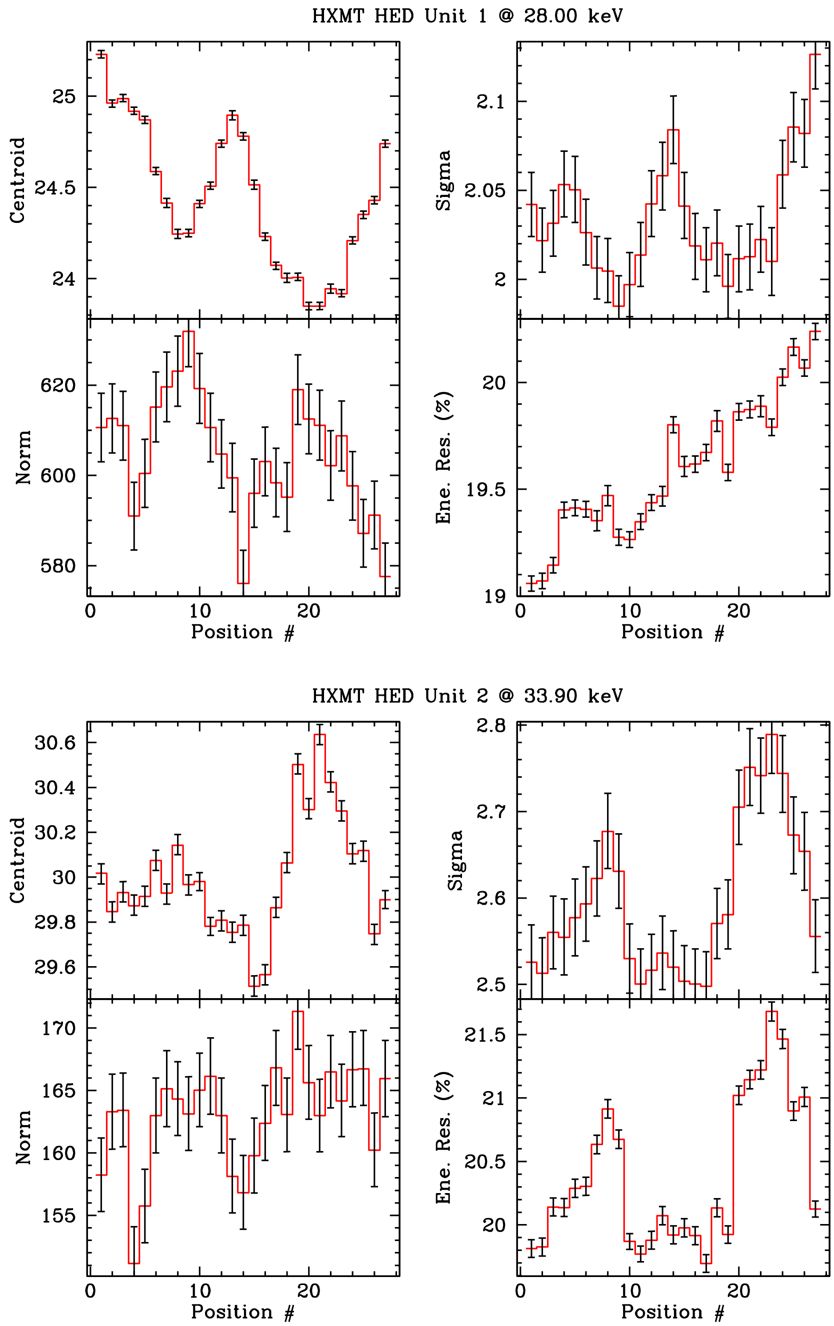


Figure 3: Best fit parameters of the Gaussian function as a function of the beam positions. *Top:* HED Z01-23 at 28 keV. *Bottom:* HED Z01-24 at 33.9 keV.

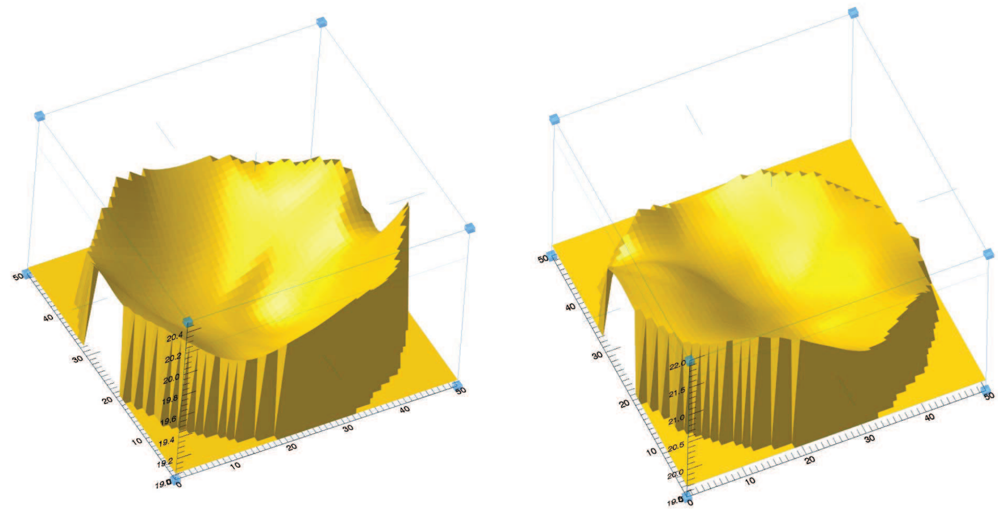


Figure 4: 3D plot of the energy resolution as a function of the beam positions. *Left:* HED `Z01-23` at 28 keV. *Right:* HED `Z01-24` at 33.9 keV. The “hole” on the side of the plot is an artifact of the IDL plotting routine.

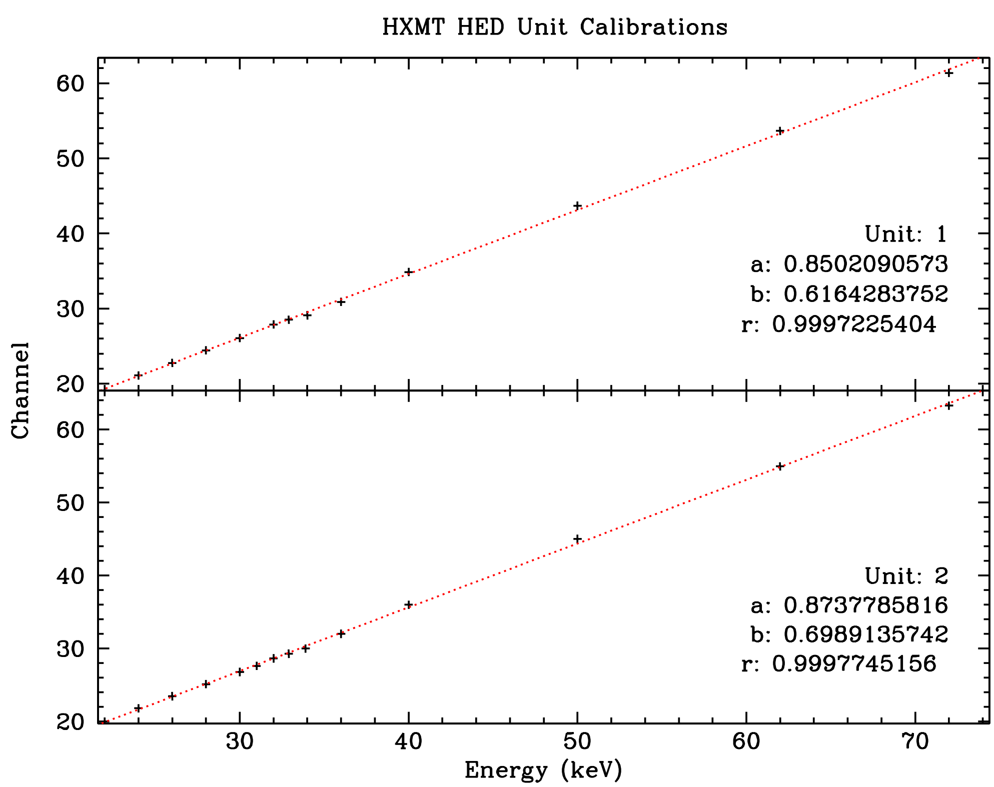
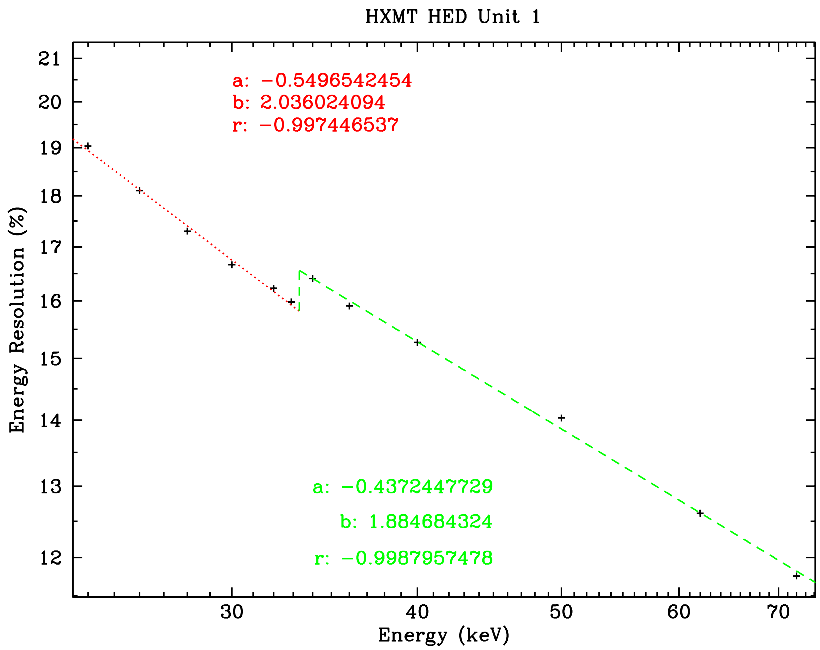


Figure 5: Channel vs Energy relation for the two HEDs. The error bars are smaller than the data points.



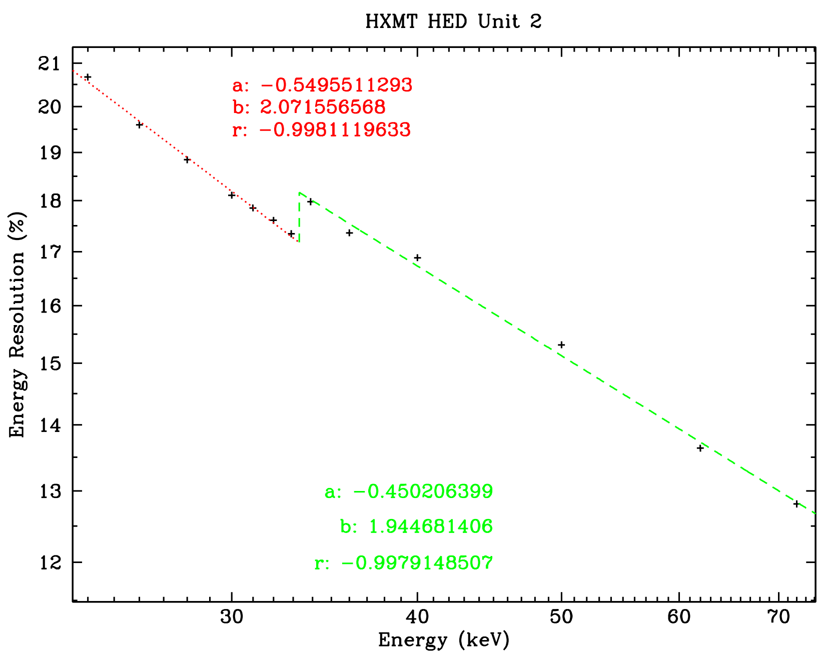


Figure 6: Energy Resolution vs Energy for the two HEDs. Two different fits were performed above and below the 33 keV Iodine edge discontinuity. The expected, theoretical value of the slope is -0.5.

References

[1] Lu, F. 2012. The Current Status of the Hard X–ray Modulation Telescope *Proc. of SPIE Vol. 8443,* 84431P-1

[2] Wells, D.C., Greisen, E.W., and Harten, R.H. 1981. *FITS: A Flexible Image Transport System,* A&A Supplement Series, 44, 363

[3] Arnaud, K.A. 1996. In *Astronomical Data Analysis Software and Systems V,* eds. Jacoby G. and Barnes J., ASP Conf. Series volume 101, 17

A Coordinates of the beam positions on the HED crystal

The origin of the Cartesian coordinate system is the center of the crystal. The units are mm, with the radius of the circle 98 mm.

#	X	Y
01	16.50	0.00
02	-8.25	14.29
03	-8.25	-14.29
04	45.00	0.00
05	34.47	-28.93
06	7.81	-44.32
07	-22.50	-38.97
08	-42.29	-15.39
09	-42.29	15.39
10	-22.50	38.97
11	7.81	44.32
12	34.47	28.93
13	75.00	0.00
14	68.52	30.51
15	50.18	55.74
16	23.18	71.33
17	-7.84	74.59
18	-37.50	64.95
19	-60.68	44.08
20	-73.36	15.59
21	-73.36	-15.59
22	-60.68	-44.08
23	-37.50	-64.95
24	-7.84	-74.59
25	23.18	-71.33
26	50.18	-55.74
27	68.52	-30.51

B Typical MCA Header

A header of a typical `mca` spectrum:

```
<<PMCA SPECTRUM>>
TAG - live_data
DESCRIPTION -
GAIN - 1
THRESHOLD - 10
LIVE_MODE - 0
PRESET_TIME - 10
LIVE_TIME - 10.000000
REAL_TIME - 10.466667
START_TIME - 10/06/2015 17:32:34
SERIAL_NUMBER - 4202
<<DATA>>
...
512 data points (no errors)
...
<<END>>
```

C List of HXMT HED keywords

List of the keywords added to the FITS files to describe the HEDs:

Keyword	Description
GAIN	From the original MCA header
THRSHOLD	From the original MCA header
LIVETIME	From the original MCA header
PRESTIME	From the original MCA header
REALTIME	From the original MCA header
SERIALNR	From the original MCA header
BEAMENGY	The energy, in keV, of the X–ray beam
DET_POS	The X–ray beam illumination position, as described in Fig. 1

D Typical HXMT HED FITS file header

```
XTENSION= 'BINTABLE'           / binary table extension
BITPIX  =                    8 / 8-bit bytes
NAXIS   =                    2 / 2-dimensional binary table
NAXIS1  =                    6 / width of table in bytes
NAXIS2  =                  512 / number of rows in table
PCOUNT  =                    0 / size of special data area
GCOUNT  =                    1 / one data group (required keyword)
TFIELDS =                    2 / number of fields in each row
TTYPE1  = 'CHANNEL '           / Pulse Height Analyser (PHA) Channel
TFORM1  = 'I       '           / data format of field: 2-byte INTEGER
TTYPE2  = 'COUNTS  '           / Counts per channel
TFORM2  = 'J       '           / data format of field: 4-byte INTEGER
TUNIT2  = 'count   '           / physical unit of field
EXTNAME = 'SPECTRUM'           / name of this binary table extension
TNULL1  =                -9999 / Null value
TNULL2  =                -9999 / Null value
HDUCLASS= 'OGIP    '           / format conforms to OGIP standard
HDUCLAS1= 'SPECTRUM'           / PHA dataset (OGIP memo OGIP-92-007)
HDUVERS1= '1.1.0   '           / Obsolete - included for backwards
compatibility
HDUVERS = '1.1.0   '           / Version of format (OGIP memo OGIP-92-007a)
HDUCLAS2= 'UNKNOWN '           / Maybe TOTAL, NET or BKG Spectrum
HDUCLAS3= 'COUNT   '           / PHA data stored as Counts (not count/s)
TLMIN1  =                    0 / Lowest legal channel number
TLMAX1  =                  511 / Highest legal channel number
TELESCOP= 'HXMT    '           / mission/satellite name
INSTRUME= 'HED     '           / instrument/detector name
DETNAM  = 'Z01-23  '           / specific detector name in use
FILTER  = 'NONE    '           / filter in use
EXPOSURE=         1.000000E+01 / exposure (in seconds)
AREASCAL=         1.000000E+00 / area scaling factor
BACKFILE= 'HXMT_HED_U1_E28_BCKG.fits' / associated background filename
BACKSCAL=         1.000000E+00 / background file scaling factor
CORRFILE= 'NONE    '           / associated correction filename
CORRSCAL=         1.000000E+00 / correction file scaling factor
RESPFILE= 'NONE    '           / associated redistrib matrix filename
ANCRFILE= 'NONE    '           / associated ancillary response filename
PHAVERSN= '1992a   '           / obsolete
DETCHANS=                  512 / total number possible channels
CHANTYPE= 'PHA     '           / channel type (PHA, PI etc)
POISSERR=                    T / Poissonian errors to be assumed
STAT_ERR=                    0 / no statistical error specified
SYS_ERR =                    0 / no systematic error specified
```

Analysis of the HXMT High Energy detector calibration data performed at the LARIX–A facility on October 2015

```
GROUPING=                    0 / no grouping of the data has been defined
QUALITY =                    0 / no data quality information specified
HISTORY infile :HXMT_HED_U1_E28_P11.dat
HISTORY  FITS SPECTRUM extension written by WTPHA1 3.2.3
DATE-OBS= '2015-10-06'         / UTC Date of Observation start yyyy-mm-dd
TIME-OBS= '23:08:00'           / UTC Time of Observation start (hh:mm:ss)
DATE-END= '2015-10-06'         / UTC Date of Observation end yyyy-mm-dd
TIME-END= '23:08:10'           / UTC Time of Observation end (hh:mm:ss)
EQUINOX =           2.0000E+03 / Equinox of Celestial coord system
DATE    = '2015-10-29T13:42:14' / file creation date (YYYY-MM-DDThh:mm:ss
UT)
CREATOR = 'ASCII2PHA 1.1.6'    / s/w task which wrote this dataset
BEAMENGY=                28.00 / The beam energy (keV)
DET_POS =                   11 / The beam position on the detector (1-27)
GAIN    =                    1
LIVEMODE=                    0
PRESTIME=                   10
REALTIME=            10.213333
SERIALNR=                 4202
THRSHOLD=                   10
END
```