HaloSat Analysis Guide

Version 1.4

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DOCUMENT TITLE: HaloSat Analysis Guide			
ISSUE	DATE	PAGES AFFECTED	DESCRIPTION
Version 1.0	Apr 2020	All	First version
Version 1.1	Jun 2020	Selected pages	Section 1.2: Fix caldb link, add link to the Halosat Archive document
Version 1.2	Feb 2021	Select Pages	Section 1.3 update the image; 2.3 add section of the background and bright sources
Version 1.3 and 1.4	Feb 2022	Select pages	Section 2.1 added the steps to rescreen the data starting from the unfiltered data, 2.2 added an example to filter unfiltered events with GTI, 2.3 added inflight calibration results

1 Data Overview

1.1 Introduction

HaloSat was designed to survey the distribution of hot gas in the Milky Way and constrain the mass and geometry of the Galactic halo (Kaaret et al 2019 ApJ 884 162k). The mission, led by the University of Iowa (UIowa, PI P. Kaaret), was deployed into circular low Earth orbit on July 13, 2018 and started science operations in October 2018. Originally approved for 12 months of science operations, HaloSat successfully collected science data from October 15, 2018, up to September 29, 2020, effectively doubling the mission life time. HaloSat reentered Earth's atmosphere on January 4, 2021 after nearly two and half year in orbit.

HaloSat is equipped with a non-focusing instrument, comprised of three co-aligned independent silicon drift detectors (SDD) with the following characteristics :

- Energy range: 0.4 -7.0 keV
- Field of View (FOV): 10 deg diameter full response, tapering to 14 deg zero response
- Energy Resolution: ~85 eV at 677 eV and ~137 eV at 5895 eV
- Grasp at 600 eV: 17.6 cm^2 deg^2 (Grasp = Telescope area x field of view)

To complete the sky survey, HaloSat divides the sky into 333 sky positions that are observed during mission operations. Additional observations are added to observe the dark Earth and other fields used for calibration. HaloSat's orbital period is about 90 minutes. The science instrument is turned on only during the night-side half of the orbit. During that time the science event data, instrument housekeeping data, orbital position information, and attitude information are collected. No science event data, housekeeping data, orbital position information, or attitude information are collected during the day-side half of the orbit. HaloSat's observation strategy is to follow two selected positions in the sky for 10 consecutive orbits, and to observe each of the positions for about 1300 seconds per orbit. At the end of the 10 orbits, the pattern is repeated for two other positions, and so on. In May 2019 the number of consecutive orbits in the observing pattern was increased to 16.

1.2 Data processing

The HaloSat data are processed at the UIowa using a Python-based software. The pipeline consists of three processing steps. In the first step, the telemetered housekeeping (hk) and science packets are organized into science and housekeeping databases where packets are sorted and bad packets discarded.

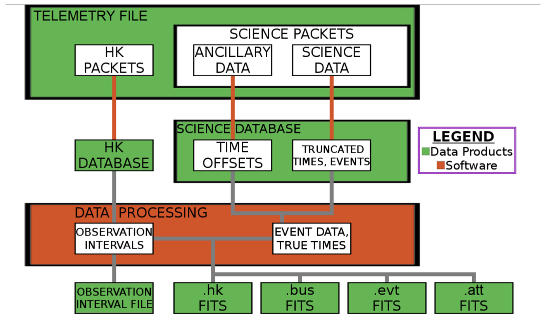


Fig 1 : First step of the pipeline processing

Time intervals when the instrument is operating are calculated as well as the information to derive the absolute time of the events based on the spacecraft GPS time. The outputs from these databases are the raw science and housekeeping data for each individual detector (numbered as SDD14, SDDD38 and SDD54) and attitude data written as FITS files (see Fig 1). This data is organized by pointing with no calibration applied. These "raw" data files are not part of the HEASARC archive.

In the second step, the calibration is applied to the science data files. Additional information is calculated and included in the housekeeping data files. The two-line elements (TLEs, from www.space-track.org) and the attitude are used within the HEASoft *prefilter* task to calculate rigidity, time since last South Atlantic Anomaly (SAA) and other orbital parameters and are added to the housekeeping file. Light curves are calculated from the science data in various bands (see Table 1) and are also added into the housekeeping file. The contents of the housekeeping file is in the appendix a (Table 5).

Table 1: Light Curve Band Definitions

Name	PHA Band	Description
LC_OXYGEN	900-1400	Science, 0.45-0.73 keV
LC_SCI	900-2250	Science, 0.45-1.2 keV
LC_HARD	5600-12900	Background, 3-7 keV
LC_VLE	12900-16384	Large events, > 7 keV
LC_GAP1	600-750	Higher amplitude electronic noise, 0.30-0.38 keV
LC_ALL	0-16384	Total count rate
LC_ALSI	2250-3750	Instrumental Lines band, 1.2-2.0 keV
LC_UP	1400-2250	Band between LC_OXYGEN and LC_ALSI, 0.73-1.2 keV
LC_RESET	0-100	Band with reset pulses

The science data are calibrated for the gain, and events acquired when the instrument performance or other condition are not nominal are filtered out. The gain is applied to the pulse height analyzer

column (PHA) and the results are written in the Pulse Invariant (PI) column. The PI calculation is described in the document "halosat_001_caldb_01", available from the HaloSat caldb page (https://heasarc.gsfc.nasa.gov/docs/heasarc/caldb/halosat/docs/halosat_caldb_docs.html).
To exclude events collected when not in nominal condition, time intervals are derived from the hk file to include times of instrument specific nominal voltages, nominal temperature, SAA exclusion and other parameters. Table 2 lists all the parameters included in the events filtering together with the acceptable ranges.

The hk and the science FITS data files for each of the detectors obtained from this second step of processing are the "unfiltered" data and are included in the archive.

The last step creates the "cleaned" science files and the spectra. The "cleaned" science files are derived by filtering the data on time intervals obtained using the LC_HARD and LC_VLE columns in the hk file. These columns are binned by a factor of 8 (64 sec) and the Good Time Intervals (GTIs) are derived using the following expression for all but the brightest targets:

('LC_HARD' <= 0.16) & ('LC_VLE' <= 0.75) .

These GTI are applied to the 'unfiltered" science data to obtain the "cleaned" data files. The spectra are derived by creating a histogram in PI of all events in the "cleaned" science file. The "cleaned" science and the spectral files for each of the detectors are part of the archive.

Table 2 : Unfiltered Data Cut

Key Name	Lower Limit (>=)	Upper Limit (<=)	Description
IN_SAA	False	-----	Remove remaining data in SAA.
SDD_TEMP	-31.0	-29.0	Instrumental cut
MON_3P3V	3.20	3.30	Instrumental cut
MON_P5V	4.80	5.10	Instrumental cut
MON_M5V	-5.10	-4.80	Instrumental cut
SDDHVMON	-138.0	-133.0	Instrumental cut
SDD0	0.060	0.080	Instrumental cut
OFFSET	-----	0.25	Require pointing within 0.25 deg of source location.
NADIR_ANGLE	92.0	181.0	Require instrument pointing away from Earth limb.
LC_ALL	> 15	140	Remove times of too few counts and too high counts to avoid deadtime issues.
LC_GAP1	-----	< 1.0	Energetic noise removal.
TIME_DUR	8.0	-----	Require standard duration of hk time bins.

The Python-based software used to generate the "unfiltered" and "cleaned" data files is not part of the archive. However, the HEASoft software package has standard tasks that may be used to reproduce the creation of the Good Time Intervals (GTIs) from the housekeeping data and the spectrum from the event data. Specifically, *maketime* calculates GTI and *xselect/extractor* extracts a spectrum.

The raw data are not included in the archive; however, the events excluded from the unfiltered data files are all those that are not qualified for science analysis. The data processing pipeline occurs at UIowa and the data outputs are provided to the HEASARC for the final archive.
File formats are provided in the Appendix of this document and /or in the "HaloSat Archive" description document (https://heasarc.gsfc.nasa.gov/docs/halosat/archive/halosat_archive.pdf)

1.3 Archival data

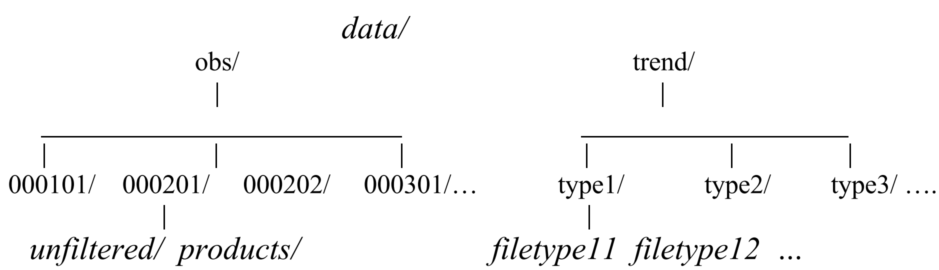
The archive is organized by observation. An observation is defined as data acquired on one specific sky position observed in a time interval where individual files do not exceed 2 Gb. Data associated with an observation are labeled with a 6-digit sequence number, *YYYYZZ,* where:

- YYYY is the target number associated to a specific RA and Dec position. The target number has always 4 digits with a range of 0001 – 0999 for sky positions and 1001 – 1999 for dark earth observations. The value of 0000 is reserved for non-science observations.

- ZZ is a number used to create sequences in the same sky position to limit the size of individual files. If all data taken for a given sky position may be included in FITS files < 2GB, there will be a single data set for that sky position and ZZ will be 01.

The sequence number is used to name the directory containing the science and HK files and is also embedded in each filename.

The HaloSat archive is divided in two areas: the obs/ directory and the trend/ directory. The obs/ directory contains the science data organized by sequence number, and the trend/ directory contains data organized by data type. The structure of the data directory is as follows:



Each observation contains the files (listed in Table 3) output from the step 2 processing (unfiltered directory) and step 3 processing (products directory).

Table 3	
unfiltered/	
hsYYYYZZ_s14.hk.gz	Housekeeping and orbital information SDD 14
hsYYYYZZ_s38.hk.gz	Housekeeping and orbital information SDD 38
hsYYYYZZ_s54.hk.gz	Housekeeping and orbital information SDD 54
hsYYYYZZ.att.gz	Attitude data

hsYYYYZZ.cat.gz	Catalog of the files included in the observation
hsYYYYZZ_s14_uf.evt.gz	Unfiltered event file for the SDD 14 detector
hsYYYYZZ_s38_uf.evt.gz	Unfiltered event file for the SDD 38 detector
hsYYYYZZ_s54_uf.evt.gz	Unfiltered event file for the SDD 54 detector
products/	
hsYYYYZZ.log.pdf.gz	Log of the processing
hsYYYYZZ_s14_cl.evt.gz	Filtered event file for the SDD 14 detector
hsYYYYZZ_s38_cl.evt.gz	Filtered event file for the SDD 38 detector
hsYYYYZZ_s54_cl.evt.gz	Filtered event file for the SDD 54 detector
hsYYYYZZ_s14.pi.gz	Spectrum for the SDD 14 detector
hsYYYYZZ_s38.pi.gz	Spectrum for the SDD 38 detector
hsYYYYZZ_s54.pi.gz	Spectrum for the SDD 54 detector
hsYYYYZZ_sp.gif	Plot of the spectra

The HaloSat archive were first released in April 2020 including all observations of the first year of science operations. After mission operations, all data collected from October 15, 2018, up to September 29, 2020 were processed to produce the final archive released in February 2021. Figure 2 shows the pointing color-coded of the data in the final archive accordingly with the exposure obtained from the detector SDD14 (the exposure is similar in all three detectors).

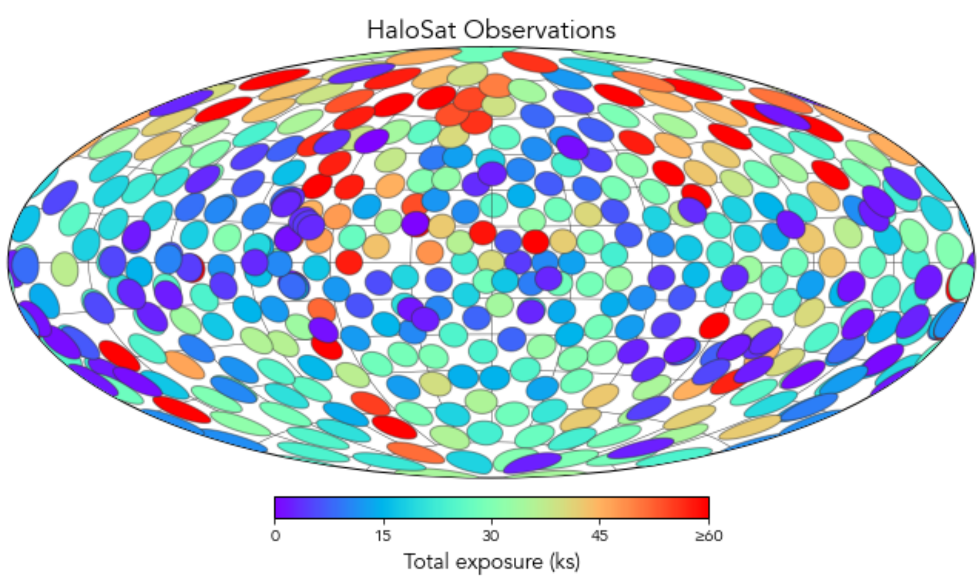


Fig 2:All HaloSat observations taken during the mission operation

2 Data Analysis

The event data in the public archive have been prepared with optimized filtering. However, users may further manipulate the data as necessary for their science goals. Using existing tools in HEASoft, users may select data and extract the resulting spectrum.

2.1 Screening

Additional screening based on specific times of the hk parameters can be achieved using generic HEASoft tasks. The screening involves four steps. For example to rescreen the unfiltered event using different LC_HARD and LC_VLE boundaries (LC_HARD <= 0.16 && LC_VLE <= 0.6) the steps are:

1)Build a lightcurve from the hk file for the LC_VLE and LC_HARD with 64 sec binning :

fcurve infile="hs002501_s14.hk.gz" gtifile="hs002501_s14_uf.evt.gz+2" outfile="hk_sel.hk" timecol=TIME columns="lc_vle lc_hard" binsz=64 lowval=619477924.0 highval=645767891.0 binmode=mean

2)Select all time with good livetime :

fselect infile=hk_sel.hk outfile=hk_sel_lvgt1.hk expr="LIVETIME=>1"

3)Create gti for the new expression to be applied to the unfiltered data:

maketime infile="hk_sel_lvgt1.hk" outfile="hk_sel_lvgt1.gti" expr="LC_HARD <= 0.16 && LC_VLE <= 0.6" time=TIME compact=no prefr=0.5 postfr=0.5 premax=32 postmax=32

4)Apply the new gti using xselect as shown in the example 2 in the next section

2.2 Using xselect to extract a spectrum and a light curve

The HEASoft tasks *xselect/extractor* have been updated to include the HaloSat specifications and released with HEASoft version 6.27 (Mar 31, 2020). Below are two examples of how to derive a spectrum and a light curve using the cleaned event file hs013201_s14_cl.evt.gz (example 1) and how to derive a spectrum using an unfiltered data file hs002501_s14_uf.evt.gz with gti file, hk_sel_lvgti.hk, obtained using different LC_HARD and LC_VLE boundaries (see section 2.1)

Example 1 :
xselect

** XSELECT V2.4m **

> Enter session name >[xselect]
xselect:SUZAKU > **read event hs002501_s14_cl.evt.gz**
> Enter the Event file dir >[.]

```
Got new mission: HALOSAT
> Reset the mission ? >[yes]

 Notes: XSELECT set up for      HALOSAT
 Time keyword is TIME       in units of s
 Default timing binsize =   16.000

Setting...
 Energy keyword   = PI                   with binning =    1

Getting Min and Max for Energy Column...
Got min and max for PI:     1    455

Got the minimum time resolution of the read data:  0.50000E-01
MJDREF =  5.1544000742870E+04 with TIMESYS = TT
 Number of files read in:           1

******************* Observation Catalogue *******************

Data Directory is: /processing/halosat/xselect/
HK Directory is: /processing/halosat/xselect/


      OBJECT           TELESCOP    INSTRUME    OBJTYPE     DATAMODE    DATE-OBS           DATE-END
     1 HaloSat J1748+0300 HALOSAT     SDD14      SCIENCE     PHOTON      2019-08-19T00:00:49 2020-06-18T03:57:02

xselect:HALOSAT-SDD14 > extract curve
extractor v5.39    23 Jun 2021
 Getting FITS WCS Keywords
 Doing file: /processing/halosat/xselect/hs002501_s14_cl.evt.gz
100% completed
        Total     Good    Bad: Time     Phase     Grade      Cut
        29950    29950          0        0        0        0
===============================================================================
    Grand Total      Good    Bad: Time     Phase     Grade      Cut
        29950    29950          0        0        0        0
   in  76544.     seconds
 Fits light curve has    29950 counts for 0.3913     counts/sec

xselect:HALOSAT-SDD14 > save curve mycurve_14
Wrote FITS light curve to file mycurve_14.lc
xselect:HALOSAT-SDD14 > extract spectrum
extractor v5.39    23 Jun 2021
 Getting FITS WCS Keywords
 Doing file: /processing/halosat/xselect/hs002501_s14_cl.evt.gz
100% completed
        Total     Good    Bad: Time     Phase     Grade      Cut
        29950    29950          0        0        0        0
===============================================================================
    Grand Total      Good    Bad: Time     Phase     Grade      Cut
        29950    29950          0        0        0        0
   in  76544.     seconds
 Spectrum         has    29950 counts for 0.3913     counts/sec
Keyword DATE-END has two values: '2020-06-18T03:39:58' and '2020-06-18T03:57:02'
 ... written the PHA data Extension
xselect:HALOSAT-SDD14 > save spectrum myspec_14
Wrote spectrum to myspec_14.pha
xselect:HALOSAT-SDD14 >
```

Example 2 :
xselect

```
                    **  XSELECT V2.4m **

> Enter session name >[xselect]
xselect SUZAKU > read event hs002501_s14_uf.evt.gz
> Enter the Event file dir >[.]
Got new mission: HALOSAT
> Reset the mission ? >[yes]

 Notes: XSELECT set up for      HALOSAT
 Time keyword is TIME       in units of s
 Default timing binsize =   16.000

Setting...
 Energy keyword   = PI                  with binning =    1

Getting Min and Max for Energy Column...
Got min and max for PI:     1    455

Got the minimum time resolution of the read data:  0.50000E-01
MJDREF =  5.1544000742870E+04 with TIMESYS = TT
 Number of files read in:           1

******************* Observation Catalogue *******************

Data Directory is: /processing/halosat/xselect/
HK Directory is: /processing/halosat/xselect/


      OBJECT           TELESCOP   INSTRUME   OBJTYPE    DATAMODE   DATE-OBS          DATE-END
    1 HaloSat J1748+0300 HALOSAT      SDD14      SCIENCE     PHOTON      2019-08-18T21:11:27 2020-06-18T03:57:34

xselect:HALOSAT-SDD14 > filter time file hk_sel_lvgt1.gti
xselect:HALOSAT-SDD14 > extract spectrum
extractor v5.39    23 Jun 2021
 Getting FITS WCS Keywords
 Doing file: /processing/halosat/xselect/hs002501_s14_uf.evt.gz
100% completed
        Total     Good    Bad: Time     Phase     Grade      Cut
        50784    28200        22584        0         0         0
===============================================================================
   Grand Total      Good    Bad: Time     Phase     Grade      Cut
        50784    28200        22584        0         0         0
  in  72480.     seconds
 Spectrum         has    28200 counts for 0.3891      counts/sec
 ... written the PHA data Extension
xselect:HALOSAT-SDD14 > save spectrum myspec2_14
Wrote spectrum to myspec2_14.pha
xselect:HALOSAT-SDD14 >
```

The spectrum may be analyzed within *xspec.* There is a single response and arf applicable to all the spectral files obtained for the three detectors. The responses are located in HEASARC caldb area: https://heasarc.gsfc.nasa.gov/FTP/caldb/data/halosat/sdd/cpf/

They are: hs_sdd_all20180701v001.arf   hs_sdd_avgnoise20180701v001.rmf

There is an additional response hs_sdd_diag20180701v001.rmf that is applicable to the background modelling (see section 2.3). These responses were released on 2020-03-20 and are valid for data taken since the start of the mission (2018-07-01).

2.3 Spectral modelling and Inflight Calibration

HaloSat has a wide field of view, thus each spectrum contains emission from several background and foreground components in addition to the emission from the astrophysical object of interest. The HaloSat team has adopted the following spectral model components:

1) Astrophysical source
2) Diffuse cosmic X-ray background (CXB)
3) Local hot bubble emission (LHB)
4) Particle-induced detector background (PIDB)

The choice of model for the astrophysical sources depends on the target of interest (Kaaret, P. et al. 2019, ApJ, 844, 162). Many models are available for the CXB. It is important to note that point sources are present in HaloSat spectra, so the CXB normalization must be chosen to include point sources. It is possible to either take the LHB as fixed, using, e.g., the results of Liu et al. 2017, ApJ, 834, 33, or to fit the LHB. However, it should be noted that the strongest emission of the LHB lies below the HaloSat band.

Modeling of the HaloSat instrumental background is continually evolving. The recommended method is to use a power law model with a diagonal response matrix. This was motivated by studies of the spectra obtained during observations of the dark Earth with high particle backgrounds that showed that the response for particle-induced events does not have the characteristic features associated with the response for X-ray events. We note that an unfolded power law is also used to model the background for XMM-Newton. The photon index of the instrumental background differs between the detectors and varies with the particle background experienced in each observation; therefore, it is a function of the filtering parameters used for cleaning the data and the background counting rate. The note "Modeling the instrumental background in HaloSat" (https://heasarc.gsfc.nasa.gov/docs/halosat/analysis/back20210209.pdf) describes an analysis of the instrumental background for fields in the southern Galactic halo as used in Kaaret et al. (2020, Nature Astronomy, 4, 1072). The recommended procedure is to fix the background photon index for each detected based on the hard (3-7 keV) band count rate and fit the background normalization. For observations with sufficient statistics, the background photon index and normalization can both be fitted.

Because the HaloSat field of view is quite large, bright X-ray sources are sometime included within the field of view and contribute to the observed spectra. Bluem et al. (2020, ApJ, 902, 91) describing fitting the spectra of a field containing the X-ray binary Cygnus X-3. Data from MAXI (Monitor of All-sky X-ray Image) were used to generate light curves and spectra for

Cyg X-3 for the times of the HaloSat observation. A model was fit to the MAXI spectrum to fix the spectral parameters and relative normalizations of the various components. The same model was included as an added component in the fit to the HaloSat spectrum with the overall normalization allowed to vary.

Inflight calibration

The X-ray data from CasA were used to calibrate the on-orbit energy scale calibration and the Crab data to investigate the residual around 1.8 keV. The note "Halosat Response Matrix modification" (https://heasarc.gsfc.nasa.gov/docs/halosat/analysis/response20220128.pdf) describes the analysis and results of these on orbit calibrations. The outcomes are two main recommendations that can be handled in the spectral analysis using the released responses. The first is to add a small gain offset adjustment of the response necessary for spectra with high statistics and/or fits with multiple components. The gain adjustment is different for each detector and is 0.0232 keV for DPU14, 0.0240 keV for DPU54, and 0.0239 keV for DPU38 respectively. The second is to add in the spectral fitting an edge model with a threshold energy of 1.839 keV and tau of 0.169 to account for the residual around 1.8 keV.

Example of Spectral Fitting

Example 1 : This example of spectral modeling includes the source model and the background power law using the HEASoft *xspec* fitting program:

```
xspec > @load_h0199_s54.xcm
xspec> @halo_fit.xcm
xspec > fit
xspec> plot data delchi
```

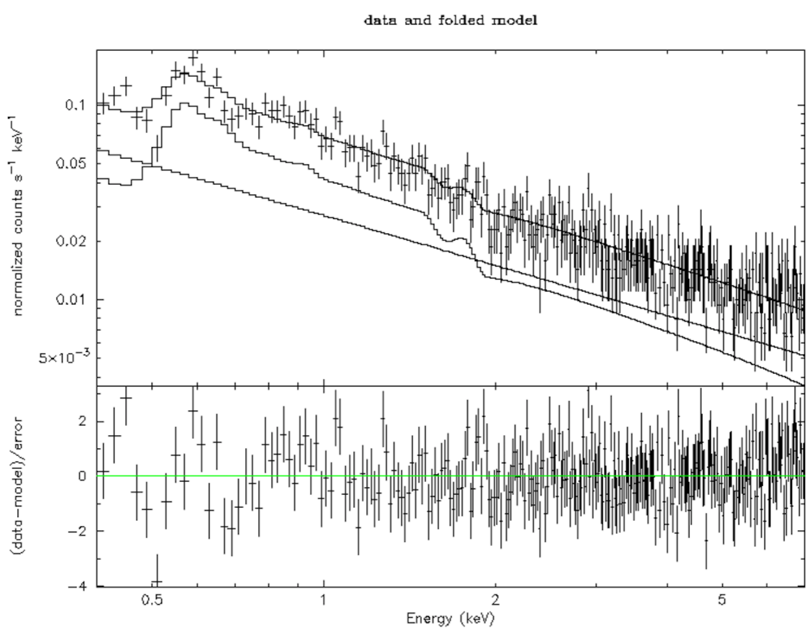


Figure 3: Data and the spectral components (upper panel); the goodness of the fit (lower panel)

where the command files contain the following settings:

load_h0199_s54.xcm

```
data hs019901_s54.pi
response halosat_avgenoise_20190423.rmf
arf halosat_20190211.arf

ign 0.0-0.4
ign 7.0-**
setplot rebin 3.0 30
plot ldata

cpd /xw
setplot energy
```

halo_fit.xcm

```
method leven 10 0.01
abund wilm
xsect vern
cosmo 70 0 0.73
xset delta 0.01
statistic cstat
systematic 0
model  TBabs(apec) + TBabs(powerlaw) + apec
      0.0116        -1         0         0     100000      1e+06
        0.18      0.01     0.008     0.008         64         64
         0.3        -1         0         0          5          5
           0     -0.01    -0.999    -0.999         10         10
           1      0.01         0         0      1e+20      1e+24
      0.0116        -1         0         0     100000      1e+06
        1.45        -1        -3        -2          9         10
        0.38        -1         0         0          1         10
       0.097        -1     0.001     0.001         64         64
           1        -1         0         0          5          5
           0        -1    -0.999    -0.999         10         10
       0.405        -1         0         0      1e+20      1e+24

response 2:1 halosat_diag_20190423.rmf
model  2:back powerlaw
       0.733        -1        -3        -2          9         10
       0.024     0.001         0         0      1e+20      1e+24
```

Example 2 : This example shows how the command files to use in *xspec* are modified to account for the gain offset as well as the edge as recommended by the in-flight calibration :

load_h0199_s54.xcm

```
data hs019901_s54.pi
response hs_sdd_avgnoise20180701v001.rmf
arf hs_sdd_all20180701v001.arf

ign 0.0-0.4
ign 7.0-**
gain 1 ,,0.0240
setplot rebin 3.0 30
```

```
plot ldata

cpd /xw
setplot energy
```

halo_fit.xcm

```
method leven 10 0.01
abund wilm
xsect vern
cosmo 70 0 0.73
xset delta 0.01
statistic cstat
systematic 0

model edge*(TBabs(apec) + TBabs(powerlaw) + apec)
       1.839       -1        0        0      100      100
       0.169       -1        0        0        5       10
      0.0116       -1        0        0   100000    1e+06
        0.18     0.01    0.008    0.008       64       64
         0.3       -1        0        0        5        5
           0    -0.01   -0.999   -0.999       10       10
           1     0.01        0        0    1e+20    1e+24
      0.0116       -1        0        0   100000    1e+06
        1.45       -1       -3       -2        9       10
        0.38       -1        0        0        1       10
       0.097       -1    0.001    0.001       64       64
           1       -1        0        0        5        5
           0       -1   -0.999   -0.999       10       10
       0.405       -1        0        0    1e+20    1e+24

response 2:1 hs_sdd_diag20180701v001.rmf
model  2:back powerlaw
       0.733       -1       -3       -2        9       10
       0.024    0.001        0        0    1e+20    1e+24
```

3 Appendix A: HaloSat event and HK FITS file formats

a) Event File : EVENT, GTI and SCREENING extensions

The keywords and column names for the EVENT, GTI and screening extensions are listed in Table 4. The unfiltered files contain the EVENT and GTI extensions, and the cleaned files contain the EVENT, GTI and SCREENING extensions. The HDUCLAS2 keyword value distinguishes the EVENT and the GTI extensions associated with the unfiltered and cleaned files (see the setting below).

Table 4		
EVENT extension, Valid for unfiltered and cleaned files		
Keyword	**Value**	**Comment**
TTYPE1	'TIME '	/Time of events
TFORM1	'1D '	/data format of field
TUNIT1	's '	/physical unit of field
TTYPE2	'PHA '	/Pulse Height Analyzer
TFORM2	'1I '	/ data format of field
TUNIT2	'chan '	/physical unit of field
TLMIN2	600	/minimum legal value of the column
TLMAX2	12900	/maximum legal value of the column
TTYPE3	'PI '	/Pulse Invariant
TFORM3	'1I '	/ data format of field
TUNIT3	'chan '	/ physical unit of field
TLMIN3	1	/minimum legal value of the column
TLMAX3	455	/maximum legal value of the column
TNULL3	-1	/ null value
PI2ENE	0.02	/ PI conversion from chan to energy keV
EXTNAME	'EVENTS'	/ Binary table extension name
HDUCLASS	'OGIP'	/Format conforms to OGIP/GSFC standards
HDUCLAS1	'EVENTS'	/ First class level
HDUCLAS2	'string'	/ Second class level
TELESCOP	'HALOSAT'	/ Telescope (mission) name
INSTRUME	'SDDnn'	/ Instrument name
DATAMODE	'PHOTON'	/Instrument datamode
OBSERVER	'PHILIP KAARET	/ Principal Investigator
OBS_ID	'string'	/ Observation ID
OBJECT	'string'	/ Object/Target name
OBJTYPE	'string'	/ Object/Target type
EQUINOX	2000	/[yr] Equinox of celestial coord system
RADECSYS	'FK5'	/ Celestial coord system
RA_NOM	0.0	/ [deg] R.A. of nominal aspect point [J2000]

DEC_NOM	0.0	/ [deg] Dec. of nominal aspect point [J2000]
RA_OBJ	0.0	/ [deg] Object Right ascension [J2000]
DEC_OBJ	0.0	/ [deg] Object Declination [J2000]
TIMESYS	‘TT’	/ Reference Time System
MJDREFI	51544	/[d] MJD reference day (2000-01-01T00:00:00)
MJDREFF	7.4287037037037E-04	/[d] MJD reference (fraction of day)
TIMEREF	‘LOCAL’	/Reference Frame
TASSIGN	‘SATELLITE’	/Time assigned by clock
TIMEUNIT	‘s’	/Time unit for timing header keyword
TIMEDEL	0.05	/[s] Data time resolution
TIMEZERO	0.0	/[s] Time Zero
TIMEPIXR	1	/Bin time beginning=0 middle=0.5 end=1
TIERRELA	1.0E-8	/[s/s] relative errors expressed as rate
TIERABSO	1.0	/[s] timing precision in seconds
TSTART	xxxxxxx.xxx	/[s] Observation Start Time
TSTOP	yyyyyyy.yyy	/[s] Observation Stop Time
TELAPSE	nnnnn.nnn	/[s] Stop – Start
ONTIME	value	/[s] Observation time on target
EXPOSURE	value	/[s] exposure
DATE-OBS	‘yyyy-mm-ddThh:mm:ss’	/Start date of observations
DATE-END	‘yyyy-mm-ddThh:mm:ss’	/End date of observations
CLOCKAPP	T	/ Clock correction applied ? (F/T)
DEADAPP	F	/ Has deadtime been applied to data? (F/T)
ORIGIN	‘UNIVERSITY OF IOWA’	/ Origin of fits file
PROCVER	‘hsuf_YYYYMMDD_hscl_YYYYMMDD’	/Processing script version number
SOFTVER	’Hea_ddmmmyyyy_Vxxxx’	/ Software version
CALDBVER	‘hsYYYYMMDD’	/CALDB index version used
TLM2FITS	‘db_YYYYMMDD’	/Telemetry converter FITS version
CREATOR	‘string’	/ Software creator of the file
DATE	‘yyyy-mm-ddThh:mm:ss’	/File creation date
CHECKSUM	value	/ data unit checksum updated date
DATASUM	value	/ HDU checksum updated date
GTI extension valid for unfiltered and cleaned files		
Keyword	**Value**	**Comment**
TTYPE1	'START '	/Start time
TFORM1	'1D '	/ data format of field
TUNIT1	's '	/physical unit of field
TTYPE1	'STOP '	/Stop time
TFORM1	'1D '	/ data format of field
TUNIT1	's '	/physical unit of field
EXTNAME	‘GTI’	/ Binary table extension name
HDUCLASS	‘OGIP’	/Format conforms to OGIP/GSFC standards

HDUCLAS1	‘GTI’	/ First class level
HDUCLAS2	‘string’	/ Second class level
TELESCOP	‘HALOSAT’	/ Telescope (mission) name
INSTRUME	‘SDDnn’	/Instrument name
OBSERVER	‘PHILIP KAARET	/ Principal Investigator
OBS_ID	‘string’	/ Observation ID
OBJECT	‘string’	/ Object/Target name
OBJTYPE	‘string’	/ Object/Target type
EQUINOX	2000	/[yr] Equinox of celestial coord system
RADECSYS	‘FK5’	/ Celestial coord system
RA_NOM	0.0	/ [deg] R.A. of nominal aspect point [J2000]
DEC_NOM	0.0	/ [deg] Dec. of nominal aspect point [J2000]
RA_OBJ	0.0	/ [deg] Object Right ascension [J2000]
DEC_OBJ	0.0	/ [deg] Object Declination [J2000]
TIMESYS	‘TT’	/ Reference Time System
MJDREFI	51544	/[d] MJD reference day (2000-01-01T00:00:00)
MJDREFF	7.4287037037037E-04	/[d] MJD reference (fraction of day)
TIMEREF	‘LOCAL’	/Reference Frame
TASSIGN	‘SATELLITE’	/Time assigned by clock
TIMEUNIT	‘s’	/Time unit for timing header keyword
TIMEZERO	0.0	/[s] Time Zero
TSTART	xxxxxxx.xxx	/[s] Observation start time
TSTOP	yyyyyyy.yyy	/[s] Observation stop time
DATE-OBS	‘yyyy-mm-ddThh:mm:ss’	/Start date of observations
DATE-END	‘yyyy-mm-ddThh:mm:ss’	/End date of observations
CLOCKAPP	T	/ Clock correction applied ? (F/T)
ORIGIN	‘UNIVERSITY OF IOWA’	/ Origin of fits file
PROCVER	‘hsuf_YYYYMMDD_hscl_YYYYMMDD’	/Processing script version number
SOFTVER	’Hea_ddmmmyyyy_Vxxxx’	/ Software version
CALDBVER	‘hsYYYYMMDD’	/CALDB index version used
TLM2FITS	‘db_YYYMMDD’	/Telemetry converter FITS version
CREATOR	‘db_hsuf’	/Software creator of the file
DATE	‘yyyy-mm-ddThh:mm:ss’	/File creation date
CHECKSUM	‘value’	/ data unit checksum updated date
DATASUM	‘value’	/ HDU checksum updated date
SCREENING extension valid for cleaned file		
Keyword	**Value**	**Comment**
TTYPE1	'EXTENSION '	/Name of extension to apply screening
TFORM1	'20A '	/ data format of field
TTYPE2	‘EXPRESSION '	/Expression
TFORM2	‘600A '	/ data format of field

EXTNAME	'SCREENING'	/ Binary table extension name
TELESCOP	'HALOSAT'	/ Telescope (mission) name
INSTRUME	'SDDnn'	/Instrument name
OBSERVER	'PHILIP KAARET	/ Principal Investigator
OBS_ID	'string'	/ Observation ID
OBJECT	'string'	/ Object/Target name
OBJTYPE	'string'	/ Object/Target type
ORIGIN	'UNIVERSITY OF IOWA'	/ Origin of fits file
PROCVER	'hsuf_YYYYMMDD_hscl_YYYYMMDD'	/Processing script version number
SOFTVER	'Hea_ddmmmyyyy_Vxxxx'	/ Software version
CALDBVER	'hsYYYYMMDD'	/CALDB index version used
TLM2FITS	'db_YYYYMMDD'	/Telemetry converter FITS version
CREATOR	'db_hsuf_hscl'	/Software creator of the file
DATE	'yyyy-mm-ddThh:mm:ss'	/File creation date
CHECKSUM	'value'	/ data unit checksum updated date
DATASUM	'value'	/ HDU checksum updated date

The TLMIN and TLMAX associated to the PI and PHA columns define the lower and upper channel for the spectrum. The lower and upper channels are positive integer numbers. The TNULL keyword contains the value associated to non-valid channel numbers.

NOTE:
HDUCLAS2 has different settings in the unfiltered and filtered data files. The values are:

- Unfiltered EVENT extension set to 'ALL'; Filtered EVENT extension 'ACCEPTED'
- Unfiltered GTI extension set to 'ALL'; Filtered GTI extension 'STANDARD'

PROCVER has different settings in the unfiltered and filtered data files. The values are:

- In EVENT and GTI extensions of the unfiltered file is set to 'hsuf_YYYYMMDD'
- In EVENT and GTI extensions of the cleaned file set to 'hsuf_YYYYMMDD_hscl_YYYYMMDD'

b) Instrument housekeeping

The housekeeping file contains the keywords and columns of the instrument housekeeping and the orbital information parameters derived by prefilter.

Table 5		
Event extension		
Keyword	**Value**	**Comment**
TTYPE1	'TIME '	/Time
TFORM1	'1D '	/ data format of field
TUNIT1	's '	/physical unit of field

TTYPE2	'SDD_TEMP '	/[deg_C] Temperature readout for Si chip
TFORM2	'1D '	/ data format of field
TTYPE3	'TEC_PWN '	/Value duty cycle of the TEC
TFORM3	'1D '	/ data format of field
TTYPE4	'ADC_TEMP '	/[deg_C] Temperature readout ADC
TFORM4	'1D '	/ data format of field
TTYPE5	'LRS_PCNT '	/Low rate science packet
TFORM5	'1D '	/ data format of field
TTYPE6	'SDDHVSET'	/ Voltage DAC on set line
TFORM6	'1D '	/ data format of field
TUNIT6	'V '	/ physical unit of field
TTYPE7	'FLEXICNT'	/ FLEXI counter
TFORM7	'1D '	/ data format of field
TTYPE8	'SDD1'	/ reset pulse threshold
TFORM8	'1D '	/ data format of field
TUNIT8	'V '	/ physical unit of field
TTYPE9	'MON_3P3V'	/ Voltage Monitor on 3.3V line
TFORM9	'1D '	/ data format of field
TUNIT9	'V '	/ physical unit of field
TTYPE10	'MON_M5V'	/ Voltage Monitor on -5V line
TFORM10	'1D '	/ data format of field
TUNIT10	'V '	/ physical unit of field
TTYPE11	'MON_P5V'	/ Voltage Monitor on +5V line
TFORM11	'1D '	/ data format of field
TUNIT111	'V '	/ physical unit of field
TTYPE12	'SDD0'	/ event detection threshold
TFORM12	'1D '	/ data format of field
TUNIT112	'V '	/ physical unit of field
TTYPE13	'DAC_TEMP '	/[deg_C]Temperature of the DAC
TFORM13	'1D '	/ data format of field
TTYPE14	'BPL_TEMP '	/[deg_C]Temperature sensor of baseplate
TFORM14	'1D '	/ data format of field
TTYPE15	'HSK_PCNT '	/Housekeeping packet counter
TFORM15	'1D '	/ data format of field
TTYPE16	'SDDHVMON'	/ Voltage DAC on monitor line
TFORM16	'1D '	/ data format of field
TUNIT16	'V '	/ physical unit of field
TTYPE17	'DPU_TEMP '	/[deg_C]Temperature DPU band
TFORM17	'1D '	/ data format of field
TTYPE18	'RA'	/ Right Ascension of the pointing
TFORM18	1D	/ data format of field
TUNIT18	'deg'	/ physical unit of field
TTYPE19	'DEC'	/ Declination of the pointing
TFORM19	1D	/ data format of field

TUNIT19	‘deg’	/ physical unit of field
TTYPE20	‘SAT_LAT’	/Satellite Latitude
TFORM20	‘1D’	/format of field
TUNIT20	‘deg’	/ physical units of field
TTYPE21	‘SAT_LON’	/Satellite Longitude
TFORM21	‘1D’	/format of field
TUNIT21	‘deg’	/ physical units of field
TTYPE22	‘NADIR_ANGLE’	/Angular distance from pointing to Nadir
TFORM22	‘1D’	/format of field
TUNIT22	‘deg’	/ physical units of field
TTYPE23	‘OFFSET’	/Offset
TFORM23	‘1D’	/format of field
TUNIT23	‘deg’	/ physical units of field
TTYPE24	‘LC_GAP1’	/Averaged 8s Count Rate in LC_GAP1 band
TFORM24	‘1D’	/format of field
TUNIT24	‘count/s’	/ physical units of field
TTYPE25	‘LC_SCI’	/Averaged 8s Count Rate in LC_SCI band
TFORM25	‘1D’	/format of field
TUNIT25	‘count/s’	/ physical units of field
TTYPE26	‘LC_ALL’	/Averaged 8s Total Count Rate
TFORM26	‘1D’	/format of field
TUNIT26	‘count/s’	/ physical units of field
TTYPE27	‘LC_HARD’	/Averaged 8s Count Rate in LC_HARD band
TFORM27	‘1D’	/format of field
TUNIT27	‘count/s’	/ physical units of field
TTYPE28	‘LC_VLE’	/Averaged 8s Count Rate in LC_VLE band
TFORM28	‘1D’	/format of field
TUNIT28	‘count/s’	/ physical units of field
TTYPE29	‘LC_OXYGEN’	/Averaged 8s Count Rate in LC_OXYGEN band
TFORM29	‘1D’	/format of field
TUNIT29	‘count/s’	/ physical units of field
TTYPE30	‘LC_RESET’	/Averaged 8s Count Rate in LC_RESET band
TFORM30	‘1D’	/format of field
TUNIT30	‘count/s’	/ physical units of field
TTYPE31	‘LC_ALSI’	/Averaged 8s Count Rate in LC_ALSI band
TFORM31	‘1D’	/format of field
TUNIT31	‘count/s’	/ physical units of field
TTYPE32	‘LC_UP’	/Averaged 8s Count Rate in LC_UP band
TFORM32	‘1D’	/format of field
TUNIT32	‘count/s’	/ physical units of field
TTYPE33	‘IN_SAA’	/Satellite in SAA?
TFORM33	‘L’	/format of field
TTYPE34	‘SAT_ALT’	/Satellite Altitude
TFORM34	‘1D’	/format of field

TUNIT34	‘km’	/ physical units of field
TTYPE35	‘ELV’	/angle between pointing and earth limb
TFORM35	‘1D’	/format of field
TUNIT35	‘deg’	/ physical units of field
TTYPE36	‘BR_EARTH’	/angle between pointing and bright earth
TFORM36	‘1D’	/format of field
TUNIT36	‘deg’	/ physical units of field
TTYPE37	‘FOV_FLAG’	/0=sky ; 1=dark earth; 2 bright earth
TFORM37	‘I’	/format of field
TNULL37	-999	/ tnull value
TTYPE38	‘SUNSHINE’	/1= in sunshine ; 0=not
TFORM38	‘I’	/format of field
TNULL38	-999	/ tnull value
TTYPE39	‘SUN_ANGLE’	/angle between pointing vector and sun vector
TFORM39	‘1D’	/format of field
TUNIT39	‘deg’	/ physical units of field
TTYPE40	‘MOON _ANGLE’	/angle between pointing vector and moon vector
TFORM40	‘1D’	/format of field
TUNIT40	‘deg’	/ physical units of field
TTYPE41	‘RAM_ANGLE’	/angle between pointing and velocity vectors
TFORM41	‘1D’	/format of field
TUNIT41	‘deg’	/ physical units of field
TTYPE42	‘ANG_DIST’	/angular distance of pointing from nominal
TFORM42	‘1D’	/format of field
TUNIT42	‘deg’	/ physical units of field
TTYPE43	‘COR_ASCA’	/magnetic cut-off rigidity (ASCA map)
TFORM43	‘1D’	/format of field
TUNIT43	‘GeV/c’	/ physical units of field
TTYPE44	‘COR_SAX’	/magnetic cut-off rigidity (IGRFmap)
TFORM44	‘1D’	/format of field
TUNIT44	‘GeV/c’	/ physical units of field
TTYPE45	‘MCILWAIN_L’	/McIlwain L parameter (SAX)
TFORM45	‘1D’	/format of field
TTYPE46	‘SAA’	/1=in ; 0=not
TFORM46	‘I’	/format of field
TNULL46	-999	/ tnull value
TTYPE47	‘SAA_TIME’	/time since entering/exiting SAA
TFORM47	‘1D’	/format of field
TUNIT47	‘s’	/ physical units of field
TTYPE48	‘RAP’	/ Right Ascension by prefilter
TFORM48	1D	/ data format of field
TUNIT48	‘deg’	/ physical unit of field
TTYPE49	‘DECP’	/ Declination by prefilter
TFORM49	1D	/ data format of field

TUNIT49	'deg'	/ physical unit of field
TTYPE50	'SAT_LATP'	/Satellite Latitude by prefilter
TFORM50	'1D'	/format of field
TUNIT50	'deg'	/ physical units of field
TTYPE51	'SAT_LONP'	/Satellite Longitude by prefilter
TFORM51	'1D'	/format of field
TUNIT51	'deg'	/ physical units of field
TTYPE52	'POSITION'	/Prefilter ECI Position satellite {X,Y,Z}
TFORM52	'3E'	/format of field
TUNIT52	'km'	/ physical units of field
TTYPE53	'VELOCITY'	/Prefilter ECI velocity satellite {vX,vY,vZ}
TFORM53	'3E'	/format of field
TUNIT53	'km/s'	/ physical units of field
TTYPE54	'ROLL'	/pointing roll angle
TFORM54	'1D'	/format of field
TUNIT54	'deg'	/ physical units of field
TTYPE55	'SUN_RA'	/ Right Ascension of Sun
TFORM55	1D	/ data format of field
TUNIT55	'deg'	/ physical unit of field
TTYPE56	'SUN_DEC'	/ Declination of Sun
TFORM56	1D	/ data format of field
TUNIT56	'deg'	/ physical unit of field
HDUCLASS	'OGIP'	/Format conforms to OGIP/GSFC standards
HDUCLAS1	'TEMPORALDATA'	/ First class level
HDUCLAS2	'HK'	/ Second class level
TELESCOP	'HALOSAT'	/ Telescope (mission) name
INSTRUME	'SDDnn'	/Instrument name
OBSERVER	'PHILIP KAARET	/ Principal Investigator
OBS_ID	'string'	/ Observation ID
OBJECT	'string'	/ Object/Target name
OBJTYPE	'string'	/ Object/Target type
EQUINOX	2000	/[yr] Equinox of celestial coord system
RADECSYS	'FK5'	/ Celestial coord system
RA_NOM	0.0	/ [deg] R.A. of nominal aspect point [J2000]
DEC_NOM	0.0	/ [deg] Dec. of nominal aspect point [J2000]
RA_OBJ	0.0	/ [deg] Object Right ascension [J2000]
DEC_OBJ	0.0	/ [deg] Object Declination [J2000]
TIMESYS	'TT'	/ Reference Time System
MJDREFI	51544	/[d] MJD reference day (2000-01-01T00:00:00)
MJDREFF	7.4287037037037E-04	/[d] MJD reference (fraction of day)
TIMEREF	'LOCAL'	/Reference Frame
TASSIGN	'SATELLITE'	/Time assigned by clock
TIMEUNIT	's'	/Time unit for timing header keyword

TIMEDEL	8.0	/[s] Data time resolution
TIMEZERO	0.0	/[s] Time Zero
TIERRELA	1.0E-8	/[s/s] relative errors expressed as rate
TIERABSO	1.0	/[s] timing precision in seconds
TSTART	xxxxxxx.xxx	/[s] Observation Start Time
TSTOP	yyyyyyy.yyy	/[s] Observation Stop Time
DATE-OBS	'yyyy-mm ddThh:mm:ss'	/Start date of observations
DATE-END	'yyyy-mm ddThh:mm:ss'	/End date of observations
CLOCKAPP	T	/ Clock correction applied ? (F/T)
ORIGIN	'UNIVERSITY OF IOWA'	/ Origin of fits file
PROCVER	'hsuf_YYYYMMDD_hscl_YYYYMMDD'	/Processing script version number
SOFTVER	'Hea_ddmmmyyyy_Vxxxx'	/ Software version
CALDBVER	'hsYYYYMMDD'	/CALDB index version used
TLM2FITS	'db_YYYMMDD'	/Telemetry converter FITS version
CREATOR	'db_hsuf'	/Software creator of the file
DATE	'yyyy-mm-ddThh:mm:ss'	/File creation date
CHECKSUM	'value'	/ data unit checksum updated date
DATASUM	'value'	/ HDU checksum updated date