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IMAGING X-RAY POLARIMETRY EXPLORER (IXPE) SCIENCE OPERATIONS CENTER (SOC)

User Guide — Data Formats

IXPE Science Operations Center
Data Formats of Level-1, Level-2 and CALDB Products

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1 Introduction

The Imaging X-ray Polarimetry Explorer (IXPE) is a NASA mission in partnership with the Italian space agency (Agenzia Spaziale Italiana, ASI). IXPE provides the capability to measure the (linear) polarization of x rays from astrophysical sources. In addition, IXPE introduces the capability for x-ray polarimetric imaging, uniquely enabling measurement of x-ray polarization with scientifically meaningful spatial, spectral, and temporal resolution.

1.1 Purpose

This document describes common tasks associated with set-up, maintenance, and operational flow of SOC-developed software to create and analyze the various data products created, utilized, and consumed by the Science Processing software cycle.

The IXPE Science Operations Center (SOC), at NASA Marshall Space Flight Center (MSFC), provides ground support for science operations of this space-based observatory. The primary functions of the SOC are these:

1. Develop software and operations to transform an IXPE long-term (1 year at a time) target list into an annual observing schedule, based upon orbital and pointing constraints, and to generate weekly Instrument Activity Plans (IAPs) that will guide the commanding of the Observatory by the Mission Operations Center (MOC) at the University of Colorado's Laboratory for Atmospheric and Space Physics (LASP). This function is identified as "Mission Planning" or MP.
2. Develop software, calibration data, and operations to translate, correct, calibrate, and transform raw science telemetry into science data products for use by the IXPE Science Team and by the greater scientific community. This function is identified as "Science Processing" or SP.

Hence, the two major components of the IXPE SOC software are Mission Planning (MP) software and Science Processing (SP) software. The purpose of this document is to detail the operational use of the IXPE SOC Science Processing software modules and associated tasks involved with maintaining the processing environment.

1.2 Scope

This document is intended to describe naming conventions and file formats of publicly released data from the Imaging X-ray Polarimetry Explorer (IXPE).

1.3 Audience

This document is intended for users of publicly released IXPE data.

2 References and Documents

1. "The JSON Data Interchange Syntax", ECMA-404, European Computer Manufacturers Association. https://www.ecma-international.org/publications-and-standards/standards/ecma-404/
2. "ISO 8601 Date and Time Format", International Organization for Standardization. https://www.iso.org/iso-8601-date-and-time-format.html

3. "Overview of the FITS Data Format", https://heasarc.gsfc.nasa.gov/docs/heasarc/fits_overview.html
4. "The Calibration Requirements for Spectral Analysis", https://heasarc.gsfc.nasa.gov/docs/heasarc/caldb/docs/memos/cal_gen_92_002/cal_gen_92_002.html

3 Organization and Responsibilities

The IXPE SOC is responsible for maintenance of this document and delivery of software and data products to NASA. Much of the Instrument-related software and calibration database (CALDB) were produced by the ASI Space Science Data Center (SSDC) with substantial contributions by the IXPE Instrument Team at Istituto Nazionale di Astrofisica (INAF) and at Istituto Nazionale di Fisica Nucleare (INFN).

4 Conventions and constants used in this document

4.1 Directory and file name conventions.

For all directory and file names and naming conventions, this document adheres to the following text conventions:

Regular text – static, exact-text portion of a directory or file name

Italics text – variable portion of the directory or file name

ALL CAPS ITALICS – installation-dependent root directory

For variable sections, the following naming sections are used repeatedly for files that employ date-time data in the filename:

YYYY – four-digit year (e.g., 2019)

YY – two-digit year (e.g., 19 for 2019)

MM – two-digit month (e.g., 01 = January)

DD – two-digit day of month (e.g., 15)

hh – two-digit, 24-hour hour of the day (e.g., 23 = 11 pm)

mm – two-digit minute of the hour (e.g., 05)

ss – two-digit second of the minute (e.g., 53)

vv – two-digit version number (e.g., 73)

4.2 Time Convention and Epoch

All engineering and science event timestamps, which are recorded by the IXPE spacecraft and sent to the ground along with engineering and event data, are converted to IXPE Time (IXT) and represented by the keyword "TIME" in the binary tables. IXT is measured in seconds in the Terrestrial Time (TT) system—meaning that seconds increase monotonically with no corrections for leap seconds—from the IXPE Time epoch.

The IXT epoch is recorded in each FITS data file using the FITS header keywords "MJDREFI" and "MJDREFF". MJDREFI stands for the Integer part of the Modified Julian Date representation of the reference time, and MJDREFF stands for the Fractional part. In this case, reference time is equivalent in meaning to IXT epoch.

For the IXPE mission, the IXT epoch time is defined as

UTC: January 1, 2017 at 00:00:00

TT: January 1, 2017 at 00:01:09.184

The offset between TT – UTC is (as of 2017) is therefore

TT – UTC = 69.184 seconds

Thus, the defined values for MJDREFI and MJDREFF are (in TT)

MJDREFI: 57754

MJDREFF: 0.00080074074074 = 8.0074074074E-4

The formula for converting IXT seconds into seconds since the start of the MJD epoch is

sec_M = (MJDREFI + MJDREFF) * 86400 + TIME

These apply to all descriptions in this document, of FITS data formats for engineering and science events.

4.3 TSTART and TSTOP convention

For the purposes of IXPE engineering and science data FITS files, the TSTART and TSTOP times refer to start and stop times of the observation, as determined with the best data available when the file is created. For Level-1 files, TSTART will be the earliest timestamp encountered in the file, and TSTOP will refer to the latest timestamp encountered in the data portion of the file, as the Level-1 files are created without knowledge of the contents of the engineering files that determine the start and the stop of an observation. For Level-2 files, TSTART is the start of the observation and TSTOP is the end of the observation, as determined from operational analysis of the engineering data.

4.4 Observation Segment UID convention

The Unique ID (UID) of an Observation Segment consists of a two-digit mission phase, a four-digit target ID for that mission phase, and a two-digit segment number. The SOC further adopts a convention for numbering the four-digit Target ID to indicate the kind of target or observation being made. The table below describes the numbering range conventions for Target ID.

Table 4-1: Observation Segment Target ID conventions

Target ID range	Description
0001 – 2499	Targets derived from the Long-Term Plan for the given mission phase
2500 – 4999	Targets of Opportunity for the given mission phase
5000 – 7499	Safe-mode intervals that occurred during the given mission phase (numbered sequentially)
7500 – 9999	Commissioning or diagnostic intervals (observations or operations not primarily for science)

4.5 FITS file default keywords and values

Primary headers of each FITS file produced by the IXPE SOC contain keywords that describe data in the file and other information that applies to the entire file. They contain common keywords with specific usage and, in some cases, specific defined values. Some are mandatory keywords as defined by HEASARC, while others are conventions used by IXPE to ensure that IXPE software can identify the contents of a file regardless of its name. In addition, Engineering and Science event data files contain not only an additional subset of common primary header keywords but also a Good Time Interval (GTI) secondary header, which is present in each file of these types. The following subsections describe these headers and the GTI secondary header.

4.5.1 Common Primary Header keywords

The following table lists keywords used in the primary header of each FITS file produced by the IXPE SOC. Per FITS file conventions, the Primary Header (or Header Data Unit, HDU) is an IMAGE type header, which typically does not contain image data. The common header keywords identify the spacecraft, instrument, detector, observation ID, times included in this file, and other identifying information. All keywords listed in the table are mandatory. The data type codes used in the "Type" column are defined in Appendix B.

Table 4-2: Level-1 Common Primary Header keywords

Keyword Name	Type	Description	Value, Range or Standard
TELESCOP	A	Telescope or mission, IXPE	'IXPE'
INSTRUME	A	Instrument of the telescope	'GPD', 'MMA', 'SC', 'DSU', e.g.
TIMESYS	A	Same as "TIMESYS" keyword in the header of EVENTS extension	'TT'
TIMEUNIT	A	Same as "TIMEUNIT" keyword in the header of EVENTS extension	's'
MJDREFI	J	Start mission MJD (integer part), copied by the header of the EVENTS extension	57754
MJDREFF	D	Start mission MJD (fractional part), copied by the header of the EVENTS extension	0.00080074074074
ORIGIN	A	Location where the FITS file was created ("IAPS", "INFN", "MSFC")	'MSFC', 'IAPS'
DATE	A	FITS File creation date	*'YYYY-MM-DD*T*hh:mm:ss.ss'*
FILENAME	A	Identifies the data by date, level, type, subtype, and version number by using the originally generated filename (in which this information is encoded) without the filename extension	See specific file type naming convention
FILETYPE	A	Brief description of the data type	See Table 4-4 below for values
CREATOR	A	Program that created the FITS file	
CREAT_ID	A	Unique ID of the creator (retained only for compatibility with I2T products)	
SOFTVER	A	HEASOFT & IXPE specific software version string	
CHECKSUM	A	HDU checksum	
DATASUM	A	Data unit checksum	

4.5.2 Common Engineering and Science Event file Primary Header keywords

The following table lists keywords used in the primary header of each engineering or science event FITS file produced by the IXPE SOC. These keywords are in addition to common keywords defined in Section 4.4.1. The data type codes used in the "Type" column are defined in Appendix B.

Table 4-3: Engineering data Primary Header keywords

Keyword Name	Type	Description	Value, Range or Standard
DETNAM	A	Name of detector or system	'DU1', 'DU2', 'MMA1', e.g.
RADECSYS	A	Name of coordinate system for RA and Dec.	'ICRS'
EQUINOX	E	Equinox of celestial coordinate system	2000.0
RA_OBJ	E	Right Ascension of object. (deg)	RA_OBJ
DEC_OBJ	E	Declination of object (deg)	DEC_OBJ
TSTART	D	Observation start time in IXT, relative to MJDREF	
TSTOP	D	Observation end time in IXT, relative to MJDREF	
TELAPSE	D	Elapsed time, TSTOP-TSTART	
TIMEREF	A	Time reference ("LOCAL", "SOLARSYSTEM", "HELIOCENTRIC", or "GEOCENTRIC")	'LOCAL'
DATE-OBS	A	[TT] Date of start of observation in "isot" format	*'YYYY-MM-DDThh:mm:ss.ss'*
DATE-END	A	[TT] Date of end of observation in "isot" format	*'YYYY-MM-DDThh:mm:ss.ss'*
PROCVER	A	Processing version	
CALDBVER	A	Version of the Calibration index that gives the calibration file list used during processing	

Table 4-4: Engineering and Science FILETYPE values

File description	Level-1 FILETYPE	Level-2 FILETYPE
Attitude Determination and Control System ADCS (Engineering)	ENG ADC <apid> 1	N/A
Temperature (Engineering)	ENG TEMP <apid> 1	N/A
Payload (Engineering)	ENG PAYLOAD <apid> 1	N/A
Attitude (Engineering)	ENG ATTITUDE 1	N/A
Orbital position (Engineering)	ENG ORBITAL 1	N/A
Level-2 Good Time Intervals	ENG GTI 1	N/A
Science events	SCI EVENT 1	SCI EVENT 2
Raw payload engineering	N/A	N/A
CALDB file	N/A	N/A

NB: In Table 4-4, the string value "iiii" indicates the 4-digit numerical Application ID (APID).

4.5.3 Common SCI Event Primary Header keywords

The following table lists keywords required in the Primary HDU of each science event FITS file. Note that keywords defined in Sections 4.4.1 and 4.4.2 are also required in the Primary Header of each science event FITS file. Additional keywords unique to certain sub-types of event files will be described later for each of those files. Note that for science event files, the "INSTRUME" value is always "GPD", and the "DETNAM" value is always one of either "DU1", "DU2", "DU3", or "DU4".

Table 4-5: Science Event Common Primary Header values

Keyword Name	Type	Description
CLOCKCOR	A	whether time (TSTART, TSTOP) given in the system defined by TIMESYS has been corrected for any drift in spacecraft clock relative to UT ("YES", "NO", "UNKNOWN")

DET_ID	A	Name of the physical ID of the detector which corresponds to the given DETNAM. Note: Both "DETNAM" and "DET_ID" in an input file must match the same-name values in the CALDB files in order to process the data. For flight, the default mapping is: DU1 = DU FM2, DU2 = DU FM3, DU3 = DU FM4 (DU FM1 is the flight spare)
FCW_CMD	I1	Commanded value of the encoder of the Filter and Calibration Wheel
FCW_ENC	I1	Readout value of encoder of the Filter and Calibration Wheel position
FCW_POS	B1	Position of Filter and Calibration Wheel (0 - 6)
FILE_TYP	A	File type (e.g., 'EVENT' or "HK")
FILE_LVL	A	Level of file of this type (e.g., "A", "1")
FILE_VER	A	Version of the file format for this type and level (e.g., '1.0')
LV1_VER	I	Level-1 version, which currently must be at least 5. (Retained for compatibility with existing processing software)
OBS_ID	J1	Observation ID (only in Level 1 and 2)
OBS_MODE	A1	DU Observation mode • "OBSERVATION" for Astrophysical and calibration sources in flight; for sources on ground • "STAND BY" (not expected to produce TM) • "ELECTRICAL CALIBRATION" (charge injection) • "PEDESTALS"
PADYN	E	Position angle of detector Y axis
TXDZN	E	Offset of detector x-axis origin from center of image
TYDZN	E	Offset of detector y-axis origin from center of image
SRC_CONF	A	NOT USED IN FLIGHT. GROUND USE ONLY. Source configuration: • "ASTRO" for Astrophysical sources • "CAL n" where n is the integer of the calibration source used for calibration in flight • "INFN SET-UP n" where n is the set-up progressive number • "IAPS SET-UP n" where n is the set-up progressive number • "MSFC SET-UP n" where n is the set-up progressive number • ... to be added

4.5.4 Common SCI Event Secondary Header keywords

The following table lists keywords in each Secondary HDU of a SCI event file. Note that keywords defined in Section 4.4.1 should also be present in secondary headers of each science event FITS file. Additional keywords unique to certain sub-types of event files will be described later for each of those files. Note that for science event files, the "INSTRUME" value is always "GPD", and the "DETNAM" value is always one of either "DU1", "DU2", "DU3", or "DU4". This section does not define those keywords present in the GTI header.

Table 4-6: Science Event Common Secondary Header values

Variable name	Type	Description
CALDBVER	A	Version of Calibration index that gives the calibration file list used during processing
CL_FREQ	I	Clock frequency of the serial readout in MHz
CL_SHIFT	I	Clock shift in ns
CLOCKCOR	A	whether time (TSTART, TSTOP) in the system defined by TIMESYS has been corrected for any drift in the spacecraft clock relative to UT ("YES", "NO", "UNKNOWN")
DATE-OBS	A	[TT] Date of start of observation in "isot" format
DATE-END	A	[TT] Date of end of observation in "isot" format

DETNAM	A	Name of Detector Unit of the instrument • DU1, DU2, DU3, DU4 in flight • 018, 019, 020, etc. on ground
DET_ID	A	See Section 4.5.3
FCW_POS	B	Position of Filter and Calibration Wheel (0 - 6)
FILE_TYP	A	File type (e.g., “EVENT” or “HK”)
FILE_LVL	A	Level of file of this type (e.g., “A”, “1”)
FILE_VER	A	Version of file format for this type and level (e.g., ‘1.0’)
LV1_VER	I	Level-1 version, which currently must be at least 5 (Retained for compatibility with existing processing software)
INSTRUME	A	Instrument of the telescope, GPD
MJDREFI	I	Integer part of reference time MJD (=57754)
MJDREFF	D	Floating point part of reference time MJD (=0.00080074074074)
OBS_MODE	A	DU Observation mode • “OBSERVATION” for astrophysical and calibration sources in flight; for sources on ground • “STAND BY” (not expected to produce TM) • “ELECTRICAL CALIBRATION” (charge injection) • “PEDESTALS”
PEDSADEL	I	Time delay between signal readout and each successive pedestal readout (in steps of μs)
PROCVER	A	Processing version (e.g., “1.0”)
RO_MODE	I	GPD readout mode (windowed or full frame)
ROIPADD	B	Lookup-table code for window padding mode (small or large)
SOFTVER	A	Software version (includes HEASARC version string)
TELAPSE	D	Elapsed time (TSTOP – TSTART)
TELESCOPE	A	Telescope or mission, (= ‘IXPE’)
TIMEREF	A	Time reference (= ‘LOCAL’)
TIMESYS	A	Time system (= ‘TT’)
TIMEUNIT	A	Unit of time (= ‘s’) seconds
TIMEZERO	D	Start time for event times in the given table, in IXT. If the keyword is missing, or the value is 0, this indicates that event times are full IXT time, not offsets from the start.
TLM2FITS	A	Software version number in the form AA.BB, where AA is the major version and BB is the minor version
TRGENDEL	I	Time delay between the last pedestal readout and the next trigger enable in μs
TRG_THR	D	Nominal first trigger threshold in mV with respect to reference voltage vref (rounded to 1 decimal place)
TRK_FULL	I	0 = No, 1 = Yes
TSTART	D	Observation start time in IXT, copied by the header of the EVENTS extension
TSTOP	D	Observation end time in IXT, copied by the header of the EVENTS extension
ZSUPTHR	I	Threshold in Analog-to Digital Converter (ADC) counts for the on-board zero suppression
CHECKSUM	A	HDU Checksum
DATASUM	A	Data unit checksum

4.5.5 Default CALDB Primary Header keywords

The following table lists keywords used in the primary header. This primary header is used to identify spacecraft, instrument, software that produced the file, and other identifying information. All keywords listed in the table are mandatory. Data type codes used in the “Type” column are defined in Appendix B.

Table 4-7: Default CALDB Primary Header keywords

Keyword Name	Type	Description	Value/Range
TELESCOP	A	Telescope or mission, IXPE	“IXPE”
ORIGIN	A	Location where the FITS file was created	(“IAPS”, “INFN”, ”MSFC”)
CHECKSUM	A	ASCII-encoded complement of the checksum of the FITS HDU: 16-character string starting in column 12	
DATASUM	J	Value of the checksum of the data records of the HDU	
CREATOR	A	Software that produced the file	‘ixpecalibconverter’, e.g.
CREAT_ID	A	Unique ID of the creator (retained for compatibility with I2T products)	

4.5.6 Default CALDB Secondary Header Keywords

The following table lists keywords used in CALDB secondary header. This secondary header is a binary table header. Keywords defined in this section are those that are involved with neither the definition of the binary table shape nor the names, types, and units of the table columns. All header keywords from the Primary Header are repeated in the secondary header and will not be repeated in the table below.

Table 4-8: Default CALDB Secondary Header keywords

Keyword Name	Type	Description	Value/Range/Example
EXTVER	J	Extension number of this HDU	1
VERSION	J	Extension version number	1
DATE	J	File creation date (TT) in “isot” format.	‘2020-05-03T06:21:33’, e.g.

4.5.7 GTI extension secondary HDU header keywords.

The Level-2 Science Event data file GTI extension header describes the overall time boundaries of data within the file, and the means by which time is measured. It also includes version information about file format, version of the firmware in the DU at the time, and run and station identifiers of the DU to describe fully how the data was acquired.

The following table defines keywords and data types of data in the GTI extension header. All keywords listed in the table are mandatory. Data type codes used in the “Type” column are defined in Appendix B.

Table 4-9: GTI header keyword description

Keyword Name	Type	Description
DATE-OBS	A	[TT] Date of start of observation in “isot” format
DATE-END	A	[TT] Date of end of observation in “isot” format
INSTRUME	A	Instrument of the telescope (e.g., “GPD”)
MJDREFI	J	Start mission MJD (integer part), copied by the header of the EVENTS extension
MJDREFF	D	Start mission MJD (fractional part), copied by the header of the EVENTS extension
PROCVER	A	Processing version
SOFTVER	A	Software suite version (include HEASOFT string)
TELAPSE	D	Elapsed time, TSTOP-TSTART
TELESCOP	A	Telescope or mission (= ‘IXPE’)
TIMEREF	A	Time reference (= ‘LOCAL’)
TIMESYS	A	Time System (= ‘TT’ for mission)
TIMEUNIT	A	Same as “TIMEUNIT” keyword in the header of EVENTS extension

TIMEZERO	D	Start time for event times in the given table, in IXT. If the keyword is missing, or the value is 0, this indicates that event times are full IXT time, not offsets from the start
TSTART	D	Observation start time in IXT, relative to MJDREF
TSTOP	D	Observation end time in IXT, relative to MJDREF
CHECKSUM	A	HDU Checksum
DATASUM	A	Data unit checksum

4.5.8 GTI extension binary table

The Engineering and Science Event data GTI extension binary table rows give start and stop (in IXPE Time (IXT) seconds) of a single "Good Time Interval" contained within the time bounds of the overall file. The table defines the times within the overall time bounds of the file for which continuous data are contained within the file.

For all Engineering data and all Science event data except Level-2 data, the GTI table reflects all intervals for which data have been received and processed at the SOC.

For Level-2 Science event data, the GTI table reflects all the intervals that satisfy all the following conditions:

- Data have been received and processed at the SOC
- Spacecraft was actively pointing to the given target
- Detectors were properly configured to observe the target
- Spacecraft was outside the SAA model polygon
- Object was occulted by neither the earth nor the moon

The following table defines column names and data types of data in the GTI binary table extension. All keywords listed in the table are mandatory. Data type codes used in the "Type" column are defined in Appendix B.

Table 4-10: GTI binary table description

Column Name	Type	Description
START	D	Start of time interval (IXT)
STOP	D	End of time interval (IXT)

4.5.9 RUN_ID extension secondary header HDU keywords

The Science Event data files include a RUN_ID extension header, which contains information about the RUN_ID variable used for processing by some I2T software. The extension holds a table that gives the value of RUN_ID and start and stop times of the interval for which that value is valid. The header information contains the same information as the "EVENTS" extension of a Science Event data file. See Section 4.4.3 of this document.

4.5.10 RUN_ID extension binary table

The Engineering and Science Event data GTI extension binary table rows give RUN_ID value and start and stop (in IXPE Time (IXT) seconds) of the interval over which this value is valid.

The following table defines the column names and data types of the data in the RUN_ID binary table extension. All keywords in the table are mandatory. Data type codes used in the "Type" column are defined in Appendix B.

Table 4-11: RUN_ID binary table description

Column Name	Type	Description

RUN_ID	I	Run ID valid over this interval.
START	D	Start of time interval (IXT)
STOP	D	End of time interval (IXT)

5 Level-1 Science Event Data

5.1 Description

Level-1 Science Event data contain the same information as Level-0 Science Event data but converted to FITS format. This is in keeping with the HEASARC rules for Level-1 data, which contain additional information (see below). Level-1 science event files convert raw input packets from the instrument and spacecraft, and they maintain all raw track data information from Level-0 Science Event data. Level-1 data and files are ordered by time at which the events were recorded by the detector, and these times have been converted to IXPE Time, which is offset from the raw Level-0 timestamps by a constant.

Level-1 raw event track data are expanded from the raw DU event data in Level 0. There, the pixels are run length encoded to omit all pixels below a given threshold. In the Level-1 Science Event data, these images are reconstructed as two-dimensional image data arrays, with all pixels omitted in the Level-0 encoding filled in with 0-value pixels.

Level 1 contains header keywords pertinent to ixpeevtrecon processing. The value of these keywords is derived from HK data. The ixpeevtrecon program expects values for these keywords to be constant for all data in a single file. Therefore, if configuration values change during an observation, the Level-1 files are split to ensure the configuration values are constant within each component.

Level-1 data are processed by ixpeevtrecon, from which the barycenter measurement of the position and the Pulse Height Amplitude of the event are calculated.

Level-1 data are also processed by ixpedet2j2000, which adds columns X, Y. The columns represent the J2000 tangent-plane coordinates centered on the tracking target, in which X is parallel to the celestial equator and Y is perpendicular (oriented to the NCP) to the celestial equator.

5.2 File naming convention

Level-1 Science Event data file names are of the form

ixpe*PPnnnnpp*_det*D*_evt1_v*xx*[_c*ii*].fits

Variable parts of the name are indicated by *italics*. Optional parts of the name are included in square brackets [] and only appear in the filename when necessary. Description, references, and range or list of valid values are given in the table below.

Table 5-1: Level-1 Science Event data naming variable description

Variable	Description	Range or Values
PPnnnnpp	IXPE observation Sequence Number	
D	Project designated identification number of DU	1, 2, or 3 (in flight)
xx	Two-digit file version number	01 – 99

ii	Two-digit optional component file index for observation segment datasets that are so large they must be divided into smaller pieces	01 – 99 (if present)

5.3 Format

The format for Science Event data at Levels 1 Science Event data is FITS file with four HDU's. All the extensions are FITS binary table extensions. The structure of the file consists of the following FITS sections.

Table 5-2: FITS structure of Level-1 Science Data file

Section/Header	Name	Description
Primary	-	FITS-required primary header
Extension 2	RUN_ID	A table of RUN_IDs with start and stop times that indicate the valid interval for each RUN_ID
Extension 3	EVENTS	Photoelectron track image data, flags, and DU information
Extension 4	GTI	Binary table of start and stop times for each interval of continuous (no missing event data packets) data

The structure and keywords of the header and binary table extensions are detailed in the subsections below.

5.3.1 Primary Header

The following table lists keywords used in the primary header. This header includes all header data from Sections 4.5.1, 4.5.2, and 4.5.3, as well as the keywords in the table below. The data type codes used in the "Type" column are defined in Appendix B.

Table 5-3: Level-1 Science Event data Primary Header keywords

Keyword Name	Type	Description
ENERGY	D	Energy of x-ray source (keV). (Optional, used on in ground tests)
RUN_DESC	A	Type of test (Optional, used on ground tests only)
SOURCE	A	X-ray source (Optional, used in ground tests only)

5.3.2 EVENTS extension header

Level-1 Science Event data EVENTS extension header describes the parameters of the recorded observation itself, including time data that are largely repeated from the primary header. It also includes operational parameters of the DU in use during the observation.

The following table defines keywords and data types of data in the EVENTS header extension. All keywords listed in Sections 4.5.1, 4.5.2, and 4.5.4 are included, as well as keywords defined in the following table. Data type codes used in the "Type" column are defined in Appendix B.

Table 5-4: Level-1 Science Events data EVENTS header description

Variable name	Type	Description
ACOLCORR	D	Coherent noise offset
ATRGCORR	D	Trigger mini-cluster offset
D_MAX	D	External radius of the horseshoe search region
D_MIN	D	Internal radius of the horseshoe search region
DEADAPP	B	"T" or True if the dead time correction has been applied

ENERGY	D	X-ray source energy (keV) (for ground test only)
FLTNAM	A	Flight detector name
RA_OBJ	E	Right Ascension of object. (deg)
DEC_OBJ	E	Declination of object (deg)
EQUINOX	D	Equinox of celestial coordinate system (= 2000.0)
RADECSYS	A	Celestial coordinate system (= “ICRS”)
MAXROISI	I	The maximum ROI size in pixels
MINDNSPT	I	Minimum density points for the DBSCAN clustering
MINROISI	I	The minimum ROI size in pixels
MINTKHIT	I	Minimum number of hits in a track
NUM_PED	I	Number of events acquired for pedestal subtraction
OBSID	A	Observation ID
ONTIME	E	Engineering-defined exposure time (sec) minus any gaps in event data
ORBIT	J	Orbit during which data were downloaded
ORIGIN	A	Location where the FITS file was created (“IAPS”, “INFN”, “MSFC”)
PKTTYPE	I	Packet Type
PKTSTYPE	I	Packet Sub-Type
ROIPADD	I	The lookup-table code for the window padding
RUN_DESC	A	Type of test (for ground test only)
SOURCE	A	X-Ray source description (For ground test only)
SRC_CONF	A	Source configuration
TCTYPE38	A	“RA---TAN” indicates that the X column is in tangent plane coordinates and the axis is parallel to Right Ascension
TCRPX38	J	Array location of the horizontal reference point in pixels (= 299)
TCRVL38	E	Array value at horizontal reference point (= target center RA)
TCDLT38	E	Coordinate increment on horizontal axis (image scale in deg/pixel) (= -0.00072222)
TCROT38	E	Rotation of horizontal axis at reference point (= 0.)
TCUNIT38	A	Units of CDELT1 and CRVAL1. (= ‘deg’)
TCTYPE39	A	“DEC—TAN” indicates that the Y column is in tangent plane coordinates and the axis is parallel to Declination
TCRPX39	J	Array location of the horizontal reference point in pixels. (= 299)
TCRVL39	E	Array value at horizontal reference point (=target center RA)
TCDLT39	E	Coordinate increment on horizontal axis (image scale in deg/pixel) (= 0.00072222)
TCROT39	E	Rotation of horizontal axis at reference point (=0.)
TCUNIT39	A	Units of CDELT1 and CRVAL1. (= ‘deg’)
XPNOIMAP	B	“T” or True to indicate that the noise map CALDB was applied to the events in this file.
XPPEDMAP	B	“T” or True to indicate that the pedestal map CALDB was applied to the events in this file.
XPPEQMAP	B	“T” or True to indicate that pixel equalization CALDB was applied to events in this file
W_SCALE	D	Scale factor for the exponential weights used during analysis

5.3.3 EVENTS extension binary table

Each raw DU event in the Level-0 Science Event data is used to create a row in the EVENTS extension binary table of the Level- 1 Science Event data. Thus, the rows of the EVENTS extension binary table contain the same information as the original Level-0 raw DU event. The exception to this is the absorption event image data. In Level-0, the data are compressed by run-length encoding only the pixels above a certain threshold. In Level-1 events, these data are used to populate the pixels of a two-dimensional sub-image from the DU, with all pixels not described explicitly by the Level-0 data set to a value of zero.

It is important to note that the variable-length portion of this binary table, the zero-filled, two-dimensional image data of the x-ray absorption event called PIX_PHAS in the binary table, is stored, according to FITS file rules, at the end of the fixed-length table in a data heap. The fixed-length table actually contains a pointer and a length to the position of the actual array data in the heap. This has implications for adding events to an existing EVENTS binary table, because doing so forces not only new data to be written into the fixed-length portion, but movement of the entire variable-length heap and writing of the variable length data into the newly relocated heap. That makes this an inefficient operation that should be mitigated by pre-figuring the total size of the fixed-length binary table before writing any events to the EVENTS binary table.

In addition, there are columns for the rough PHA energy of the pixels in the event image, and for the position on the J2000 tangent plan, which are the result of a preliminary aspect correction of rough positions calculated from the event.

Table 5-5 defines the column names and data types of the data in the EVENTS binary table extension. All the keywords listed in the table are mandatory. The data type codes used in the “Type” column are defined in Appendix B.

Table 5-5: Level-1 Science Events data EVENTS binary table description

Column Name	Type	Description
PAKTNUMB	J	Packet number
TRG_ID	J	The trigger identifier. The use of trigger ID, instead of event ID, is to emphasize that the DAQ can discard triggers based on the ROI size
SEC	J	Integer part of event time in seconds (IXPE time)
MICROSEC	J	Fractional part of event time in microseconds (IXPE time)
TIME	D	Seconds since time reference
LIVETIME	J	Detector live time in microseconds since the previous event
MIN_CHIPX	I	The minimum column number in the ROI
MAX_CHIPX	I	The maximum column number in the ROI
MIN_CHIPY	I	The minimum row number in the ROI
HDUCLASS	A	HDU class. Must be set to “OGIP”
HDUCLAS1	A	Secondary HDU Class. Must be set to “EVENTS”
MAX_CHIPY	I	The maximum row number in the ROI
ROI_SIZE	J	The size of the ROI
ERR_SUM	J	The error summary for the event
DU_STATUS	I	DU-supplied status bytes
DSU_STATUS	I	DSU-supplied status bytes
PIX_PHAS	QI	Amplitude (in ADC channels) of all pixels in the ROI
PIX_PHAS_EQ	QI	Amplitude (in scaled corrected ADC channels) of all pixels in the ROI, corrected for pixel equalization
STATUS	16X	16-bits of processing status/error flags
STATUS2	16X	16-bits of processing status/error flags
NUM_CLU	I	Number of clusters in event
NUM_PIX	I	Number of pixels in event
EVT_FRA	E	Event frame
SN	E	Signal-to-noise ratio

TRK_SIZE	I	Track size
TRK_BORD	I	Track border
PHA	J	Total event PHA signal
TLMINn	I	Start channel for PHA (1). Note: n must be column number of PHA
TLMAXn	I	Start channel for PHA (60000). Note: n must be column number of PHA
PHA_EQ	E	Pixel-equalization and gain-corrected event signal
PHI1	E	Initial electron ejection angle, from stage-1 computation
PHI2	E	Initial electron ejection angle, from stage-2 computation
DETPHI	E	Best estimate of initial electron ejection angle for detector
ABSX	E	Calculated detector position in detector x-coordinate (mm)
ABSY	E	Calculated detector position in detector y-coordinate (mm)
BARX	E	Barycenter-computed detector position of x-coordinate (mm)
BARY	E	Barycenter-computed detector position of y-coordinate (mm)
TRK_M2T	E	Second moment of track T
TRK_M2L	E	Second moment of track L
TRK_M3L	E	Third moment of track L
TRK_SKEW	E	Skewness of track
X	E	Calculated position, projected onto the J2000 tangent plane axis parallel to celestial equator using the preliminary aspect correction
Y	E	Calculated position, projected onto the J2000 tangent plane axis perpendicular to celestial equator using the preliminary aspect correction

The STATUS2 value is a 16-bit field of logical flags that can be used to mask out certain events. The definition of the STATUS2 flags is given in the table below.

Note that the order of the flags maps to the 16 bits of an integer by starting at the left-most (i.e., flag 0 maps to the most significant bit of the integer value.) Also note that in Level 2 data, only flags 1, 12, and 15 should appear, as the rest of the flags are filtered out.

Table 5-6: STATUS2 bit description

Flag	Description
0	Set when no attitude data exists for this event
1	Set when the GPS position is not valid
2	Set when the DSU mode is not OBSERVATION
3	Set when the S/C ADCS mode is not “pointing”
4	Set when FCW is set to CAL_POL
5	Set when FCW is set to CAL_SPOT
6	Set when FCW is set to CAL_HI
7	Set when FCW is set to CAL_LO
8	Set when FCW is set to CLOSED
9	Set when the S/C is slewing
10	Set when target is occulted by the upper occultation radius
11	Set when target is occulted by the lower occultation radius
12	Set when the position of the satellite indicates it is within the boundaries of the SAA
13	Set when an event lies within one of the designated edge-exclusion regions of the bad pixel map
14	Set when an event lies within a designated anomaly-exclusion region of the bad pixel map
15	Set when an event lies within a designated “GRAY” exclusion region (edge or anomaly) of the bad pixel map

5.3.4 GTI extension header

The Level-1 Science Event data file GTI extension header describes the overall time boundaries of the data within the file, as well as the means by which time is measured. Header keywords are defined in Section 4.5.7, and additional keywords are defined in the following table.

Table 5-7: GTI header keyword description

Keyword Name	Type	Description
CL_FREQ	I	The clock frequency of the serial readout in MHz
CL_SHIFT	I	The clock shift in ns
DEADAPP	Logical	Flag indicating if dead time correction has been applied (‘T’ if True, ‘F’ if False)
DEADC	D	The ratio of LIVETIME/ONTIME values
HDUCLASS	A	HDU class. Must be set to “OGIP” (Level 1)
HDUCLAS1	A	Secondary HDU Class. Must be set to “GTI” (Level 1)
LIVETIME	D	Sum of LIVETIME column for all unfiltered events within the valid GTI of the file, converted to seconds (Seconds)
ONTIME	D	Engineering-defined exposure time, minus any intervals of science data not received on the ground (seconds)
OBS_MODE	A	DSU Observation mode (usually = ‘OBSERVATION’)

5.3.5 GTI extension binary table

Level-1 Science Event data GTI extension binary table rows give the start and stop (in IXPE time seconds) of a single “Good Time Interval” contained within the time bounds of the overall file. The table defines times within the observation or segment bounds for which continuous event data was received by the SOC. It does not account for pointing, position, or spacecraft state.

6 Level-2 Science Event Data

6.1 Description

Level-2 Science Event data files are FITS format files that contain highly processed event data produced by the Instrument Pipeline. The Instrument Pipeline produces a refined detector position; a Pulse Invariant energy that has been corrected for pixel-to-pixel, temporal, thermal, charging, and large-scale spatial gain; and an initial electron ejection direction resolved into Stokes parameters and corrected for spurious modulation.

Level-2 data are further processed by ixpedet2j2000 and ixpeaspcorr to convert the detector coordinate positions and electron directions to the J2000 tangent plane centered on the target. Not only are detector coordinates transformed by the measured system rotations and the measured Star Tracker rotations, but the resultant image is analyzed and corrected on smaller timescales to add correction for potential thermal effects.

Level-2 files will only contain events that are from times during which the instrument was on, correctly configured for observing, pointed at the target, and not occulted by the earth or its atmosphere. In addition, certain flagged data values may be removed to clean the data set.

6.2 File naming convention

The Level-2 Science Event data file names are of the form

ixpe*PPnnnnpp*_det*D*_evt1_v*xx*[_c*ii*].fits

The variable parts of the name are indicated by *italics*. The optional parts of the name are included in square brackets [], and only appear in the filename when necessary. The description, references, and range or list of valid values are given in the table below.

Table 6-1: Level-2 Science Event data naming variable description

Variable	Description	Range or Values
PPnnnnpp	The IXPE observation Sequence Number	
D	Project designated identification number of DU	1, 2, or 3 (in flight)
Vv	Two-digit version number	01 – 99
Ii	Optional component file index for observation segment datasets that are so large they must be divided into smaller pieces	01 – 99 (if present)

6.3 Format

The Level-2 Science Event data format consists of a FITS file with three HDU's. All the extensions are FITS binary table extensions. The structure of the file consists of the following FITS sections:

Table 6-2: FITS structure of Level-2 Science Data file

Section/Header	Name	Description
Primary	-	FITS-required primary header
Extension 2	EVENTS	Photoelectron track image data, flags, and DU information
Extension 3	GTI	Contains the Good Time Intervals.

6.3.1 Primary Header

The following table lists keywords used in the primary header. All the keywords listed in Sections 4.5.1, 4.5.2, and 4.5.3 are included, as well as the keywords defined in the following table. The data type codes used in the "Type" column are defined in Appendix B.

Table 6-3: Levels-2 Science Event data Primary Header keywords

Keyword Name	Type	Description	
CONTNUMB	J	Contact Number (progressive within a contact)	
ORIGIN	A	Location where the FITS file was created ("IAPS", "INFN", "MSFC")	
RA_OBJ	E	Right Ascension of object (deg)	
DEC_OBJ	E	Declination of object. (deg)	
EQUINOX	D	Equinox of celestial coordinate system	2000.0
RADECSYS	A	Celestial coordinate system	'ICRS'
POLCCONV	A	Polarization coordinate convention	'IAU'
XPCHRG	Bool	"T" if charging correction applied; "F" otherwise	
XPNOIMAP	Bool	"T" if appropriate CALDB noise map was applied; "F" otherwise	
XPADJMOD	Bool	"T" if appropriate CALDB spurious modulation map was applied by ixpeadjmod; "F" otherwise	

XPPEDMAP	Bool	"T" if appropriate CALDB pedestal map was applied; "F" otherwise
XPPEQMAP	Bool	"T" if appropriate CALDB pixel equalization map was applied; "F" otherwise
XPPKGAIN	Bool	"T" if appropriate CALDB peak gain map was applied; "F" otherwise
XPSTOKES	Bool	"T" if optimum Stokes parameters were calculated; "F" otherwise
XPTGAIN	Bool	"T" if temperature gain correction applied; "F" otherwise
XPWEIGHT	Bool	"T" if event-by-event weights were calculated; "F" otherwise
XPASPCOR	Bool	"T" if x-ray aspect correction as applied; "F" otherwise

6.3.2 EVENTS extension header

The Level-2 Science Event data EVENTS extension header describes parameters of the recorded observation itself, including time data that are largely repeated from the primary header. It also includes the operational parameters of the DU in use during the observation.

The following table defines the keywords and data types of the data in the EVENTS header extension. All the keywords listed in Sections 4.5.1, 4.5.2, and 4.5.4 are included, as well as the keywords defined in the following table. The data type codes used in the "Type" column are defined in Appendix B.

Table 6-4: Level-2 Science Events data EVENTS header description

Variable name	Type	Description	
ACOLCORR	D	Coherent noise offset	
ATRGCORR	D	Trigger mini-cluster offset	
D_MAX	D	External radius of the horseshoe search region	
D_MIN	D	Internal radius of the horseshoe search region	
HDUCLASS	A	HDU class. Must be set to "OGIP" (Level 2)	
HDUCLAS1	A	Secondary HDU Class. Must be set to "EVENTS" (Level 2)	
RA_OBJ	E	Right Ascension of object. (deg)	
DEC_OBJ	E	Declination of object. (deg)	
EQUINOX	D	Equinox of celestial coordinate system	2000.0
RADECSYS	A	Celestial coordinate system	'ICRS'
MAXROISI	I	The maximum ROI size in pixels (smaller windows will be discarded)	
MINDNSPT	I	Minimum density points for the DBSCAN clustering	
MINROISI	I	The minimum ROI size in pixels (smaller windows will be discarded)	
MINDNSPT	I	Minimum density points for the DBSCAN clustering	
MOM1_THR	D	Threshold for initial moment analysis	
MOM2_THR	D	Threshold for secondary moment analysis	
NUM_PED	I	Number of events acquired for pedestal subtraction	
OBSID	A	Observation ID (Level 1 only)	
ONTIME	E	Engineering-defined exposure time (sec) minus any gaps in event data.	
POLCCONV	A	Polarization coordinate convention. Must be set to "IAU" (Level 2)	
REC_THR	I	Zero-suppression threshold for the track reconstruction	
REC_VER	I	Version of the GPD software used to generate the file.	
S_VBOT	E	GEM bottom HV setting for this DU (volts)	
S_VTOP	E	GEM top HV setting for this DU (volts)	
S_DRIFT	E	Drift HV setting for this DU (volts)	

W_SCALE	D	Scale factor for the exponential weights used during analysis.
XPNOIMAP	B	"T" or True to indicate that noise map CALDB was applied to the events in this file
XPPEDMAP	B	"T" or True to indicate that pedestal map CALDB was applied to the events in this file
XPPEQMAP	B	"T" or True to indicate that pixel equalization CALDB was applied to events in this file
XPPKGAIN	B	"T" or True to indicate that peak gain correction CALDB was applied to events in this file
XPADJMOD	B	"T" or True indicate that ixpeadjmod has already subtracted the spurious modulation, and is a flag to ixpeadjmod not to process this file
XPWEIGHT	B	"T" or True to indicate that event-by-event weights were calculated.
XPASPCOR	B	"T" or True to indicate that ixpedet2j2000 corrected the events for sky projection and spacecraft attitude
XPTGAIN	B	"T" or True to indicate that ixpegaincorrtemp corrected the gain for temperature effects
XPSTOKES	B	"T" or True to indicate that ixpecalcstokes was run to pick the weighted optimum set of Stokes parameters
TCTYPE8	A	"RA---TAN" indicates that the X column is in tangent plane coordinates and the axis is parallel to Right Ascension.
TCRPX8	J	299
TCRVL8	D	9.778451208224594
TCDLT8	E	-0.00072222
TCTYPE9	A	"DEC—TAN" indicates that the Y column is in tangent plane coordinates and the axis is parallel to Declination
TCRPX9	J	299
TCRVL9	D	9.778451208224594
TCDLT9	E	-0.00072222

6.3.3 EVENTS extension binary table

Table 6-5 defines the column names and data types of the data in the EVENTS binary table extension. All keywords listed in the table are mandatory. The data type codes used in the "Type" column are defined in Appendix B.

Table 6-5: Level-2 Event data EVENTS binary table description

Column Name	Type	Description
TRG_ID	J	Trigger identifier. The use of trigger ID, instead of event ID, is to emphasize that the DAQ can discard triggers based on ROI size
TIME	D	Sum of SEC and MICROSEC
STATUS	16X	16-bits of processing status/error flags
PI	1J	Pixel-equalization and gain-corrected event signal
W_MOM	E	Statistical weight of this event (from Moments Analysis)
Q	D	Value of Stokes parameter q in J2000 tangent plane axis
U	D	Value of Stokes parameter u in J2000 tangent plane axis
X	E	Calculated position, projected onto the J2000 tangent plane axis parallel to celestial equator using the preliminary aspect correction
Y	E	Calculated position, projected onto the J2000 tangent plane axis perpendicular to celestial equator using the preliminary aspect correction
STATUS2	16X	16-bits of processing status/error flags (see Table 5-6)

6.3.4 GTI extension header

The Level-2 Science Event data file GTI extension header describes the overall time boundaries of the data within the file, and the means by which time is measured. The header keywords are defined in Section 4.5.7, and additional keywords are defined in the following table.

For Level-2 data, DEADC and LIVETIME cannot reliably be calculated directly from the Level 2 events. This is because some Level-2 events are removed from the event list based on criteria other than when the events occurred. That means that between any two consecutive Level-2 events some detector-recorded events may be missing and LIVETIME information may have been lost. Therefore, the DEADC and LIVETIME for the Level-2 data are calculated by applying the Level-2 GTI to the Level-1 event lists, and then calculating the LIVETIME by summing all the events within the GTI.

Table 6-6: GTI header keyword description

Keyword Name	Type	Description
DEADC	D	Ratio of LIVETIME/ONTIME values
HDUCLASS	A	HDU class. Must be set to “OGIP” (Level 2)
HDUCLAS1	A	Secondary HDU Class. Must be set to “GIT” (Level 2)
LIVETIME	D	Sum of LIVETIME column for all unfiltered events (i.e., Level 1) within the valid GTI (i.e., Level 2) of the file, converted to seconds (Seconds)
ONTIME	D	Engineering-defined exposure time, minus any intervals of science data not received on the ground (seconds)
OBS_MODE	A	DSU Observation mode (usually = ‘OBSERVATION’)

6.3.5 GTI extension binary table

The Level-2 Science Event data GTI extension binary table rows give the start and stop (in IXPE time seconds) of a single “Good Time Interval” contained within the time bounds of the overall file. The entire table defines all the time intervals in the file in which the IXPE mirror/detector field of view contained the target, the Filter Wheel Assembly was in the nominal observing position, and the DU detector in question was operating in the nominal observing mode.

7 Level-1 Engineering data format

7.1 Description

The Level-1 engineering data files are created by the SOC from the Level-0 Engineering data files. Most Level-1 engineering files (denoted as “type A”) are derived from files which contain information from several subsystems and a single packet ID, are combined into FITS format files also separated and named by the subsystem and the packet ID.

However, two types of Level-1 engineering files (denoted as “type B”) are further processed to gather selections of engineering data of specific area of scientific interest and secondary calculations based on that data. These are the Attitude files and the Orbital files.

The most important change to the overall structure of the Level-1 engineering data and files from Level 0 is that data gaps and data overlaps due to missed data and retransmitted data have been removed, such that all overlaps are resolved in favor of the latest data received. In addition, the Level-1 data and files are ordered by the time in which the data were recorded by the spacecraft or detector, and this time has been converted to Terrestrial Time, which is offset from the raw Level-0 timestamps by a constant.

7.2 File naming convention

The Level-1 engineering data filenames of type A are of the form

ixpe*PPnnnnpp*_*inst*_*engtypeA*_*aaaa*_v*xx*.fits

for files of type B, the filename convention is

ixpe*PPnnnnpp*_*inst*_*engtypeB*_v*xx*.fits

The variable parts of the name are indicated by *italics*. The description, references, and range or list of valid values are given in the table below.

Table 7-1: Level-1 Engineering data naming variable description

Variable	Description	Range or Values
PPnnnnpp	The IXPE observation Sequence Number	
inst	ID of the instrument which produced the data	= det1-3 for data specific to a single DU = all for all other data
engtypeA	Type A engineering data	adc – ADCS data
		tmp – Thermal data
		pay – Payload data
engtypeB	Type B engineering data	att – Attitude solution data (uses det1, 2, etc.)
		orb – GPS orbital position data
		gti – Level-2 Good Time Intervals
aaaa	Packet ID of packet from which type A data were derived	4 Digit ID of packet (see Table 7-12). Data derived from multiple APIDs are given an APID value of "9999"
xx	Two-digit version number	01 - 99

7.3 Header Data Unit structure

7.3.1 Header Data Unit structure of General Engineering Data Files

Level-1 Engineering General Engineering Data FITS files contain a primary HDU, one binary table HDU with the name "HK" to hold the HK data for the given sub-type and APID in that file, and one binary table HDU to hold the GTI data. The seven sub-types are based on the seven Ball-defined subsystems, consisting of the Attitude Determination and Control Subsystem (ADCS), Power, Command and Data Handling (CDH), Thermal, Payload, Communications, and FSW files.

The following table gives the types of payload data to be found in each packet APID. The first column lists the APID, and the next seven ??? columns indicate which subystems contribute data to that APID. An 'X' in a given APID row indicates that the subystem indicated in the given column contributes data to that APID. A '-' indicates in a given APID row indicates that the subsystem for that column does not contribute data to the APID. Note that all APID's above 1000 are for the Payload only, and for the DSU and DU's specifically.

Table 7-2: Packet APID's and the subsystem data contained in them

APID	Subsystems with data in given APID						
	Adc	Pwr	Cdh	Tmp	Pay	Com	Fsw
0031	-	-	X	-	-	-	-
0100	X	X	X	-	-	X	X
0110	X	-	-	-	-	-	X
0120	X	X	-	X	X	-	X
0130	X	X	X	X	X	X	X
0140	-	-	-	-	-	X	X
0150	-	-	X	-	-	X	X
0160	-	-	-	-	-	-	X
0170	-	-	-	-	X	-	X
0200	-	-	-	-	-	-	X
0201	-	-	-	-	-	-	X
1118-1120	-	-	-	-	X	-	-
1200-1203	-	-	-	-	X	-	-
1210-1215	-	-	-	-	X	-	-
1220-1221	-	-	-	-	X	-	-
1230-1236	-	-	-	-	X	-	-
1260-1263	-	-	-	-	X	-	-
1270	-	-	-	-	X	-	-
1280	-	-	-	-	X	-	-
1300	-	-	-	-	X	-	-
1321-1326	-	-	-	-	X	-	-
1400-1406	-	-	-	-	X	-	-
1450-1451	-	-	-	-	X	-	-
GTI	X	X	X	X	X	X	X

7.3.2 Header Data Unit structure of Special Interest Engineering Data Files

The Level-1 Special Interest Engineering Data files are FITS files containing a primary header and two binary table extensions of data culled from the General Engineering data file and extended with additional data calculated for scientific use. The second extension is a FITS binary table extension containing the time-ordered data for the entire Observation Segment. The third extension is a FITS binary table extension containing the start and stop times of all intervals of continuous engineering data (i.e., with no missing packets or duplications that indicate missed data). The structure of these file consists of the following FITS sections:

Table 7-3: Level-1 Special Interest Engineering Data Format

Section/Header	Name	Description
Primary	-	FITS-required primary header
Extension 1	HK	HK data for the given type.
	GPS_TPV	GPS-derived orbital position data (for “orb” files).
Extension 2	GTI	Binary table of start and stop times for each interval of continuous (no time gaps in engineering) data.

7.3.3 Primary Header format

The following table lists keywords used in the primary header of the General Engineering Data file. Note, this header contains all the standard keywords defined in Sections 4.5.1 and 4.5.2. All the keywords listed in this table and reference tables are mandatory. The data type codes used in the “Type” column are defined in Appendix B.

Table 7-4: Level-1 General Engineering data Primary Header keywords

Keyword Name	Type	Description	Value, Range or Standard
OBS_ID	J	Observation ID (Only in Level 1 and 2)	*PPnnnnpp*
TLM2FITS	A	Software version number in the form AA.BB, where AA is the major version and BB is the minor version.	
TXYDZN	E	Nominal offset of target from center of detector (pixels)	Derived from ADPOINTFF quaternion
PADYN	E	Position angle of the y-axis (radians)	Derived from ADPOINTFF quaternion

7.3.4 Secondary header (non GTI) format

All Level-1 Engineering non-GTI secondary headers are binary table extensions. The first column of the extension is always “TIME”, which is seconds since the IXPE epoch time of the (Consultative Committee for Space Data Systems) CCSDS Space Packet timestamp of the packet in which the data arrived, except for the Attitude files, in which “TIME” is seconds since the IXPE epoch time of the specific time stamp of the Star Tracker fix. For the General Engineering files, the rest of the column names and descriptions are found in the Command and Telemetry Database (CTDB) produced by Ball Aerospace. Special-interest engineering data formats are described in the following subsections. Keywords of the secondary headers are defined in Sections 4.5.1, and 4.5.2.

7.3.4.1 Attitude data format

The first FITS extension of a spacecraft attitude file consists of a binary table HDU with selected Star Tracker telemetry values and additional columns for quaternions that transform spacecraft coordinates to Earth-Centered Inertial (ECI) or J2000 coordinates. The columns are described below. All quaternions are in scalar-last format.

Table 7-5: Attitude data column names and formats

Column Name	Type	Description
TIME	D	Seconds since IXPE epoch time for this specific Star Tracker fix (from Level-A data)
QSJ_ST1	4E	Quaternion to transform from spacecraft coordinates to J2000 coordinates (or ECI) based on the Star Tracker Optical Head 1 quaternion (Quaternion format is scalar-last)
QSJ_ST2	4E	Quaternion to transform from spacecraft coordinates to J2000 coordinates (or ECI) based on the Star Tracker Optical Head 2 quaternion (Quaternion format is scalar-last)
ST1RAWQ	4E	Raw quaternion to transform Star Tracker Optical Head 1 coordinates to J2000 (or ECI) (Copied from Level-A file)
ST2RAWQ	4E	Raw quaternion to transform Star Tracker Optical Head 2 coordinates to J2000 (or ECI) (Copied from Level-A file)
OBS_SEG_Q	4E	Desired quaternion for the give observation segments
STANGVELX	E	Angular velocity about the ECEF X axis
STANGVELY	E	Angular velocity about the ECEF Y axis
STANGVELZ	E	Angular velocity about the ECEF Z axis
QDJ	4E	Calculated rotation quaternion from DU to J2000 frame
PADY	E	Calculated J2000 position angle of transformed DU Y-axis
TXYDZ	2E	Calculated J2000 tangent plan X, Y coordinates of DU Z-axis (i.e., DU center)

7.3.4.2 Orbital position data format

The first FITS extension of an orbital position file contains a binary table HDU with selected GPS telemetry values, and additional columns of calculated values. These calculated values have transformed the default GPS positions—Earth-Centered, Earth-Fixed (ECEF) coordinates—into Latitude, Longitude and Altitude (LLA), and the positions and velocities into Earth-Centered Inertial (ECI) coordinates.

Table 7-6: Level-1 Orbital position columns

Column Name	Type	Description
TIME	D	Seconds since IXPE epoch time (from CCSDS Space Packet timestamp)
ADGPSDST	I	GPS status copied from Level-A file
ADGPSGDOP	I	GPS degree of precision (data quality index)
ADGPSWEEK	J	GPS week number (weeks since 6/1/1980) extended beyond 16 bits to allow for rollovers since epoch
ADGPSECONDS	D	GPS seconds since the last GPS week.
ADGPSECEFX	D	X-coordinate of GPS position in ECEF meters (copied from Level-A file)
ADGPSECEFY	D	Y-coordinate of GPS position in ECEF meters (copied from Level-A file)
ADGPSECEFZ	D	Z-coordinate of GPS position in ECEF meters (copied from Level-A file)
ADGPSECIX	D	X-coordinate of GPS position in ECI meters (calculated)
ADGPSECIY	D	Y-coordinate of GPS position in ECI meters (calculated)
ADGPSECIZ	D	Z-coordinate of GPS position in ECI meters (calculated)
ADGPSLON	D	Longitude of GPS position in LLA degrees (calculated)
ADGPSLON	D	Latitude of GPS position in LLA degrees (calculated)
ADGPSLON	D	Altitude of GPS position in LLA meters (calculated)
ADGPSECEFVELX	D	X-coordinate of GPS velocity in ECEF meters/sec (copied from Level-A file)
ADGPSECEFVELY	D	Y-coordinate of GPS velocity in ECEF meters/sec (copied from Level-A file)
ADGPSECEFVELZ	D	Z-coordinate of GPS velocity in ECEF meters/sec (copied from Level-A file)
ADGPSECIVELX	D	X-coordinate of GPS velocity in ECI meters/sec (calculated)
ADGPSECIVELY	D	Y-coordinate of GPS velocity in ECI meters/sec (calculated)

ADGPSECIVELZ	D	Z-coordinate of GPS velocity in ECI meters/sec (calculated)

7.4 Level-2 GTI data format

7.4.1 Description

All science event data files except Level-2 science event data files contain event data from any time during which the given detector was producing data. This includes during calibrations, occultations, slews, and any other occasions during which the spacecraft may have not been viewing the target designated in the Observation Segment parameters. The GTI for these event files covers all portions of these intervals during which event data was received at the SOC.

Level-2 science event files, however, only contain data from the intervals during which we expect data from the target source to be dominant. Thus, the Level-2 science event GTI includes intervals in which the detectors and the DSU were properly configured and the star tracker was actively tracking the source in the instrument field of view, but does not include intervals of calibration, occultation, or slew. The Level-2 GTI for each detector covers all portions of these intervals during which event data for that detector was received at the SOC. Level-2 GTI data for each detector are provided as a Level-1 Engineering file, so that users may apply these intervals to the Level-1 science event files.

7.4.2 File naming convention.

Level-2 GTI data file names are of the form

ixpe*PPnnnnpp*_det*D*_gti_v*xx*[_c*ii*].fits

Variable parts of the name are indicated by *italics*. Optional parts of the name are included in square brackets [], and only appear in the filename when necessary. The description, references, and range or list of valid values are given in the table below.

Table 7-7: Level-2 GTI data file naming variable description

Variable	Description	Range or Values
PPnnnnpp	The IXPE observation Sequence Number	
D	Project designated identification number of DU	1, 2, or 3 (in flight)
xx	Two-digit file version number	01 – 99
ii	Two-digit optional component file index for observation segment datasets that are so large they must be divided into smaller pieces	01 – 99 (if present)

7.4.3 Format

The Level-2 GTI data file format is a FITS file with the following FITS sections.

Table 7-8: Level-2 GTI Data file format

Section/Header	Name	Description
Primary	-	FITS-required primary header
Extension 2	GTI	Binary table of start and stop times for each interval of Level-2 time, as described above

The format of the primary header is described in Sections 4.4.1 and 4.4.2. The format of the GTI extension is described in Sections 4.4.7 and 4.4.8.

7.5 Level-1 Exposure Map

7.5.1 Description

The Level-1 Exposure Map is a FITS file that maps onto the sky the effective exposure time for each pixel in the tangent-plane projection of the field of view of the target object. It is also possible to generate an Exposure Map from a Level-1 Attitude Solution file.

7.5.2 File naming convention

The Level-1 Exposure Map data file names are of the form

ixpe*PPnnnnpp*_det*D*_expmap_*vv*.fits

The variable parts of the name are indicated by *italics*. The description, references, and range or list of valid values are given in the table below.

Table 7-9: Level-1 Exposure Map data naming variable description

Variable	Description	Range or Values
PPnnnnpp	The IXPE observation Sequence Number	
D	Project designated identification number of DU	1, 2, or 3 (in flight)
vv	Two-digit version number	01 - 99

7.5.3 Format

The Level-1 Exposure Map data format includes the Primary section/header which contains an image—namely a 1024x1024 image with 32 bits per pixel. The structure of the file consists of the following FITS sections.

Table 7-10: FITS structure of Level-1 Exposure Map data

Section/Header	Name	Description
Primary	EXPMAP	FITS-required primary header

7.5.3.1 Primary Header

The following table lists keywords used in the primary header. Keywords for this primary header include those defined in Sections 4.5.1 and 4.5.5, in addition to those defined in the following table. The data type codes used in the “Type” column are defined in Appendix B.

Table 7-11: Level-1 Exposure Map data Primary Header keywords

Keyword Name	Type	Description	Value/Range/Example
DET_ID	A	Name of physical ID of the detector which corresponds to given DETNAM. Note: Both “DETNAM” and “DET_ID” in an input file must match the same-name values in the CALDB files in order to process the data.	“DU_FM1”, e.g.
ORIGIN	A	Location where the FITS file was created	(“IAPS”, “INFN”, “MSFC”)
CREATOR	A	Software that produced the file	‘ixpecalibconverter’, e.g.
CREAT_ID	A	Unique ID of the creator (retained for compatibility with I2T products)	
OBS_ID	J	Observation ID (Only in Level 1 and 2)	

TIMEREF	A	Time Reference	‘LOCAL’
XMAP_VER	I	Version of the exposure map file format	1
ONTIME	D	On-source time	Any
LIVETIME	D	On-source time corrected for deadtime	Any
EXPOSURE	D	Exposure time	Any
DTCORR	D	Dead time correction	Any
EXTNAME	A	Name of the binary extension	‘EXPMAP’
FCW_POS	B	Position of the Filter and Calibration Wheel	0 – 6
FCW_CMD	I	Commanded value of encoder of Filter and Calibration Wheel	
FCW_ENC	I	Readout value of encoder of Filter and Calibration Wheel position	
EQUINOX	D	Equinox of celestial coordinate system	2000.0
RADECSYS	A	Celestial coordinate system	‘ICRS’
BITPIX	I	Number of bits per pixel	-32
NAXIS	I	Number of axes (2)	2
NAXIS1	I	Length of data axis 1 (1024)	1024
NAXIS2	I	Length of data axis 2 (1024)	1024
BUNIT	A	Unites of image array values.	
CTYPE1	A	Horizontal axis coordinate type (tangent plane parallel to RA)	RA---TAN
CRPIX1	E	Array location of the horizontal reference point in pixels	300
CRVAL1	E	Array value at horizontal reference point (target center RA)	0-360.
CRDELT1	E	Coordinate increment on horizontal axis (image scale in deg/pixel)	
CROTA1	E	Rotation of horizontal axis at reference point	0.
CUNIT1	E	Units of CDELT1 and CRVAL1	Deg
CTYPE2	A	Vertical axis coordinate type (tangent plane parallel to Declination).	DEC---TAN
CRPIX2	E	Array location of the vertical reference point in pixels	300
CRVAL2	E	Array value at vertical reference point (target center Dec)	-90 - +90
CRDELT2	E	Coordinate increment on vertical axis (image scale in deg/pixel)	
CROTA2	E	Rotation of axis at reference point	0.
CUNIT2	E	Units of CDELT1 and CRVAL1	Deg

8 Science Processing CALDB data

8.1 Basic Telescope Data CALDB file

8.1.1 Description

The basic telescope data CALDB is a collection of basic data for each DU/MMA pair. It includes the DU dead time parameter, the mirror nominal focal length, and other simple data parameters necessary for understanding the instrument and processing the science data.

8.1.2 Format

The format of the basic telescope data CALDB files is a standard CALDB FITS file, with a primary header only, in which telescope parameters are defined with keywords and values. The table below lists the HDU section; the following section describes the primary HDU and the values defined within it.

Table 8-1: FITS structure of Basic Telescope Data CALDB file

Section/Header	Name	Description
Primary	-	FITS-required primary header that defines basic telescope parameters

8.1.2.1 Primary HDU

The following table lists keywords used in the primary header. Keywords for this primary header include those defined in Sections 4.5.1 and 4.5.5, in addition to those defined in the following table. Data type codes used in the “Type” column are defined in Appendix B.

Table 8-2: Basic Telescope Data CALDB Primary Header keywords

Keyword Name	Type	Description	Value/Range
INSTRUME	A	Name of the instrument (which is everything)	‘ALL’
FILENAME	A	Name of this file	‘ixpe_a0_190905_teldef_01.fits’, e.g.
CONTENT	A	Description of contents	‘TELESCOPE DEFINITION FILE’
CCLS0001	A	Type of dataset: Basic Calibration File (BCF), or Calibration Product File (CPF)	‘BCF’
CDTP0001	A	Calibration data type	‘DATA’
CCNM0001	A	Type of calibration data	‘TELDEF’
CVSD0001	A	Date when this file should first be used. (TT)	‘2021-01-03’, e.g.
CVST0001	A	Time of day when this file should first be used (TT, goes with date above)	‘00:00:00’, e.g.
CDES0001	A	Description of the contents of this file	‘TELESCOPE DEFINITION FILE’
NCOORDS	I	Number of coordinates defined in this file	‘3’
COORD0	A	First coordinate system (RAWX, RAWY)	‘RAW’
COORD1	A	Second coordinate system (DETX, DETY)	‘DET’
COORD2	A	Third coordinate system (X, Y)	‘SKY’
RAW_XSIZ	I	Raw address space X size (pixels)	300
RAWXPIX1	E	Raw address space X first pixel number (pixel)	0
RAW_XSCL	E	Raw X scale (mm/pixel)	0.05
RAW_XCOL	A	Name of raw X column in event files	‘CHIPX’
RAW_YSIZ	I	Raw address space Y size (pixels)	352
RAWYPIX1	E	Raw address space Y first pixel number (pixel)	0
RAW_YSCL	E	Raw Y scale (mm/pixel)	0.0426
RAW_YCOL	A	Name of raw Y column in event files	‘CHIPY’
RAW_UNIT	A	Physical unit of RAW coordinates	‘mm’
DET_XSIZ	I	DET address space X size (pixels)	300
DETXPIX1	E	DET address space X first pixel number (pixel)	0
DET_XSCL	E	DET PX scale (mm/pixel)	0.05
DET_XCOL	A	Name of DET PX column in event files	‘DETX’

DET_YSIZ	I	DET address space Y size (pixels)	300
DETYPIX1	E	DET address space Y first pixel number (pixel)	0
DET_YSCL	E	DET Y scale (mm/pixel)	0.05
DET_YCOL	A	Name of DET Y column in event files	‘DETY’
DET_UNIT	A	Physical units of DET coordinates	‘mm’
SKY_XSIZ	I	SKY address space X size (pixels)	600
SKYXPIX1	E	SKY address space X first pixel number (pixel)	0
SKY_XSCL	E	SKY X scale (deg/pixel)	7.2222E-04
SKY_XCOL	A	Name of SKY X column in event files	‘X’
SKY_YSIZ	I	SKY address space Y size (pixels)	600
SKYYPIX1	E	SKY address space Y first pixel number (pixel)	0
SKY_YSCL	E	SKY Y scale (deg/pixel)	7.2222E-04
SKY_YCOL	A	Name of SKY Y column in event files	‘Y’
SKY_UNIT	A	Physical units of SKY coordinates	’deg’
SKY_FROM	A	Indicates coordinates from which SKY coordinates are calculated	‘DET’
COE_X1_A	E	Offset coefficient translating DU1 DETX to DET_PX	7.5
COE_X1_B	E	Linear coefficient translating DU1 DETX to DET PY	1.0/0.05
COE_X1_C	E	Linear coefficient translating DU1 DETX to DET PY	0
COE_Y1_A	E	Offset coefficient translating DU1 DETY to DET_PY	7.5
COE_Y1_B	E	Linear coefficient translating DU1 DETY to DET PY	1.0/0.05
COE_Y1_C	E	Linear coefficient translating DU1 DETY to DET PY	0
COE_X2_A	E	Offset coefficient translating DU2 DETX to DET_PX	7.5
COE_X2_B	E	Linear coefficient translating DU2 DETX to DET PX	1.0/0.05
COE_X2_C	E	Linear coefficient translating DU2 DETX to DET PX	0
COE_Y2_A	E	Offset coefficient translating DU2 DETY to DET_PY	7.5
COE_Y2_B	E	Linear coefficient translating DU2 DETY to DET_PY	1.0/0.05
COE_Y2_C	E	Linear coefficient translating DU2 DETY to DET PY	0
COE_X3_A	E	Offset coefficient translating DU3 DETX to DET_PX	7.5
COE_X3_B	E	Linear coefficient translating DU3 DETX to DET PX	1.0/0.05
COE_X3_C	E	Linear coefficient translating DU3 DETX to DET PX	0
COE_Y3_A	E	Offset coefficient translating DU3 DETY to DET_PY	7.5
COE_Y3_B	E	Linear coefficient translating DU3 DETY to DET PY	1.0/0.05
COE_Y3_C	E	Linear coefficient translating DU3 DETY to DET PY	0
DET_XOFF	E	X offset between intermediate and DET coordinates	0.0, e.g.
DET_YOFF	E	Y offset between intermediate and DET coordinates	0.0, e.g.
DETXFLIP	I	Signed to indicate x-axis flips in RAW->DET	1 or -1
DETYFLIP	I	Signed to indicate y-axis flips in RAW->DET	1 or -1
DET_SCAL	E	Scaling between RAW and DET	Any number
DET_ROTD	E	Rotation (degrees)	Any number
ROLLSIGN	E	Sign of roll positive direction about boresight	1.0 or -1.0
ROLLOFF	E	Offset of roll angle in degrees	-180. - +180.0
FOCALLEN	E	Focal length of optics (mm)	4001.0, e.g.
OPTAXISX	I	Optical axis X in DET_PX coordinates (pixel)	150
OPTAXISY	I	Optical axis Y in DET_PX coordinates (pixel)	150
D_NAMID1	A	Defines the valid value of “DET_ID” corresponding to DETNAM = “DU1”	“DU_FM2”

D_NAMID2	A	Defines the valid value of "DET_ID" corresponding to DETNAM = "DU2"	"DU_FM3"
D_NAMID3	A	Defines the valid value of "DET_ID" corresponding to DETNAM = "DU3"	"DU_FM4"
D_NAMID4	A	Defines the valid value of "DET_ID" corresponding to DETNAM = "DU4"	"DU_FM1"

8.2 Detector Unit (DU) Pixel equalization CALDB file

8.2.1 Description

The Detector Unit Pixel Equalization CALDB is a pixel-by-pixel map of the relative gain of the Detector Unit. It is used to correct each pixel of a Level-1 event image for gain variations across the detector before the event image is analyzed. The DU gain map CALDB's is produced for the three flight detectors and the one flight spare by the I2C and delivered electronically to the SOC.

8.2.2 Format

The format of the gain map files is a standard CALDB FITS file, with a primary header and a single extension for the binary table that holds the gain map. The table below lists the HDU sections. The following subsections describe the HDU's and their subsections.

Table 8-3: FITS structure of DU Gain Map CALDB file

Section/Header	Name	Description
Primary	-	FITS-required primary header
Extension 1	PIXGAIN	Gain map binary table data

8.2.2.1 Primary HDU

The following table lists keywords used in the primary header. Keywords for this primary header include those defined in Sections 4.5.1 and 4.5.5, in addition to those defined in the following table. The data type codes used in the "Type" column are defined in Appendix B.

Table 8-4: Gain Map CALDB Primary Header keywords

Keyword Name	Type	Description	Value/Range
INSTRUME	A	Instrument of the telescope	GPD
DETNAM	A	Name of the Detector Unit of the instrument	• DU1, DU2, DU3, DU4 in flight • 018, 019, 020, etc. on ground
DET_ID	A	See Section 4.5.3	

8.2.2.2 PIXGAIN Extension: Header

The following table lists keywords used in the Gain Table (PIXGAIN) header. This secondary header is a binary table header. Keywords defined in this section are those that are not involved with the definition of the binary table shape nor the names, types, and units of the table columns. All header keywords from the Primary Header are repeated in the Gain Table Header and will not be repeated in the table below.

Table 8-5: PIXGAIN Extension Header keywords

Keyword Name	Type	Description	Value/Range/Example
EXTNAME	A	Name of the binary extension	'PIXGAIN'
FILENAME	A	Name of CALDB file	'ixpe_d1_200523_gain_01.fits', e.g.
CONTENT	A	Description of the contents of this HDU	'IXPE Gain'

CCLS0001	A	Type of dataset: Basic Calibration File (BCF) or Calibration Product File (CPF)	'BCF'
CDTP0001	A	Calibration data type	'DATA'
CCNM0001	A	Type of calibration data	'GAIN'
CVSD0001	A	Date when this file should first be used. (TT)	'2021-01-03', e.g.
CVST0001	A	Time of day when this file should first be used (TT, goes with date above)	'00:00:00', e.g.
CDES0001	A	Description of the contents of this file	'IXPE Gain coefficients'

8.2.2.3 PIXGAIN Extension: Table Columns

The table itself is a list of the gain calibration times, raw detector positions, temperatures, slopes, and offsets. Data are supplied for each pixel, and therefore occupy 5 columns by 105,600 rows. The table below describes the columns. The data type codes used in the "Type" column are defined in Appendix B.

Table 8-6: Gain Table Columns

Name	Type	Units	Description
CHIPX	I	Pixels	Raw x-pixel ID
CHIPY	I	Pixels	Raw y-pixel ID
EQ_SLOPE	D	PI/PHA	Gain slope coefficient

8.3 Detector Unit (DU) Noise Map CALDB file

8.3.1 Description

The Detector Noise Map CALDB is a pixel-by-pixel map of the noise coefficients of the Detector Unit. It is used to suppress false triggers due to noisy pixels. The DU noise map CALDB's will be produced for the three flight detectors and the one flight spare by the I2C and delivered electronically to the SOC.

8.3.2 Format

The format of the noise map files is a standard CALDB fits file, with a primary header and a single extension for the binary table that holds the noise map. The table below lists the HDU sections. The following subsections describe the HDU's and their subsections.

Table 8-7: FITS structure of DU Noise Map CALDB file

Section/Header	Name	Description
Primary	-	FITS-required primary header
Extension 1	PIXNOISE	Noise map binary table data

8.3.2.1 Primary HDU

The following table lists keywords used in the primary header. Keywords for this primary header include those defined in Sections 4.5.1 and 4.5.5 in addition to those defined in the following table. The data type codes used in the "Type" column are defined in Appendix B.

Table 8-8: Noise Map CALDB Primary Header keywords

Keyword Name	Type	Description	Value/Range
INSTRUME	A	Instrument of the telescope	GPD
DETNAM	A	Name of the Detector Unit of the instrument	• DU1, DU2, DU3, DU4 in flight • 018, 019, 020, etc. on ground

DET_ID	A	See Section 4.5.3	

8.3.2.2 PIXNOISE Extension: Header

The following table lists keywords used in the Noise Table (PIXNOISE) header. This secondary header is a binary table header. Keywords defined in this section are those that are not involved with the definition of the binary table shape nor the names, types, and units of the table columns. All header keywords from the Primary Header are repeated in the Noise Table Header and will not be repeated in the table below.

Table 8-9: PIXNOISE Extension Header keywords

Keyword Name	Type	Description	Value/Range/Example
EXTNAME	A	Name of the binary extension	'PIXNOISE'
FILENAME	A	Name of CALDB file	'ixpe_d1_200523_noise_01.fits', e.g.
CONTENT	A	Description of the contents of this HDU	'IXPE Noise'
CCLS0001	A	Type of dataset: Basic Calibration File (BCF) or Calibration Product File (CPF)	'BCF'
CDTP0001	A	Calibration data type	'DATA'
CCNM0001	A	Type of calibration data	'NOISE'
CVSD0001	A	Date when this file should first be used (TT)	'2021-01-03', e.g.
CVST0001	A	Time of day when this file should first be used (TT, goes with date above)	'00:00:00', e.g.
CDES0001	A	Description of the contents of this file	'IXPE Noise coefficients'

8.3.2.3 PIXNOISE Extension: Table Columns

The table itself is a list of the noise calibration times, raw detector positions, temperatures, slopes, and offsets. Data are supplied for each pixel, and therefore occupy 4 columns by 105,600 rows. The table below describes the columns. The data type codes used in the "Type" column are defined in Appendix B.

Table 8-10: PIXENOISE Extension Table Columns

Name	Type	Units	Description
CHIPX	I	Pixels	Raw x-pixel ID
CHIPY	I	Pixels	Raw y-pixel ID
NOISE	D	N/A	Noise coefficient
TIME	D	Sec	Time (IXPE time)

8.4 Detector Unit (DU) Pedestal Map CALDB file

8.4.1 Description

The Detector Pedestal Map CALDB is a pixel-by-pixel map of the pedestal coefficients of the Detector Unit. It is used when post-event pedestal measurements are not taken and subtracted by the DSU, to subtract a noise pedestal from each pixel. The DU pedestal map CALDB's will be produced for the three flight detectors and the one flight spare by the I2C and delivered electronically to the SOC.

8.4.2 Format

The format of the pedestal map files is a standard CALDB fits file, with a primary header and a single extension for the binary table that holds the pedestal map. The table below lists the HDU sections. The following subsections describe the HDU's and their subsections.

Table 8-11: FITS structure of DU Pedestal Map CALDB file

Section/Header	Name	Description
Primary	-	FITS-required primary header
Extension 1	PIXPEDS	Pedestal map binary table data

8.4.2.1 Primary HDU

The following table lists keywords used in the primary header. Keywords for this primary header include those defined in Sections 4.5.1 and 4.5.5 in addition to those defined in the following table. The data type codes used in the "Type" column are defined in Appendix B.

Table 8-12: Pedestal Map CALDB Primary Header keywords

Keyword Name	Type	Description	Value/Range
INSTRUME	A	Instrument of the telescope	GPD
DETNAM	A	Name of the Detector Unit of the instrument	• DU1, DU2, DU3, DU4 in flight • 018, 019, 020, etc. on ground
DET_ID	A	See Section 4.5.3	

8.4.2.2 PIXPEDS Extension: Header

The following table lists keywords used in the Pedestal Table (PIXPEDS) header. This secondary header is a binary table header. Keywords defined in this section are those that are not involved with the definition of the binary table shape nor the names, types, and units of the table columns. All header keywords from the Primary Header are repeated in the Pedestal Table Header and will not be repeated in the table below.

Table 8-13: PIXPEDS Extension Header keywords

Keyword Name	Type	Description	Value/Range/Example
EXTNAME	A	Name of the binary extension	'PIXPEDS'
FILENAME	A	Name of CALDB file	'ixpe_d1_200523_pedestal_01.fits', e.g.
CONTENT	A	Description of the contents of this HDU	'IXPE Pedestal'
CCLS0001	A	Type of dataset: Basic Calibration File (BCF) or Calibration Product File (CPF)	'BCF'
CDTP0001	A	Calibration data type	'DATA'
CCNM0001	A	Type of calibration data	'PEDESTAL'
CVSD0001	A	Date when this file should first be used. (TT)	'2021-01-03', e.g.
CVST0001	A	Time of day when this file should first be used (TT, goes with date above)	'00:00:00', eg.
CDES0001	A	Description of the contents of this file	'IXPE Pedestal coefficients'

8.4.2.3 PIXPEDS Extension: Table Columns

The table itself is a list of the pedestal calibration times, raw detector positions, temperatures, slopes, and offsets. Data are supplied for each pixel, and therefore occupy 4 columns by 105,600 rows. The table below describes the columns. The data type codes used in the "Type" column are defined in Appendix B.

Table 8-14: PIXPEDS Extension Table Columns

Name	Type	Units	Description
CHIPX	I	Pixels	Raw x-pixel ID.
CHIPY	I	Pixels	Raw y-pixel ID.
PEDESTAL	D	N/A	Pedestal coefficient
TIME	D	Sec	Time (IXPE time)

8.5 Detector Unit (DU) Bad-Pixel Map CALDB file

8.5.1 Description

The Detector Unit bad pixel map CALDB is a list of the positions of the pixels in a given DU that, for reasons of extreme gain variation, flickering response, or other defect, are not useable for science. It is used in the calculation of the exposure map and in the analysis of the Level-1 data. If bad pixels are identified during ground calibration, the bad pixel map CALDB files for the three flight detectors and the flight spare will be produced by the I2C and delivered electronically to the SOC. If no bad pixels are identified during ground calibration, the SOC will produce initially empty bad-pixel maps for incorporating flight and user additions, as necessary.

8.5.2 Format

The format of the bad-pixel files is a standard CALDB fits file, with a primary header and a single extension for the binary table that holds the bad pixel data. The table below lists the HDU sections. The following subsections describe the HDU's and their subsections.

Table 8-15: FITS structure of Bad pixel Map CALDB file

Section/Header	Name	Description
Primary	-	FITS-required primary header
Extension 1	BADPIX	Bad pixel binary table data

8.5.2.1 Primary HDU

The following table lists keywords used in the primary header. Keywords for this primary header include those defined in Sections 4.5.1 and 4.5.5 in addition to those defined in the following table. The data type codes used in the "Type" column are defined in Appendix B.

Table 8-16: Bad Pixel CALDB Primary Header keywords

Keyword Name	Type	Description	Value/Range
INSTRUME	A	Instrument of the telescope	GPD
DETNAM	A	Name of the Detector Unit of the instrument	• DU1, DU2, DU3, DU4 in flight • 018, 019, 020, etc. on ground
DET_ID	A	See Section 4.5.3	

8.5.2.2 BADPIX Extension: Header

The following table lists keywords used in the Bad Pixel Table header. This secondary header is a binary table header. Keywords defined in this section are those that are not involved with the definition of the binary table shape nor the names, types, and units of the table columns. All the header keywords from the Primary Header are repeated in the Bad Pixel Table Header and will not be repeated in the table below.

Table 8-17: BADPIX Extension Header keywords

Keyword Name	Type	Description	Value/Range/Example
EXTNAME	A	Name of the binary extension	‘BADPIX’
FILENAME	A	Name of CALDB file	‘ixpe_d1_200523_badpix_01.fits’, e.g.
CONTENT	A	Description of the contents of this HDU	‘IXPE Ground Bad Pixel Table’
CCLS0001	A	Type of dataset: Basic Calibration File (BCF) or Calibration Product File (CPF)	‘BCF’
CDTP0001	A	Calibration data type	‘DATA’
CCNM0001	A	Type of calibration data	‘BADPIX’
CVSD0001	A	Date when this file should first be used. (TT)	‘2021-01-03’, e.g.
CVST0001	A	Time of day when this file should first be used (TT, goes with date above)	‘00:00:00’, e.g.
CDES0001	A	Description of the contents of this file	‘IXPE Ground Bad Pixel Table’

8.5.2.3 BADPIX Extension: Table Columns

The table itself is a list of the bad calibration times, raw detector positions, and bad pixel flag bits. Data are supplied only for bad pixels, and therefore occupy 4 columns by a number of rows that may be zero and may be different for each detector unit. The table below describes the columns. The data type codes used in the “Type” column are defined in Appendix B.

Table 8-18: BADPIX Extension Table Columns

Name	Type	Units	Description
DET_PX	I	Bins	Detector x-position bin (0-300 = -7.475 to +7.475 mm)
DET_PY	I	Bins	Detector x-position bin (0-300 = -7.475 to +7.475 mm)
BADFLAG	16X	bits	Bit-wise flags 0x0001 = Left edge excluded 0x0002 = Right edge excluded 0x0004 = Top edge excluded 0x0008 = Bottom edge excluded 0x0010 = Left edge conditional (gray) 0x0020 = Right edge conditional (gray) 0x0040 = Top edge conditional (gray) 0x0080 = Bottom edge conditional (gray) 0x0100 = Interior excluded (bad pixel) 0x0200 = Interior conditional (gray pixel)

8.6 Detector Unit (DU) Peak Gain Map CALDB file

8.6.1 Description

The Detector Peak Gain CALDB is a map of the peak gain corrections of each Detector Unit. It is used after event reconstruction to remove remaining variations in gain across a detector and among detectors. The DU Peak Gain map CALDB’s will be produced for the three flight detectors and the one flight spare by the I2C and delivered electronically to the SOC.

8.6.2 Format

The format of the Peak Gain map files is a standard CALDB FITS file, with a primary header and a single extension for the binary table that holds the noise map. The table below lists the HDU sections. The following subsections describe the HDU's and their subsections.

Table 8-19: FITS structure of DU Peak Gain Map CALDB file

Section/Header	Name	Description
Primary	-	FITS-required primary header
Extension 1	PKGAIN	Peak Gain binary table data

8.6.2.1 Primary HDU

The following table lists keywords used in the primary header. Keywords for this primary header include those defined in Sections 4.5.1 and 4.5.5 in addition to those defined in the following table. The data type codes used in the "Type" column are defined in Appendix B.

Table 8-20: Peak Gain Map CALDB Primary Header keywords

Keyword Name	Type	Description	Value/Range
INSTRUME	A	Instrument of the telescope	GPD
DETNAM	A	Name of the Detector Unit of the instrument	• DU1, DU2, DU3, DU4 in flight • 018, 019, 020, etc. on ground
DET_ID	A	See Section 4.5.3	

8.6.2.2 PKGAIN Extension: Header

The following table lists keywords used in the PKGAIN header. This secondary header is a binary table header. Keywords defined in this section are those that are not involved with the definition of the binary table shape nor the names, types, and units of the table columns. All header keywords from the Primary Header are repeated in this header and will not be repeated in the table below.

Table 8-21: PKGAIN Extension Header keywords

Keyword Name	Type	Description	Value/Range/Example
EXTNAME	A	Name of the binary extension	'PKGAIN'
FILENAME	A	Name of CALDB file	'ixpe_d1_200523_pkgain_01.fits', e.g.
CONTENT	A	Description of the contents of this HDU	'IXPE Peak Gain'
CCLS0001	A	Type of dataset: Basic Calibration File (BCF) or Calibration Product File (CPF)	'BCF'
CDTP0001	A	Calibration data type	'DATA'
CCNM0001	A	Type of calibration data	'PKGAIN'
CVSD0001	A	Date when this file should first be used. (TT)	'2021-01-03', e.g.
CVST0001	A	Time of day when this file should first be used (TT, goes with date above)	'00:00:00', e.g.
CDES0001	A	Description of the contents of this file	'IXPE Peak Gain coefficients'

8.6.2.3 PKGAIN Extension: Table Columns

The table itself is a list of the peak gain measurement times, detected (post-ixpeevtrecon) positions, slopes, and offsets. Data are supplied for each pixel, and therefore occupy 5 columns by 90000 rows. The table below describes the columns. The data type codes used in the "Type" column are defined in Appendix B.

Table 8-22: PKGAIN Extension Table Columns

Name	Type	Units	Description
BARX_PX	I	Pixels	Detector x-position bin (0-300 = -7.475 to +7.475 mm) from event barycenter
BARY_PX	I	Pixels	Detector y-position bin (0-300 = -7.475 to +7.475 mm) from event barycenter
SLOPE	D	PI/PHA	Slope of peak gain fit
OFFSET	D	PI	Offset of peak gain fit

8.7 Detector Unit (DU) GEM High Voltage Gain Correction CALDB file

8.7.1 Description

The GEM High Voltage Gain Correction CALDB is a table of values for scaling the gain of the detector from one GEM HV setting to another for each Detector Unit. It is used in association with the peak gain map and the secular gain correction to correct the gain of a detector due to changes in GEM HV setting. The GEM High Voltage Gain Correction CALDB's will be produced for the three flight detectors and the one flight spare by the I2C and delivered electronically to the SOC.

8.7.2 Format

The format of the GEM High Voltage Gain Correction files is a standard CALDB FITS file, with a primary header and a single extension for the binary table that holds the noise map. The table below lists the HDU sections. The following subsections describe the HDU's and their subsections.

Table 8-23: FITS structure of DU GEM High Voltage Gain Correction CALDB file

Section/Header	Name	Description
Primary	-	FITS-required primary header
Extension 1	HVGAIN	GEM High Voltage Gain Correction binary table data

8.7.2.1 Primary HDU

The following table lists keywords used in the primary header. Keywords for this primary header include those defined in Sections 4.5.1 and 4.5.5 in addition to those defined in the following table. The data type codes used in the "Type" column are defined in Appendix B.

Table 8-24: GEM High Voltage Gain Correction CALDB Primary Header keywords

Keyword Name	Type	Description	Value/Range
INSTRUME	A	Instrument of the telescope	GPD
DETNAM	A	Name of the Detector Unit of the instrument	• DU1, DU2, DU3, DU4 in flight • 018, 019, 020, etc. on ground
DET_ID	A	See Section 4.5.3	

8.7.2.2 HVGAIN Extension: Header

The following table lists keywords used in the HVGAIN header. This secondary header is a binary table header. Keywords defined in this section are those that are not involved with the definition of the binary table shape nor the names, types, and units of the table columns. All the header keywords from the Primary Header are repeated in this header and will not be repeated in the table below.

Table 8-25: HVGAIN Extension Header keywords

Keyword Name	Type	Description	Value/Range/Example
EXTNAME	A	Name of the binary extension	‘HVGAIN’
FILENAME	A	Name of CALDB file	‘ixpe_d1_200523_hvgain_01.fits’, e.g.
CONTENT	A	Description of the contents of this HDU	‘IXPE GEM HV Gain’
CCLS0001	A	Type of dataset: Basic Calibration File (BCF) or Calibration Product File (CPF)	‘BCF’
CDTP0001	A	Calibration data type	‘DATA’
CCNM0001	A	Type of calibration data	‘HVGAIN’
CVSD0001	A	Date when this file should first be used. (TT)	‘2021-01-03’, e.g.
CVST0001	A	Time of day when this file should first be used (TT, goes with date above)	’00:00:00’, eg.
CDES0001	A	Description of the contents of this file	‘IXPE GEM HV Gain coefficients’

8.7.2.3 HVGAIN Extension: Table Columns

The table itself is a list of the GEM gain correction parameters. Data are supplied for each HV and consist of a single row for each value of HV (this will initially be a single row, and will grow with time). The table below describes the columns. The data type codes used in the “Type” column are defined in Appendix B.

Table 8-26: HVGAIN Extension Table Columns

Name	Type	Units	Description
Time	D	S	IXPE seconds
DVGEM	D	V	High voltage setting of GEM
DVGEM_NOMINAL	D	V	Nominal high voltage setting of GEM.
GAMMA	D	N/A	Exponential gain parameter for HV variation model.
VDRIFT	D	V	High voltage drift setting
VDRIFT_NOMINAL	D	V	Nominal high voltage drift setting
VBOTTOM	D	V	High voltage setting on GEM bottom
VBOTTOM_NOMINAL	D	V	Nominal high voltage setting on GEM bottom

8.8 Detector Unit (DU) Secular Gain Correction CALDB file

8.8.1 Description

The Secular Gain Correction CALDB is table of coefficients used to correct the pressure-dependent (and thus time-dependent) gain variation of a DU. It is used after event reconstruction to remove remaining variations in gain across a detector and among detectors. The DU Secular Gain Correction CALDB is produced for the three flight detectors and the one flight spare by the I2T and delivered electronically to the SOC.

8.8.2 Format

The format of the Secular Gain Correction files is a standard CALDB FITS file, with a primary header and a single extension for the binary table that holds the noise map. The table below lists the HDU sections. The following subsections describe the HDU’s and their subsections.

Table 8-27: FITS structure of Secular Gain Correction CALDB file

Section/Header	Name	Description
Primary	-	FITS-required primary header
Extension 1	SECVAR	Secular Gain Correction binary table data

8.8.2.1 Primary HDU

The following table lists keywords used in the primary header. Keywords for this primary header include those defined in Sections 4.5.1 and 4.5.5 in addition to those defined in the following table. The data type codes used in the “Type” column are defined in Appendix B.

Table 8-28: Secular Gain Correction CALDB Primary Header keywords

Keyword Name	Type	Description	Value/Range
INSTRUME	A	Instrument of the telescope	GPD
DETNAM	A	Name of the Detector Unit of the instrument	• DU1, DU2, DU3, DU4 in flight • 018, 019, 020, etc. on ground
DET_ID	A	See Section 4.5.3	

8.8.2.2 SECVAR Extension: Header

The following table lists keywords used in the SECVAR header. This secondary header is a binary table header. Keywords defined in this section are those that are not involved with the definition of the binary table shape nor the names, types, and units of the table columns. All the header keywords from the Primary Header are repeated in this header and will not be repeated in the table below.

Table 8-29: SECVAR Extension Header keywords

Keyword Name	Type	Description	Value/Range/Example
EXTNAME	A	Name of the binary extension	‘SECVAR’
FILENAME	A	Name of CALDB file	‘ixpe_d1_200523_secvar_01.fits’, e.g.
CONTENT	A	Description of the contents of this HDU	‘IXPE Secular Gain’
CCLS0001	A	Type of dataset: Basic Calibration File (BCF) or Calibration Product File (CPF)	‘BCF’
CDTP0001	A	Calibration data type	‘DATA’
CCNM0001	A	Type of calibration data	‘SECVAR’
CVSD0001	A	Date when this file should first be used. (TT)	‘2021-01-03’, e.g.
CVST0001	A	Time of day when this file should first be used (TT, goes with date above)	‘00:00:00’, eg.
CDES0001	A	Description of the contents of this file	‘IXPE Secular Gain coefficients’

8.8.2.3 SECVAR Extension: Table Columns

The table itself is a list of the coefficients to calculate the pressure change in a DU with time, and to scale this pressure change to a change in gain slope. Data are supplied for each pixel and therefore occupy 8 columns by 1 row. The table below describes the columns. The data type codes used in the “Type” column are defined in Appendix B.

Table 8-30: SECVAR Extension Table Columns

Name	Type	Units	Description
P_0	I	Mbar	Initial pressure measured at TIME_0
TIME_0	D	sec	IXPE Time of initial P_0 measurement
DELTA_1	I	mbar	Magnitude of first exponential component
TAU_1	D	N/A	Decay constant of first exponential component
DELTA_2	I	Mbar	Magnitude of second exponential component
TAU_2	D	N/A	Decay constant of second exponential component
PSCALE	D	N/A	Exponential parameter to convert pressure changes into gain scale corrections

8.9 Detector Unit (DU) Temperature Gain Correction CALDB file

8.9.1 Description

The Detector Temperature Gain Correction CALDB is a list of weighting coefficients for several DU temperatures that affect the gain of the DU, a reference temperature, and the slope and offset of the gain correction to apply based on the weighted sum of the temperatures relative to the reference temperature. It is used after event reconstruction to remove remaining variations in gain across a detector and among detectors. The DU Temperature Gain Correction CALDB is produced for the three flight detectors and the one flight spare by the I2C and delivered electronically to the SOC.

8.9.2 Format

The format of the Temperature Gain Correction files is a standard CALDB FITS file, with a primary header and a single extension for the binary table that holds the noise map. The table below lists the HDU sections. The following subsections describe the HDU's and their subsections.

Table 8-31: FITS structure of DU Temperature Gain Correction CALDB file

Section/Header	Name	Description
Primary	-	FITS-required primary header
Extension 1	TEMPGAIN	Temperature Gain Correction binary table data

8.9.2.1 Primary HDU

The following table lists keywords used in the primary header. Keywords for this primary header include those defined in Sections 4.5.1 and 4.5.5 in addition to those defined in the following table. The data type codes used in the "Type" column are defined in Appendix B.

Table 8-32: Peak Gain Map CALDB Primary Header keywords

Keyword Name	Type	Description	Value/Range
INSTRUME	A	Instrument of the telescope	GPD
DETNAM	A	Name of the Detector Unit of the instrument	• DU1, DU2, DU3, DU4 in flight • 018, 019, 020, etc. on ground
DET_ID	A	See Section 4.5.3	

8.9.2.2 TEMPGAIN Extension: Header

The following table lists keywords used in the TEMPGAIN header. This secondary header is a binary table header. Keywords defined in this section are those that are not involved with the definition of the binary table shape nor the names, types, and units of the table columns. All the header keywords from the Primary Header are repeated in this header and will not be repeated in the table below.

Table 8-33: TEMPGAIN Extension Header keywords

Keyword Name	Type	Description	Value/Range/Example
EXTNAME	A	Name of the binary extension	'TEMPGAIN'
FILENAME	A	Name of CALDB file	'ixpe_d1_200523_tempgain_01.fits', e.g.
CONTENT	A	Description of the contents of this HDU	'IXPE Temperature Gain'
CCLS0001	A	Type of dataset: Basic Calibration File (BCF) or Calibration Product File (CPF)	'BCF'
CDTP0001	A	Calibration data type	'DATA'
CCNM0001	A	Type of calibration data	'TEMPGAIN'
CVSD0001	A	Date when this file should first be used. (TT)	'2021-01-03', e.g.
CVST0001	A	Time of day when this file should first be used (TT, goes with date above)	'00:00:00', eg.
CDES0001	A	Description of the contents of this file	'IXPE Temperature Gain coefficients'

8.9.2.3 TEMPGAIN Extension: Table Columns

The table itself is a list of the peak gain measurement times, detected (post-ixpeevtrecon) weighting coefficients, slopes, and offsets. Data are supplied for each usable DU temperature, and therefore occupy 11 columns by 1 row. The table below describes the columns. The data type codes used in the "Type" column are defined in Appendix B.

Table 8-34: Temperature Gain Table Columns

Name	Type	Units	Description
GPD_COEFF	E	N/A	Weighting coefficient for GPD temperature
DAQ1_COEFF	E	N/A	Weighting coefficient for DAQ1 temperature
DAQ2_COEFF	E	N/A	Weighting coefficient for DAQ2 temperature
HV1_COEFF	E	N/A	Weighting coefficient for HV1 temperature
HV2_COEFF	E	N/A	Weighting coefficient for HV2 temperature.
LVPS1V5_COEFF	E	N/A	Weighting coefficient for LVPS 1.5V temperature
LVPS1V8_COEFF	E	N/A	Weighting coefficient for LVPS 1.8V temperature
LVPS3V3_COEFF	E	N/A	Weighting coefficient for LVPS 3.3V temperature
TEMP_SLOPE	E	N/A	Slope of gain change vs temperature change
TEMP_OFFSET	E	PHA	Gain change offset (PHA at reference temperature)
TEMP_REF	E	C	Reference temperature for nominal gain

8.10 Detector Unit (DU) ASIC Correction CALDB file

8.10.1 Description

The Detector ASIC Correction CALDB is a list of the ASIC correction values (scalar) for each detector.

8.10.2 Format

The format of the ASIC correction files is a standard CALDB fits file, with a primary HDU.

Table 8-35: FITS structure of DU Noise Map CALDB file

Section/Header	Name	Description
Primary	-	FITS-required primary header
Extension 1	ASICCOR	ASIC Correction keywords and data table

8.10.2.1 Primary HDU

The following table lists keywords used in the primary header. Keywords for this primary header include those defined in Sections 4.5.1 and 4.5.5 in addition to those defined in the following table. The data type codes used in the “Type” column are defined in Appendix B.

Table 8-36: Noise Map CALDB Primary Header keywords

Keyword Name	Type	Description	Value/Range
ACORR1	J	ASIC correction (value to subtract from pixels) for DU1	5
ACORR2	J	ASIC correction (value to subtract from pixels) for DU2	5

8.10.2.2 ASICCORR Extension: Header

The following table lists keywords used in the ASICCORR header. This secondary header is a binary table header. Keywords defined in this section are those that are not involved with the definition of the binary table shape nor the names, types, and units of the table columns. All the header keywords from the Primary Header are repeated in this header and will not be repeated in the table below.

Table 8-37: ASICCORR Extension Header keywords

Keyword Name	Type	Description	Value/Range/Example
EXTNAME	A	Name of the binary extension	‘ASICCORR’
FILENAME	A	Name of CALDB file	‘ixpe_d1_20170101_asiccorr_01.fits’, e.g.
CONTENT	A	Description of the contents of this HDU	‘IXPE DU ASIC CORRECTION’
CCLS0001	A	Type of dataset: Basic Calibration File (BCF) or Calibration Product File (CPF)	‘BCF’
CDTP0001	A	Calibration data type	‘DATA’
CCNM0001	A	Type of calibration data	‘ASICCORR’
CVSD0001	A	Date when this file should first be used (TT)	‘2021-01-03’, e.g.
CVST0001	A	Time of day when this file should first be used (TT, goes with date above)	‘00:00:00’, e.g.
CDES0001	A	Description of the contents of this file	‘IXPE ASIC Correction coefficients’

8.10.2.3 ASICCORR Extension: Table Columns

The table itself is a list of the ASIC corrections for a single detector, consisting of two columns and 1 row. The table below describes the columns. The data type codes used in the “Type” column are defined in Appendix B.

Table 8-38: ASICCORR Extension Table Columns

Name	Type	Units	Description

CoherentNoiseOffset	D	N/A	Coherent noise ASIC offset
TriggerMiniclusterOffset	D	N/A	Trigger Mini-cluster ASIC offset

8.11 Detector Unit (DU) Spurious Modulation map CALDB file

8.11.1 Description

The DU spurious modulation map CALDB file contains the energy-dependent spurious modulation information as a function of off-axis angle of the collimator of each detector unit.

8.11.2 Format

The format of the DU spurious modulation map is a standard CALDB FITS file, with a primary header and a single extension for the binary table that holds the spurious modulation data. The table below lists the HDU sections. The following subsections describe the HDU's and their subsections.

Table 8-39: FITS structure of DU Spurious Modulation CALDB file

Section/Header	Name	Description
Primary	-	FITS-required primary header
Extension 1	SPMOD	Spurious modulation table data

8.11.2.1 Primary HDU

The following table lists keywords used in the primary header. Keywords for this primary header include those defined in Sections 4.5.1 and 4.5.5 in addition to those defined in the following table. The data type codes used in the "Type" column are defined in Appendix B.

Table 8-40: DU Residual modulation CALDB Primary Header keywords

Keyword Name	Type	Description	Value/Range
INSTRUME	A	Instrument of the telescope	GPD
DETNAM	A	Name of the Detector Unit of the instrument	• DU1, DU2, DU3, DU4 in flight • 018, 019, 020, etc on ground
DET_ID	A	See Section 4.5.3	

8.11.2.2 SPMOD Extension: Header

The following table lists keywords used in the DU spurious modulation Table header. This secondary header is a binary table header. Keywords defined in this section are those that are not involved with the definition of the binary table shape nor the names, types, and units of the table columns. All the header keywords from the Primary Header are repeated in the DU spurious modulation Table Header and will not be repeated in the table below.

Table 8-41: SPMOD Extension Header keywords

Keyword Name	Type	Description	Value/Range/Example
EXTNAME	A	Name of the binary extension	'SPMOD'
FILENAME	A	Name of CALDB file	'ixpe_d1_200523_rpmod_01.fits', e.g.
CCLS0001	A	Type of dataset: Basic Calibration File (BCF) or Calibration Product File (CPF)	'BCF'
CDTP0001	A	Calibration data type	'DATA'
CCNM0001	A	Type of calibration data	'SPMOD'
CVSD0001	A	Date when this file should first be used (TT)	'2021-01-03', e.g.

CVST0001	A	Time of day when this file should first be used (TT, goes with date above)	‘00:00:00’, e.g.
CDES0001	A	Description of the contents of this file	‘IXPE Det1 spurious modulation ARF correction’

8.11.2.3 SPMOD Extension: Table Columns

The table itself is an array of energy bin lower limits, an array of energy bin upper limits, an array of angles, and an array of spurious modulation for each combination of energy bin and angle. The data occupy 7 columns by N rows, where N is the number of pixels (300x300 = 90000) measured. Note that many of the columns are array columns and not single-value columns as described in the table below. The data type codes used in the “Type” column are defined in Appendix B. Note that the energy, q_sm, u_sm, dq_sm, and du_sm columns have 6 values, equal to the number of energies at which the spurious modulation was mapped.

Table 8-42: SPMOD Extension Table Columns

Name	Type	Units	Description
DETX_PX	I	Pixel	Detector x-position bin (0-300)
DETY_PX	I	Pixel	Detector y-position bin (0-300)
PI	6E	Channel	Detector energy of source from which this map data was derived (values are 51, 57, 55, 77, 92, 148, which correspond to input energies of 2, 2.2, 2.7, 3, 3.7 and 6 keV).
DETQ_SM	6E	Dimensionless	Spurious initial electron track direction modulation (Stokes q component in detector coordinates)
DETU_SM	6E	Dimensionless	Spurious initial electron track direction modulation (Stokes u component in detector coordinates)
DETQ_SM	6E	Dimensionless	Standard error of Q_SM
DETU_SM	6E	Dimensionless	Standard deviation of U_SM

8.12 Payload sub-system alignment CALDB file

8.12.1 Description

The payload sub-system alignment CALDB file contains both translations of the DUs and the MMAs from the spacecraft coordinate origin and alignment quaternions of the DU’s, MMA optical axes, and star trackers. All quaternions are in scalar-last format (x, y, z, w). These are used to transform the DU position of an x-ray event into spacecraft coordinates, project the event through the MMA onto the sky, and align that projection with J2000 celestial coordinates using the star tracker data. The alignment CALDB file will be created by the SOC from measurements taken during spacecraft integration by Ball Aerospace.

8.12.2 Format

The format of the alignment file is a standard CALDB fits file, with a primary header and a two extension for the binary tables that holds the system and optical alignment data. The table below lists the HDU sections. The following subsections describe the HDU’s and their subsections.

Table 8-43: FITS structure of sub-system alignment CALDB file

Section/Header	Name	Description
Primary	-	FITS-required primary header
Extension 1	SYSTEM_ALIGNMENT	System alignment binary table data

8.12.2.1 Primary HDU

The following table lists keywords used in the primary header. Keywords for this primary header include those defined in Sections 4.5.1 and 4.5.5 in addition to those defined in the following table. The data type codes used in the "Type" column are defined in Appendix B.

Table 8-44: Alignment CALDB Primary Header keywords

Keyword Name	Type	Description	Value/Range
INSTRUME	A	Instrument of the telescope	GPD
DETNAM	A	Name of the Detector Unit of the instrument	• DU1, DU2, DU3, DU4 in flight • 018, 019, 020, etc. on ground
DET_ID	A	See Section 4.5.3	

8.12.2.2 SYSTEM_ALIGNMENT Extension: Header

The following table lists keywords used in the System Alignment Table header. This secondary header is a binary table header. Keywords defined in this section are those that are not involved with the definition of the binary table shape nor the names, types, and units of the table columns. All the header keywords from the Primary Header are repeated in the System Alignment Table Header and will not be repeated in the table below.

Table 8-45: SYSTEM_ALIGNMENT Extension Header keywords

Keyword Name	Type	Description	Value/Range/Example
EXTNAME	A	Name of the binary extension	'SYSTEM_ALIGNMENT'
FILENAME	A	Name of CALDB file	'ixpe_a0_200523_align_01.fits', e.g.
CONTENT	A	Description of the contents of this HDU	'IXPE Alignment'
CCLS0001	A	Type of dataset: Basic Calibration File (BCF) or Calibration Product File (CPF)	'BCF'
CDTP0001	A	Calibration data type	'DATA'
CCNM0001	A	Type of calibration data	'ALIGNMENT'
CBD10001	A	Parameter boundary for type of data	'TYPE(SYSTEMS)'
CVSD0001	A	Date when this file should first be used. (TT)	'2021-01-03', e.g.
CVST0001	A	Time of day when this file should first be used (TT, goes with date above)	'00:00:00', e.g.
CDES0001	A	Description of the contents of this file	'IXPE Alignment of sub-coordinate systems'

8.12.2.3 SYSTEM_ALIGNMENT Extension: Table Columns

The table itself is a list of the offsets and orientations of each payload sub-system relative to the space craft, focal plane, or optical bench. This results in 28 columns with a single row. The table below describes the columns. The data type codes used in the "Type" column are defined in Appendix B.

Table 8-46: SYSTEM_ALIGNMENT Extension Table Columns

Name	Type	Units	Description
V_IN_SC	3D	mm	Vector of SC origin in inertial coordinates
Q_IN_SC	4D	Dimensionless	Quaternion to transform SC to inertial coordinates
V_SC_FP	3D	mm	Vector of focal plane origin in spacecraft coordinates
Q_SC_FP	4D	Dimensionless	Quaternion to transform focal plane to spacecraft coordinates

V_FP_DU1	3D	mm	Vector of DU1 origin in focal plane coordinates
Q_FP_DU1	4D	Dimensionless	Quaternion to transform DU1 to focal plane coordinates
Q_FP_TEL1	4D	Dimensionless	Quaternion to correct for telescope 1 (DU1, MMA1) pointing axis
V_FP_DU2	3D	mm	Vector of DU2 origin in focal plane coordinates
Q_FP_DU2	4D	Dimensionless	Quaternion to transform DU2 to focal plane coordinates
Q_FP_TEL2	4D	Dimensionless	Quaternion to correct for telescope 2 (DU2, MMA2) pointing axis
V_FP_DU3	3D	mm	Vector of DU3 origin in focal plane coordinates
Q_FP_DU3	4D	Dimensionless	Quaternion to transform DU3 to focal plane coordinates
Q_FP_TEL3	4D	Dimensionless	Quaternion to correct for telescope 3 (DU3, MMA3) pointing axis
V_FP_AS1	3D	mm	Vector of aperture stop 1 origin in focal plane coordinates
Q_FP_AS1	4D	Dimensionless	Quaternion to transform AS1 to focal plane coordinates
V_FP_AS2	3D	mm	Vector of aperture stop 2 origin in focal plane coordinates
Q_FP_AS2	4D	Dimensionless	Quaternion to transform AS2 to focal plane coordinates
V_FP_AS3	3D	mm	Vector of aperture stop 3 origin in focal plane coordinates
Q_FP_AS3	4D	Dimensionless	Quaternion to transform AS3 to focal plane coordinates
V_FP_OA	3D	mm	Vector of optical assembly origin in focal plane coordinates
Q_FP_OA	4D	Dimensionless	Quaternion to transform optical assembly to focal plane coordinates (TTR transform)
V_OA_MMA1	3D	mm	Vector position of MMA1 in optical assembly coordinates
V_OA_MMAX1	3D	Dimensionless	Pointing vector of MMA1 optical axis in optical assembly coordinates
V_OA_MMA2	3D	mm	Vector position of MMA2 in optical assembly coordinates
V_OA_MMAX2	3D	Dimensionless	Pointing vector of MMA2 optical axis in optical assembly coordinates
V_OA_MMA3	3D	mm	Vector position of MMA3 in optical assembly coordinates
V_OA_MMAX3	3D	Dimensionless	Pointing vector of MMA3 optical axis in optical assembly coordinates
V_SC_OH1	3D	mm	Vector of origin of Star Tracker optical head 1 in spacecraft coordinates
Q_SC_OH1	4D	Dimensionless	Quaternion to transform Star Tracker optical head 1 to spacecraft coordinates
V_SC_OH2	3D	mm	Vector of origin of Start Tracker optical head 2 in spacecraft coordinates
Q_SC_OH2	4D	Dimensionless	Quaternion to transform Start Tracker optical head 2 to spacecraft coordinates

8.13 Mirror Module Unit (MMA) Encircled energy function CALDB

8.13.1 Description

The encircled energy function CALDB file describes the position resolution of a MMA with a table of annulus radii and the fraction of the total counts from a point source contained within that annulus. It is used as to calculate an ancillary response function.

8.13.2 Format

The format of the DU encircled energy function is a standard CALDB FITS file, with a primary header and a single extension for the binary table that holds the encircled energy data. The table below lists the HDU sections. The following subsections describe the HDU's and their subsections.

Table 8-47: FITS structure of MMA encircled energy CALDB file

Section/Header	Name	Description
Primary	-	FITS-required primary header

Extension 1	REEF	Radial encircled energy function table data

8.13.2.1 Primary HDU

The following table lists keywords used in the primary header. Keywords for this primary header include those defined in Sections 4.5.1 and 4.5.5 in addition to those defined in the following table. The data type codes used in the "Type" column are defined in Appendix B.

Table 8-48: MMA encircled energy CALDB Primary Header keywords

Keyword Name	Type	Description	Value/Range
INSTRUME	A	Instrument of the telescope	XRT
DETNAM	A	Name of the Detector Unit of the instrument	MMA1, MMA2, MMA3, MMA4

8.13.2.2 REEF Extension: Header

The following table lists keywords used in the Encircled Energy Table (REEF) binary table header. Keywords defined in this section are those that are not involved with the definition of the binary table shape nor the names, types, and units of the table columns. All the header keywords from the Primary Header are repeated in the Encircled Energy Table Header and will not be repeated in the table below.

Table 8-49: REEF Extension Header keywords

Keyword Name	Type	Description	Value/Range/Example
EXTNAME	A	Name of the binary extension	'REEF'
1CTYP7	A	First axis label	'SPATIAL_OFFSET'
2CTYP7	A	Second axis label	'COORD-1'
3CTYP7	A	Third axis label	'COORD-2'
4CTYP7	A	Fourth axis label	'ENERGY'
CREF7	A	Column referencing	'(RAD_LO:RAD_HI,THETA,PHI,ENERG_LO:ENERG_HI)'
CSYSNAME	A	Spatial coordinate system in use	'XNA_POL', e.g.
HDUCLASS	A	Class of HDU	'OGIP'
HDUCLAS1	A	Sub-classification of OGIP class	'RESPONSE'
HDUCLAS2	A	Sub-classification of RESPONSE class	'REEF'
HDUCLAS3	A	Sub-classification of REEF class	'NET'
HDUVERS	A	Version of format	'1.0.0', e.g.
HDUDOC	A	OGIP memo for File Format definition	'CAL/GEN/92-020'
AREA_WGT	E	Area weighting factor	'1.00000', e.g.
ENERG_LO	E	Lower energy bound	'1.50000', e.g.
ENERGY_HI	E	Upper energy bound	'8.00000', e.g.
PHI	E	Value of azimuthal angle	'0.0', e.g.
EXTVER	J	Extension number of this HDU	1
VERSION	J	Extension version number	1
FILENAME	A	Name of CALDB file	'ixpe_d1_200523000000_eef_01.fits', e.g.
CCLS0001	A	Type of dataset: Basic Calibration File (BCF) or Calibration Product File (CPF)	'BCF'

CDTP0001	A	Calibration data type	'DATA'
CCNM0001	A	Type of calibration data	'REEF'
CBD10001	A	Energy parameter boundary	'ENERGY(2.2-7.0)keV', e.g.
CBD20001	A	Off-axis angle boundary	'THETA(-8-8)arcmin', e.g.
CBD30001	A	Azimuthal angle boundary	'PHI(0-135)deg', e.g.
CVSD0001	A	Date when this file should first be used. (TT)	'2021-01-03', e.g.
CVST0001	A	Time of day when this file should first be used (TT, goes with date above)	'00:00:00', e.g.
CDES0001	A	Description of the contents of this file	'Radial Enclosed Energy Fraction Profiles Based on SLTF Tests'

8.13.2.3 REEF Extension: Table Columns

The table itself is an array of angular bin lower limits, an array of angular bin upper limits, an array of off-axis angles for the source, a value of azimuthal angle, and an array of radial encircled energies for each combination of radial bin and off-axis angle. The data occupy 7 columns by 4 rows, but the columns are array columns and not single-value columns as described in the table below. The data type codes used in the "Type" column are defined in Appendix B. Note that radial bin columns have 1440 values equal to the number of bins, the energy column has 3 values (equal to the number of energy bins), and the encircled energy array has 1440 × 17 values.

Table 8-50: REEF Extension Table Columns

Name	Type	Units	Description
RAD_LO	1440E	arcsec	Radial bin inner radius
RAD_HI	1440E	arcsec	Radial bin outer radius
THETA	51E	arcmin	Theta setting
PHI	K	deg	Phi
ENERGY_LO	3E	keV	Lower bound of Energy band of x-ray source for each measurement
ENERGY_HI	3E	keV	Upper bound of Energy band of x-ray source for each measurement
REEF	24480E	Dimensionless	Radial encircled energy function

8.14 Detector Unit (DU) Quantum efficiency CALDB

8.14.1 Description

The DU quantum efficiency or collection efficiency CALDB files describe the fraction of incoming photons expected to be absorbed in the detector as a function of the energy of the incoming photons. It can used to calculate an ancillary response function (ARF)

8.14.2 Format

The format of the DU quantum efficiency files is function is a standard CALDB FITS file, with a primary header and a single extension for the binary table that holds the quantum efficiency data. The table below lists the HDU sections. The following subsections describe the HDU's and their subsections.

Table 8-51: FITS structure of DU quantum efficiency CALDB file

Section/Header	Name	Description

Primary	-	FITS-required primary header
Extension 1	QE	Quantum efficiency table data

8.14.2.1 Primary HDU

The following table lists keywords used in the primary header. Keywords for this primary header include those defined in Sections 4.5.1 and 4.5.5 in addition to those defined in the following table. The data type codes used in the "Type" column are defined in Appendix B.

Table 8-52: DU Quantum Efficiency CALDB Primary Header keywords

Keyword Name	Type	Description	Value/Range
INSTRUME	A	Instrument of the telescope	GPD
DETNAM	A	Name of the Detector Unit of the instrument	• DU1, DU2, DU3, DU4 in flight • 018, 019, 020, etc. on ground
DET_ID	A	See Section 4.5.3	

8.14.2.2 QE Extension: Header

The following table lists keywords used in the Quantum Efficiency Table header. This secondary header is a binary table header. Keywords defined in this section are those that are not involved with the definition of the binary table shape nor the names, types, and units of the table columns. All the header keywords from the Primary Header are repeated in the Quantum Efficiency Table Header and will not be repeated in the table below.

Table 8-53: QE Extension Table Header keywords

Keyword Name	Type	Description	Value/Range/Example
EXTNAME	A	Name of the binary extension	'QE'
HDUCLASS	A	Class of HDU	'ASC'
HDUCLAS1	A	Sub-classification of ASC class	'DETCHAR'
HDUCLAS2	A	Sub-classification of RESPONSE class	'QE'
HDUCLAS3	A	Sub-classification of QE class	'MEAN'
HDUVERS	A	Version of format	'1.0.0', e.g.
HDUDOC	A	OGIP memo for File Format definition	'ASC-FITS-2.0', e.g.
FILENAME	A	Name of CALDB file	'ixpe_d1_200523000000_qe_01.fits', e.g.
CCLS0001	A	Type of dataset: Basic Calibration File (BCF) or Calibration Product File (CPF)	'BCF'
CDTP0001	A	Calibration data type	'DATA'
CCNM0001	A	Type of calibration data	'QE'
CVSD0001	A	Date when this file should first be used (TT)	'2021-01-03', e.g.
CVST0001	A	Time of day when this file should first be used (TT, goes with date above)	'00:00:00', e.g.
CDES0001	A	Description of the contents of this file	'IXPE DU1 mean quantum efficiency', e.g.

8.14.2.3 QE Extension: Table Columns

The table itself is an array of detector radius bin lower limits, an array of detector radius bin upper limits, an array of off-axis angles, a value of azimuthal angle, and an array of radial encircled energies for each combination of radial bin and off-axis angle. The data occupy 3 columns by 3 rows, where the number of rows is the number of energies at which the quantum efficiency is measured.

Table 8-54: QE Extension Table Columns

Name	Type	Units	Description
ENERGY	E	keV	Energy
QE	E	Dimensionless	Quantum efficiency at this energy
SYS_MIN	E	Dimensionless	Systematic minimum (negative) error

8.15 MMA Effective Area CALDB

8.15.1 Description

The MMA effective area CALDB file gives the effective area of a mirror assembly as a function of photon energy, off-axis angle, and azimuthal angle of incidence. It can be used to calculate an ancillary response function (ARF).

8.15.2 Format

The format of the MMA effective-area function is a standard CALDB FITS file, with a primary header and a single extension for the binary table that holds the effective-area data. The table below lists the HDU sections. The following subsections describe the HDUs and their subsections.

Table 8-55: FITS structure of MMA effective area CALDB file

Section/Header	Name	Description
Primary	-	FITS-required primary header
Extension 1	AXEFFA	Effective area function table data

8.15.2.1 Primary HDU

The following table lists keywords used in the primary header. Keywords for this primary header include those defined in Sections 4.5.1 and 4.5.5 in addition to those defined in the following table. The data type codes used in the “Type” column are defined in Appendix B.

Table 8-56: MMA Effective Area CALDB Primary Header keywords

Keyword Name	Type	Description	Value/Range
INSTRUME	A	Instrument of the telescope	XRT
DETNAM	A	Specific MMA designation	MMA1, MMA2, MMA3 or MMA4
DET_ID	A	See Section 4.5.3	

8.15.2.2 AXEFFA Extension: Header

The following table lists keywords used in the MMA Effective Area Table header. This secondary header is a binary table header. Keywords defined in this section are those that are not involved with the definition of the binary table shape nor the names, types, and units of the table columns. All the header keywords from the Primary Header are repeated in the MMA Effective Area Table Header and will not be repeated in the table below.

Table 8-57: AXEFFA Extension Header keywords

Keyword Name	Type	Description	Value/Range/Example
EXTNAME	A	Name of the binary extension	‘AXEFFA’

HDUCLASS	A	Class of HDU	'OGIP'
HDUCLAS1	A	Sub-classification of OGIP class	'RESPONSE'
HDUCLAS2	A	Sub-classification of RESPONSE class	'AXEFFA'
HDUVERS1	A	Version of family of format	'1.0.0', e.g.
HDUVERS2	A	Version of format (OGIP memo CAL/GEN/92-021))	'1.1.0'
FILENAME	A	Name of CALDB file	'ixpe_m1_200523_eaf_01.fits', e.g.
CCLS0001	A	Type of dataset: Basic Calibration File (BCF) or Calibration Product File (CPF)	'BCF'
CDTP0001	A	Calibration data type	'DATA'
CCNM0001	A	Type of calibration data	'AXEFFA'
CVSD0001	A	Date when this file should first be used. (TT)	'2021-01-03', e.g.
CVST0001	A	Time of day when this file should first be used (TT, goes with date above)	'00:00:00', e.g.
CDES0001	A	Description of the contents of this file	'IXPE MMA1 AXIAL EFFECTIVE AREA', e.g.

8.15.2.3 AXEFFA Extension: Table Columns

The table itself is an array of energy-bin lower limits, an array of energy-bin upper limits, an array of angles, and an array of effective area for each combination of energy bin and angle. The data occupy 4 columns by 1 row, but the columns are array columns and not single-value columns as described in the table below. The data type codes used in the "Type" column are defined in Appendix B. Note that each column has 375 sub-columns equal to the number of energy bins measured.

Table 8-58: AXEFFA Extension Table Columns

Name	Type	Units	Description
ENERG_LO	375E	keV	Energy-bin lower bound
ENERG_HI	375E	keV	Energy-bin upper bound
AXEFFA	375E	cm**2	On-axis effective area of mirror plus thermal shield
MAXEFFA	375E	cm**2	On-axis effective area of MMA
TSXTRANS	375E	Dimensionless	On-axis relative transmission of thermal shield

8.16 MMA 2-D Point Spread Function CALDB file

8.16.1 Description

The MMA point spread function defines the effects of the MMA on the position of an event. Specifically, it gives the probability of an event falling within a given position relative to the theoretical position of focus for the MMA. This is a function of both energy and offset angle.

8.16.2 Format

The format of the MMA 2-D point spread function is a standard CALDB FITS file, with a primary header and 195 2-D point spread function images, one for each unique setting of energy, THETA angle (magnitude of offset from the optical axis) and PHI angle (azimuthal direction of THETA offset). The data were taken with three values of ENERG: 6.40 keV, 4.51 k3V, and 2.29 keV. There are 4 values of THETA: 0, 45, 90, and 135 degrees. Finally, there are 16 values of PHI: -8, -7, -6, -5, -4, -3, -2, -1, 1, 2, 3, 4, 5, 6, 7, and 8 (arc minutes). Note that this give 3 * 4 * 16 = 192 images. There are three additional images: 1 for each energy at a PHI of 0 and a THETA of 0 (since all values of THETA are degenerate for PHI = 0). The table below lists the HDU sections. The following subsections describe the HDU's and their subsections.

Table 8-59: FITS structure of MMA 2-D point spread function CALDB file

Section/Header	Name	Description
Primary	-	FITS-required primary header
Extension 1-195	Unique to Energy, PHI and THETA used.	Radial point spread function images

8.16.2.1 Primary HDU

The following table lists keywords used in the primary header. Keywords for this primary header include those defined in Sections 4.5.1 and 4.5.5 in addition to those defined in the following table. The data type codes used in the "Type" column are defined in Appendix B.

Table 8-60: MMA 2-D point spread CALDB Primary Header keywords

Keyword Name	Type	Description	Value/Range
INSTRUME	A	Instrument of the telescope	MMA
DETNAM	A	Specific MMA designation	MMA1, MMA2, MMA3 or MMA4.
DET_ID	A	See Section 4.5.3	

8.16.2.2 IMAGE Extensions: Header

The following table lists keywords used in the MMA Radial point spread function Table header. This secondary header is a binary table header. Keywords defined in this section are those that are not involved with the definition of the binary table shape nor the names, types, and units of the table columns. All the header keywords from the Primary Header are repeated in the MMA Radial point spread function Table Header and will not be repeated in the table below.

Table 8-61: MMA Radial point spread function Table Header keywords

Keyword Name	Type	Description	Value/Range/Example
EXTNAME	A	Name of the binary extension	'PSF_640_-4_045', e.g.
FILENAME	A	Name of CALDB file	'ixpe_m1_200523_psfimage_01.fits', e.g.
CCLS0001	A	Type of dataset: Basic Calibration File (BCF) or Calibration Product File (CPF)	'BCF'
CDTP0001	A	Calibration data type	'DATA'
CCNM0001	A	Type of calibration data	'2D_PSF'
CVSD0001	A	Date when this file should first be used (TT)	'2021-01-03', e.g.
CVST0001	A	Time of day when this file should first be used (TT, goes with date above)	'00:00:00', e.g.
CDES0001	A	Description of the contents of this file	'IXPE MMA1 point spread function image'
CBD10001	A	Description of THETA angle	"THETA(-4)arcmin", e.g.
CBD20001	A	Description of PHI angle	"PHI(45)deg", e.g.
CBD30001	A	Description of energy	"ENERG(6.40)keV", e.g.
HDUCLAS1	A	HDU classification (1)	"IMAGE"

HDUCLAS2	A	HDU classification (2)	"PSF"
HDUCLAS3	A	HDU classification (3)	"OBSERVED"
HDUCLAS4	A	HDU classification (4)	"NET"

8.17 MMA Vignetting CALDB file

8.17.1 Description

The Mirror Module Assembly (MMA) vignetting files defines the vignetting effects of the MMA on counting rates as a function of energy and off-axis position. Specifically, it gives the effect on counting rate as a fraction of the counting rate expected on axis.

8.17.2 Format

The format of the MMA vignetting function is a standard CALDB FITS file, with a primary header and a single extension for the binary table that holds the vignetting data. The table below lists the HDU sections. The following subsections describe the HDU's and their subsections.

Table 8-62: FITS structure of MMA vignetting CALDB file

Section/Header	Name	Description
Primary	-	FITS-required primary header
Extension 1	VIGNET	Vignetting function table data

8.17.2.1 Primary HDU

The following table lists keywords used in the primary header. Keywords for this primary header include those defined in Sections 4.5.1 and 4.5.5 in addition to those defined in the following table. The data type codes used in the "Type" column are defined in Appendix B.

Table 8-63: MMA vignetting CALDB Primary Header keywords

Keyword Name	Type	Description	Value/Range
INSTRUME	A	Instrument of the telescope	MMA
DETNAM	A	Specific MMA designation:	MMA1, MMA2, MMA3 or MMA4
DET_ID	A	See Section 4.5.3	

8.17.2.2 VIGNET Extension: Header

The following table lists keywords used in the MMA Vignetting Table header. This secondary header is a binary table header. Keywords defined in this section are those that are not involved with the definition of the binary table shape nor the names, types, and units of the table columns. All the header keywords from the Primary Header are repeated in the MMA Vignetting Table Header and will not be repeated in the table below.

Table 8-64: VIGNET Extension Header keywords

Keyword Name	Type	Description	Value/Range/Example
EXTNAME	A	Name of the binary extension	'VIGNET'
HDUCLASS	A	Class of HDU	'OGIP'
HDUCLAS1	A	Sub-classification of OGIP class	'RESPONSE'
HDUCLAS2	A	Sub-classification of RESPONSE class	'VIGNET'
HDUVERS1	A	Version of family of format	'1.0.0', e.g.

HDUVERS2	A	Version of format (OGIP memo CAL/GEN/92-021)	‘1.1.0’
1CTYP3	A	OGIP label of first axis	‘Energy’
2CTYP3	A	OGIP label of second axis	‘THETA’
CREF3	A	Column referencing	‘(ENERG_LO:ENERG_HI, THETA)’
FILENAME	A	Name of CALDB file	‘ixpe_m1_200523000000_vign_01.fits’, e.g.
CCLS0001	A	Type of dataset: Basic Calibration File (BCF) or Calibration Product File (CPF)	‘BCF’
CDTP0001	A	Calibration data type	‘DATA’
CCNM0001	A	Type of calibration data	‘TVIGNET’
CVSD0001	A	Date when this file should first be used (TT)	‘2021-01-03’, e.g.
CVST0001	A	Time of day when this file should first be used (TT, goes with date above)	‘00:00:00’, e.g.
CDES0001	A	Description of the contents of this file	‘IXPE MMA1 Vignetting’

8.17.2.3 VIGNET Extension: Tab;e Columns

The table itself is an array of energy-bin lower limits, an array of energy-bin upper limits, an array of angles, and an array of vignetting for each combination of energy bin and angle. The data occupy 4 columns by 1 row, but the columns are array columns and not single-value columns as described in the table below. The data type codes used in the “Type” column are defined in Appendix B. Note that the energy columns have 3 values equal to the number of energy bins, the angle column has 17 values equal to the number of angle bins, and the vignetting functions has $3 \times 17 = 51$.

Table 8-65: VIGNET Extension Table Columns

Name	Type	Units	Description
ENERG_LO	3E	keV	Energy-bin lower bound
ENERG_HI	3E	keV	Energy-bin upper bound
THETA	17E	arc min	Angle bins
VIGNET	51E	Dimensionless	Vignetting function

8.18 MMA Thermal Shield Transmission CALDB

8.18.1 Description

The MMA thermal shield transmission CALDB defines the transmission of the thermal shield material surrounding the MMA’s. The material is not the same thickness for all the MMAs, so the transmission is given for two different thicknesses (1.35 and 1.60 microns).

8.18.2 Format

The format of the DU window/filter transmission files is a standard CALDB FITS file, with a primary header and a single extension for the binary table that holds the window/filter transmission data. The table below lists the HDU sections. The following subsections describe the HDU’s and their subsections.

Table 8-66: FITS structure of MMA Thermal Shield Transmission CALDB file

Section/Header	Name	Description

Primary	-	FITS-required primary header
Extension 1	TS_TRANS	Transmission table data for the MMA thermal shields

8.18.2.1 Primary HDU

The following table lists keywords used in the primary header. Keywords for this primary header include those defined in Sections 4.5.1 and 4.5.5 in addition to those defined in the following table. The data type codes used in the "Type" column are defined in Appendix B.

Table 8-67: DU Window/filter transmission CALDB Primary Header keywords

Keyword Name	Type	Description	Value/Range
INSTRUME	A	Instrument of the telescope	MMA
DETNAM	A	Name of the MMA	MMA0

8.18.2.2 TS_TRANS Extension: Header

The following table lists keywords used in the MMA Thermal Shield Transmission Table header. This secondary header is a binary table header. Keywords defined in this section are those that are not involved with the definition of the binary table shape nor the names, types, and units of the table columns. All the header keywords from the Primary Header are repeated in the Window/filter transmission Table Header and will not be repeated in the table below.

Table 8-68: TS_TRANS Extension Header keywords

Keyword Name	Type	Description	Value/Range/Example
EXTNAME	A	Name of the binary extension	'TS_TRANS'
FILENAME	A	Name of CALDB file	'ixpe_m0_20210103_tstrans_01.fits', e.g.
CCLS0001	A	Type of dataset: Basic Calibration File (BCF) or Calibration Product File (CPF)	'BCF'
CDTP0001	A	Calibration data type	'DATA'
CCNM0001	A	Type of calibration data	'FTRANS'
CVSD0001	A	Date when this file should first be used. (TT)	'2021-01-03', e.g.
CVST0001	A	Time of day when this file should first be used (TT, goes with date above)	'00:00:00', e.g.
CDES0001	A	Description of the contents of this file	'Thermal shield transmission at 1.35 and 1.60 μm thickness', e.g.

8.18.2.3 TS_TRANS Extension: Table Columns

The table itself is an array of energies at which the transmission is measured, and the relative transmission of the given thickness of the thermal shield material at that energy. The data occupy 3 columns by 112 rows, where the number of rows is the number of energies at which the transmission is measured.

Table 8-69: TS_TRANS Extension Table Columns

Name	Type	Units	Description
ENERGY	1D	keV	Energy
TRANS135	1D	Dimensionless	Transmission of 1.35 μm of material.
TRANS160	1D	Dimensionless	Transmission of 1.60 μm of material.

8.19 Telescope Ancillary Response CALDB file

8.19.1 Description

The telescope ancillary response contains combined effects MMA effective area, MMA vignetting, DU collimator vignetting, DU filter and/or DU window transmission, and DU quantum efficiency as a function of energy averaged over time. This gives a calibrated value of the response of the telescope to x-rays of various energies and is used to determine the effective area of the entire optical train.

8.19.2 Format

The format of the Telescope ancillary response function is a standard CALDB FITS file, with a primary header and a single extension for the binary table that holds the ancillary response data. The table below lists the HDU sections. The following subsections describe the HDU's and their subsections.

Table 8-70: FITS structure of Telescope ancillary response CALDB file

Section/Header	Name	Description
Primary	-	FITS-required primary header
Extension 1	SPECRESP	Ancillary response function table data

8.19.2.1 Primary HDU

The following table lists keywords used in the primary header. Keywords for this primary header include those defined in Sections 4.5.1 and 4.5.5 in addition to those defined in the following table. The data type codes used in the "Type" column are defined in Appendix B.

Table 8-71: Telescope ancillary response CALDB Primary Header keywords

Keyword Name	Type	Description	Value/Range
INSTRUME	A	Instrument of the telescope	MMA
DETNAM	A	Specific MMA designation:	MMA1, MMA2, MMA3 or MMA4
DET_ID	A	See Section 4.5.3	

8.19.2.2 SPECRESP Extension: Header

The following table lists keywords used in the Telescope ancillary response Table header. This secondary header is a binary table header. Keywords defined in this section are those that are not involved with the definition of the binary table shape nor the names, types, and units of the table columns. All the header keywords from the Primary Header are repeated in the Telescope ancillary response Table Header and will not be repeated in the table below.

Table 8-72: SPECRESP Extension Header keywords

Keyword Name	Type	Description	Value/Range/Example
EXTNAME	A	Name of the binary extension	'SPECRESP'
HDUCLASS	A	Class of HDU	'OGIP'
HDUCLAS1	A	Sub-classification of OGIP class	'RESPONSE'
HDUCLAS2	A	Sub-classification of RESPONSE class	'SPECRESP'
HDUVERS1	A	Version of family of format	'1.0.0', e.g.
HDUVERS2	A	Version of format (OGIP memo CAL/GEN/92-021)	'1.1.0'
IRFTYPE	A	Type of file	'arf'

FILENAME	A	Name of CALDB file	‘ixpe_m1_200523_arf_01.fits’, e.g.
CCLS0001	A	Type of dataset: Basic Calibration File (BCF) or Calibration Product File (CPF)	‘CPF’
CDTP0001	A	Calibration data type	‘DATA’
CCNM0001	A	Type of calibration data	‘SPECRESP’
CVSD0001	A	Date when this file should first be used. (TT)	‘2021-01-03’, e.g.
CVST0001	A	Time of day when this file should first be used (TT, goes with date above)	‘00:00:00’, e.g.
CDES0001	A	Description of the contents of this file	‘IXPE DU1 Ancillary Response File”
CBD10001	A	Description of parameter bounds	‘WEIGHT(NONE)” or “WEIGHT(ALPHA075)”

8.19.2.3 SPECRESP Extension: Table Columns

The table itself is an array of energy-bin lower limits, an array of energy-bin upper limits, and an array of ancillary response function for each energy bin. The data occupy 3 columns by 275 rows. The data type codes used in the “Type” column are defined in Appendix B. Note that each column has n values equal to the number of energy bins measured.

Table 8-73: SPECRESP Extension Table Columns

Name	Type	Units	Description
ENERG_LO	E	keV	Energy-bin lower bound
ENERG_HI	E	keV	Energy-bin upper bound
SPECRESP	E	cm**2	On-axis ancillary response function

8.20 DU Modulation Factor CALDB

8.20.1 Description

The DU modulation factor CALDB is used to calculate the polarization modulation factor as a function of input energy.

8.20.2 Format

The format of the DU modulation factor files is a standard CALDB FITS file, with a primary header, an extension for the binary table that holds the energy bounds and the corresponding modulation factor response for each energy bound. The table below lists the HDU sections. The following subsections describe the HDU’s and their subsections.

Table 8-74: FITS structure of Modulation Factor CALDB file

Section/Header	Name	Description
Primary	-	FITS-required primary header
Extension 1	SPECRESP	Modulation factor as a function of input energy.

8.20.2.1 Primary HDU

The following table lists keywords used in the primary header. Keywords for this primary header include those defined in Sections 4.5.1 and 4.5.5 in addition to those defined in the following table. The data type codes used in the “Type” column are defined in Appendix B.

Table 8-75: Modulation Factor CALDB Primary Header keywords

Keyword Name	Type	Description	Value/Range
INSTRUME	A	Instrument name	GPD
DETECTOR	A	Name of the Detector Unit of the instrument	DU1, DU2, DU3, DU4 in flight 018, 019, 020, etc. on ground

8.20.2.2 SPECRESP Extension: Header

The following table lists keywords used in the Modulation Factor Table header. This secondary header is a binary table header. Keywords defined in this section are those that are not involved with the definition of the binary table shape nor the names, types, and units of the table columns. All the header keywords from the Primary Header are repeated in the Modulation Factor Table Header and will not be repeated in the table below.

Table 8-76: SPECRESP Extension Header keywords

Keyword Name	Type	Description	Value/Range/Example
EXTNAME	A	Name of the binary extension	'SPECRESP'
HDUCLASS	A	Class of HDU	'OGIP'
HDUCLAS1	A	Sub-classification of OGIP class	'RESPONSE'
HDUCLAS2	A	Sub-classification of RESPONSE class	'SPECRESP"
HDUVERS1	A	Version of family of format	'1.0.0', e.g.
HDUVERS2	A	Version of format (OGIP memo CAL/GEN/92-021)	'1.3.0'
HDUDOC	A	OGIP document describing content	'OGIP memos CAL/GEN/92-002 & 92-002a'
IRFTYPE	A	Type of file	"modf"
FILENAME	A	Name of CALDB file	'ixpe_t1_200523_mfact_01.fits', e.g.
CCLS0001	A	Type of dataset: Basic Calibration File (BCF) or Calibration Product File (CPF)	'CPF'
CDTP0001	A	Calibration data type	'DATA'
CCNM0001	A	Type of calibration data	'MODFACT'
CVSD0001	A	Date when this file should first be used. (TT)	'2021-01-03', e.g.
CVST0001	A	Time of day when this file should first be used (TT, goes with date above)	'00:00:00', e.g.
CBD10001	A	Parameter boundaries of detector channels	'WEIGHT(NONE)' or 'WEIGHT(ALPHA075)"
CDES0001	A	Description of the contents of this file	'IXPE reference DU1 Modulation Factor', e.g.

8.20.2.3 SPECRESP Extension: Table Columns

The table itself is an array of energy-bin lower limits, an array of energy-bin upper limits, and an array of modulation factor response functions for each energy bin. The data occupy 3 columns by 275 rows. The data type codes used in the "Type" column are defined in Appendix B. Note that the MATRIX columns have n values equal to the number of detector energy bins.

Table 8-77: SPECRESP Extension Table Columns

Name	Type	Units	Description

ENERG_LO	E	keV	Low-energy limit for this band
ENERG_HI	E	keV	High-energy limit for this band
SPECRESP	E	N/A	Modulation factor response for this band

8.21 DU Modulation Response Function CALDB

8.21.1 Description

The DU modulation factor CALDB is used to calculate the effective area for polarization modulation as a function of input energy.

8.21.2 Format

The format of the DU modulation response files is a standard CALDB FITS file, with a primary header, an extension for the binary table that holds the energy bounds and the corresponding modulation response function for each energy bound. The table below lists the HDU sections. The following subsections describe the HDU's and their subsections.

Table 8-78: FITS structure of Modulation Response Function CALDB file

Section/Header	Name	Description
Primary	-	FITS-required primary header
Extension 1	SPECRESP	Modulation response function as a function of input energy

8.21.2.1 Primary HDU

The following table lists keywords used in the primary header. Keywords for this primary header include those defined in Sections 4.5.1 and 4.5.5 in addition to those defined in the following table. The data type codes used in the "Type" column are defined in Appendix B.

Table 8-79: Modulation Response Function CALDB Primary Header keywords

Keyword Name	Type	Description	Value/Range
INSTRUME	A	Instrument name	GPD
DETECTOR	A	Name of the Detector Unit of the instrument	DU1, DU2, DU3, DU4 in flight 018, 019, 020, etc. on ground

8.21.2.2 SPECRESP Extension: Header

The following table lists keywords used in the Modulation Response Function Table header. This secondary header is a binary table header. Keywords defined in this section are those that are not involved with the definition of the binary table shape nor the names, types, and units of the table columns. All the header keywords from the Primary Header are repeated in the Modulation Response Function Table Header and will not be repeated in the table below.

Table 8-80: SPECRESP Extension Header keywords

Keyword Name	Type	Description	Value/Range/Example
EXTNAME	A	Name of the binary extension	'SPECRESP'
HDUCLASS	A	Class of HDU	'OGIP'
HDUCLAS1	A	Sub-classification of OGIP class	'RESPONSE'
HDUCLAS2	A	Sub-classification of RESPONSE class	'SPECRESP"
HDUVERS1	A	Version of family of format	'1.0.0', e.g.
HDUVERS2	A	Version of format (OGIP memo CAL/GEN/92-021)	'1.3.0'

HDUDOC	A	OGIP document describing content	‘OGIP memos CAL/GEN/92-002 & 92-002a’
IRFTYPE	A	Type of file	“mrf”
FILENAME	A	Name of CALDB file	‘ixpe_t1_20200523_01.mrf’, e.g.
CCLS0001	A	Type of dataset: Basic Calibration File (BCF) or Calibration Product File (CPF)	‘CPF’
CDTP0001	A	Calibration data type	‘DATA’
CCNM0001	A	Type of calibration data	‘MODSPECRESP’
CVSD0001	A	Date when this file should first be used (TT)	‘2021-01-03’, e.g.
CVST0001	A	Time of day when this file should first be used (TT, goes with date above)	‘00:00:00’, e.g.
CBD10001	A	Parameter boundaries of detector channels	‘WEIGHT(NONE)’ or ‘WEIGHT(ALPHA075)”
CDES0001	A	Description of the contents of this file	‘IXPE reference DU1 Modulation Factor’, e.g.

8.21.2.3 SPECRESP Extension: Table Columns

The table itself is an array of energy-bin lower limits, an array of energy-bin upper limits, and an array of modulation response functions for each energy bin. The data occupy 3 columns by 275 rows. The data type codes used in the “Type” column are defined in Appendix B. Note that the MATRIX columns have n values equal to the number of detector energy bins.

Table 8-81: SPECRESP Extension Columns

Name	Type	Units	Description
ENERG_LO	E	keV	Low-energy limit for this band
ENERG_HI	E	keV	High-energy limit for this band
SPECRESP	E	cm**2	Modulation factor response for this band

8.22 Telescope Response Matrix CALDB

8.22.1 Description

The telescope response matrix file combines the detector gain and detector energy resolution CALDB data to define the response of the detector to photons of a given energy. It is used to give the most probable energy range for each measured pulse height amplitude, and to fold input spectra into detector response histograms.

8.22.2 Format

The format of the telescope response matrix files is a standard CALDB FITS file, with a primary header, an extension for the binary table that holds the energy bounds, and an extension for the binary table that holds the spectral response matrix data. The table below lists the HDU sections. The following subsections describe the HDU’s and their subsections.

Table 8-82: FITS structure of RMF CALDB file

Section/Header	Name	Description
Primary	-	FITS-required primary header
Extension 1	EBOUNDS	Energy bounds table data
Extension 2	MATRIX	Spectral response matrix table data

8.22.2.1 Primary HDU

The following table lists keywords used in the primary header. Keywords for this primary header include those defined in Sections 4.5.1 and 4.5.5 in addition to those defined in the following table. The data type codes used in the "Type" column are defined in Appendix B.

Table 8-83: RMF CALDB Primary Header keywords

Keyword Name	Type	Description	Value/Range
INSTRUME	A	Instrument name	GPD
DETECTOR	A	Name of the Detector Unit of the instrument	DU1, DU2, DU3, DU4 in flight 018, 019, 020, etc. on ground

8.22.2.2 EBOUNDS Extension: Header

The following table lists keywords used in the Energy Bounds Table header. This secondary header is a binary table header. Keywords defined in this section are those that are not involved with the definition of the binary table shape nor the names, types, and UNITS of the table columns. All the header keywords from the Primary Header are repeated in the Energy Bounds Table Header and will not be repeated in the table below.

Table 8-84: EBOUNDS Extension Header keywords

Keyword Name	Type	Description	Value/Range/Example
EXTNAME	A	Name of the binary extension	'EBOUNDS'
HDUCLASS	A	Class of HDU	'OGIP'
HDUCLAS1	A	Sub-classification of OGIP class	'RESPONSE'
HDUCLAS2	A	Sub-classification of RESPONSE class	'EBOUNDS
CHANTYPE	A	Channel type	"PI"
HDUVERS1	A	Version of family of format	'1.0.0', e.g.
HDUVERS2	A	Version of format (OGIP memo CAL/GEN/92-021)	'1.3.0'
HDUDOC	A	OGIP document describing content	'OGIP memos CAL/GEN/92-002 & 92-002a'
IRFTYPE	A	File type	"rmf"
FILENAME	A	Name of CALDB file	'ixpe_t1_200523_rmf_01.fits', e.g.
DETCHANS	J	Total number of detector channels.	375
TLMIN4	J	First channel number	0
TLMAX4	J	Last channel number	374
CCLS0001	A	Type of dataset: Basic Calibration File (BCF) or Calibration Product File (CPF)	'CPF'
CDTP0001	A	Calibration data type	'DATA'
CCNM0001	A	Type of calibration data	'EBOUNDS'
CVSD0001	A	Date when this file should first be used (TT)	'2021-01-03', e.g.
CVST0001	A	Time of day when this file should first be used (TT, goes with date above)	'00:00:00', e.g.
CBD10001	A	Parameter boundaries of detector channels	'WEIGHT(NONE)" or "WEIGHT(ALPH075)".

CDES0001	A	Description of the contents of this file	'IXPE TEL1 FPM EBOUNDS'

8.22.2.3 EBOUNDS Extension: Table Columns

The table itself is an array of detector channels, and an array of energy bounds for each detector channel. The data occupy 3 columns by n rows, where n is the number of energy bins in the detector. The data type codes used in the "Type" column are defined in Appendix B.

Table 8-85: EBOUNDS Extension Table Columns

Name	Type	Units	Description
CHANNEL	J	Chan	Detector channel number
E_MIN	E	keV	Energy minimum.
E_MAX	E	keV	Energy maximum

8.22.2.4 MATRIX Extension: Header

The following table lists keywords used in the Response Matrix Table header. This secondary header is a binary table header. Keywords defined in this section are those that are not involved with the definition of the binary table shape nor the names, types, and units of the table columns. All the header keywords from the Primary Header are repeated in the Response Matrix Table Header and will not be repeated in the table below.

Table 8-86: MATRIX Extension Header keywords

Keyword Name	Type	Description	Value/Range/Example
EXTNAME	A	Name of the binary extension	'SPECRESP MATRIX'
HDUCLASS	A	Class of HDU	'OGIP'
HDUCLAS1	A	Sub-classification of OGIP class	'RESPONSE'
HDUCLAS2	A	Sub-classification of RESPONSE class	'RSP_MATRIX"
CHANTYPE	A	Channel type	"PI"
HDUVERS1	A	Version of family of format	'1.0.0', e.g.
HDUVERS2	A	Version of format (OGIP memo CAL/GEN/92-021)	'1.3.0'
HDUDOC	A	OGIP document describing content	'OGIP memos CAL/GEN/92-002 & 92-002a'
IRFTYPE	A	Type of file	"rmf"
FILENAME	A	Name of CALDB file	'ixpe_t1_200523_rmf_01.fits', e.g.
DETCHANS	J	Total number of detector channels	375
TLMIN4	J	First channel number	0
TLMAX4	J	Last channel number	374
CCLS0001	A	Type of dataset: Basic Calibration File (BCF) or Calibration Product File (CPF)	'CPF'
CDTP0001	A	Calibration data type	'DATA'
CCNM0001	A	Type of calibration data	'MATRIX'
CVSD0001	A	Date when this file should first be used (TT)	'2021-01-03', e.g.
CVST0001	A	Time of day when this file should first be used (TT, goes with date above)	'00:00:00', e.g.

CBD10001	A	Parameter boundaries of detector channels	'WEIGHT(NONE)' or "WEIGHT(0750)"
CDES0001	A	Description of the contents of this file	'IXPE reference DU1 RESPONSE MATRIX', e.g.

8.22.2.5 MATRIX Extension: Table Columns

The table itself is an array of energy-bin lower limits, an array of energy-bin upper limits, an array of angles, and an array of response functions for each energy bin. The data occupy 6 columns by 275 rows, but the sixth column is an array of 375 columns and not single-value columns as described in the table below. Data type codes used in the "Type" column are defined in Appendix B. Note that the MATRIX columns have n values equal to the number of detector energy bins.

Table 8-87: MATRIX Extension Table Columns

Name	Type	Units	Description
ENERG_LO	E	keV	Low-energy limit for this band
ENERG_HI	E	keV	High-energy limit for this band
N_GRP	I	N/A	Number of groups
F_CHAN	I	N/A	First channel in matrix
N_CHAN	I	N/A	Number of channels in matrix
MATRIX	375E	N/A	Response matrix for this energy band

9 Level-1 Science Support File data format

9.1 Description

Level-1 Science Support File data is data derived from both engineering data (usually Level 1) and science event data (usually post-Level 1 data with some corrections applied). The data is used to process science event data from Level 1 to Level 2.

Level 1 Science Support File data is most closely related to CALDB files in both structure and use. Structurally, the files contain a primary header and one or more uniquely named extensions that indicate how the file will be used. Functionally, the files are limited to a single observation segment, and may contain timing information in the extension headers that indicate the time bounds for which the given extension is to be used.

9.2 File naming convention

The Level-1 science support data filenames are of the form

ixpe*PPnnnnpp*_*inst*_*dtype*_v*xx*.fits

The variable parts of the name are indicated by *italics*. The description, references, and range or list of valid values are given in the table below.

Table 9-1: Level-1 Engineering data naming variable description

Variable	Description	Range or Values
PPnnnnpp	The IXPE observation Sequence Number	
inst	ID of the instrument which produced the data	= det1-3 for data specific to a single DU

dtype	Data type designation	chgmap1 – Charge map data
		ppg1 – Periodic Peak Gain Map data
xx	Two-digit version number	01 - 99

9.3 Charge Map file

9.3.1 Description

The charge map file records the charging state of a given DU at the start of an observation segment. Thus, it is produced by processing the data from the previous observation segment. The file is used by ixpechrgcorr to correct the gain of the given DU due to charging of the GEM, and to calculate the charge map file for the next observation segment.

9.3.2 Format

The format of the charge map file is a standard FITS file, with a primary header and an extension for the binary table that holds the energy bounds, and an extension for the binary table that holds the charge map data. The table below lists the HDU sections. The following subsections describe the HDU's and their tables.

Table 9-2: FITS structure of Charge Map files

Section/Header	Name	Description
Primary	-	FITS-required primary header
Extension 1	CHRG_MAP	Charge map binary table extension

9.3.2.1 Primary HDU

The following table lists keywords used in the primary header. Keywords for this primary header include those defined in Sections 4.5.1 and 4.5.2 in addition to those defined in the following table. The data type codes used in the "Type" column are defined in Appendix B.

Table 9-3: Charge Map Primary Header keywords

Keyword Name	Type	Description	Value/Range
TLM2FITS	A	Version of software that converts the telemetry data to FITS data.	1.2, e.g.

9.3.2.2 CHRG_MAP Extension: Header

The CHRG_MAP extension does not define any special-purpose keywords.

9.3.2.3 CHRG_MAP Extension: Table Columns

The table itself is an array of detector X and Y bin ID's, and the SLOW and FAST initial charge amplitude for that bin. The data occupy 4 columns by 2500 rows. This means that the detector area is divided into a square array of 50x50 bins. Data type codes used in the "Type" column are defined in Appendix B.

Table 9-4: CHRG_MAP Extension Table Columns

Name	Type	Units	Description
BINX	I	None	Bin ID of the X axis bin (1 – 50).
BINY	I	None	Bin ID of the Y axis bin (1 – 50).
FAST	D	None	Initial amplitude for the FAST charging model.

SLOW	D	None	Initial amplitude for the SLOW charging model.

9.4 Periodic Peak Gain Map file

9.4.1 Description

The periodic peak gain map file exists to model the Pulse Invariant (PI) value as a function of corrected Pulse Height Amplitude across the detector and as a function of time. It consists of a series of maps of the offset and slope of this linear model over the active surface of a given DU at various points of time. Measurements of calibration sources at different energies taken before and during the observation provide the basis for the model. The file is used by ixpegaincorrpkmap to correct the PI output of the given DU, and to calculate the initial periodic peak gain map data for the next observation segment.

9.4.2 Format

The format of the periodic peak gain map file is a standard FITS file, with a primary header and multiple extensions for the binary tables that hold the peak gain maps and the peaks of each of the two calibration sources used to derive the peak gain maps. These last two tables are the last two calibration peak maps from the previous observation. The table below lists the HDU sections for a file with N periodic peak gain map binary tables. Note that N is variable and depends on the number of calibrations taken during an observation segment. The following subsections describe the HDU's and their tables.

Table 9-5: FITS structure of Periodic Peak Gain map files

Section/Header	Name	Description
Primary	-	FITS-required primary header
Extension 1 - N	GAIN	Periodic peak gain map binary table extensions
Extension N+1	CALC_PEAK	Cal C peak map
Extension N+2	CALD_PEAK	Cal D peak map

9.4.2.1 Primary HDU

The following table lists keywords used in the primary header. Keywords for this primary header include those defined in Sections 4.5.1 and 4.5.2 in addition to those defined in the following table. The data type codes used in the "Type" column are defined in Appendix B.

Table 9-6: Periodic Peak Gain map Primary Header keywords

Keyword Name	Type	Description	Value/Range
TLM2FITS	A	Version of software that converts the telemetry data to FITS data.	1.2, e.g.

9.4.2.2 GAIN Extension: Header

The GAIN extension defines the following unique keywords in the table below. The data type codes used in the "Type" column are defined in Appendix B.

Table 9-7: GAIN extension keywords

Keyword Name	Type	Description	Value/Range
TIME_CAL	D	Mean time of the calibration used to derive this periodic peak gain map (IXPE Time, seconds).	See section 4.2

9.4.2.3 GAIN Extension: Table Columns

The table itself is an array of detector X and Y bin ID's, and the SLOPE and OFFSET of the PHA-to-PI linear conversion for that bin. The data occupy 4 columns by 90000 rows. This means that the detector area is divided into a square array of 300x300 bins. Data type codes used in the "Type" column are defined in Appendix B.

Table 9-8: GAIN Extension Table Columns

Name	Type	Units	Description
BARX_PX	I	None	Barycenter X position in pixels (1-300)
BARY_PY	I	None	Barycenter Y position in pixels (1-300).
SLOPE	E	PI/PHA	Slope of the linear PHA-to-PI model.
OFFSET	E	PI	Offset of the linear PHA-to-PI model.

9.4.2.4 CALC_PEAK Extension: Header

The CALC_PEAK extension defines the following unique keywords in the table below. The type codes used in the "Type" column are defined in Appendix B.

Table 9-9: CALC_PEAK extension keywords

Keyword Name	Type	Description	Value/Range
TIME_CAL	D	Mean time of the calibration used to derive this peak map (IXPE Time, seconds).	See section 4.2

9.4.2.5 CALC_PEAK Extension: Table Columns

The table itself is an array of detector X and Y bin ID's, and the fitted peak PHA of the calibration source for that bin. The data occupy 3 columns by 90000 rows. This means that the detector area is divided into a square array of 300x300 bins. Data type codes used in the "Type" column are defined in Appendix B.

Table 9-10: CALC_PEAK Extension Table Columns

Name	Type	Units	Description
BARX_PX	I	None	Barycenter X position in pixels (1-300)
BARY_PY	I	None	Barycenter Y position in pixels (1-300).
PEAK	E	ADC	Fitted peak ADC value of the calibration source.

9.4.2.6 CALD_PEAK Extension: Header

The CALD_PEAK extension defines the following unique keywords in the table below. The type codes used in the "Type" column are defined in Appendix B.

Table 9-11: CALD_PEAK extension keywords

Keyword Name	Type	Description	Value/Range
TIME_CAL	D	Mean time of the calibration used to derive this peak map (IXPE Time, seconds).	See section 4.2

9.4.2.7 CALD_PEAK Extension: Table Columns

The table itself is an array of detector X and Y bin ID's, and the fitted peak PHA of the calibration source for that bin. The data occupy 3 columns by 90000 rows. This means that the detector area is divided into a square array of 300x300 bins. Data type codes used in the “Type” column are defined in Appendix B.

Table 9-12: CALD_PEAK Extension Table Columns

Name	Type	Units	Description
BARX_PX	I	None	Barycenter X position in pixels (1-300)
BARY_PY	I	None	Barycenter Y position in pixels (1-300).
PEAK	E	ADC	Fitted peak ADC value of the calibration source.

Appendix A: Acronyms and Definitions

A.1 Acronyms

ADC	Analog-to-Digital Converter
ADCS	Attitude Determination and Control Subsystem
APID	Application ID
ARF	Ancillary Response Function
ASI	Agenzia Spaziale Italiana (Italian Space Agency)
BCF	Basic Calibration File
CALDB	(HEASARC) Calibration DataBase
CCSDS	Consultative Committee for Space Data Systems
CDH	Command and Data Handling
CPF	Calibration Product File
DSU	(IXPE) Detectors Service Unit
DU	(IXPE) Detector Unit
ECEF	Earth-Centered, Earth-Fixed (coordinates)
ECMA	European Computer Manufacturers Association
ECI	Earth-Centered Inertial (coordinates)
FCW	(DU) Filter and Calibration Wheel
FITS	Flexible Image Transport System
FSW	Flight Software
GPD	Gas Pixel Detector
GPS	Global Positioning System
GTI	Good Time Interval
HDU	Header Data Unit (FITS file extension)
HEASARC	High-Energy Astrophysics Science Archive Research Center
INAF	Instituto Nazionale di Astrofisica
INFN	Instituto Nazionale di Fisica Nucleare
ISO	International Organization for Standards
ISOT	ISO 8601 Time standard
IXPE	Imaging X-ray Polarimetry Explorer
IXT	IXPE Time
LLA	Latitude, Longitude, and Altitude (coordinates)
MMA	IXPE Mirror Module Assembly
MOC	Mission Operations Center
MP	(SOC) Mission Planning

MSFC	Marshall Space Flight Center
OGIP	(HEASARC) Office of Guest Investigator Programs
PHA	Pulse Height Amplitude
RMF	Response Matrix File
ROI	Region of Interest (detector sub-image)
SAA	South Atlantic Anomaly
SC	Spacecraft
SMA	Software Mission Assurance
SOC	Science Operations Center
SP	(SOC) Science Processing
SSDC	(ASI) Space Science Data Center
TT	Terrestrial Time
TWG ???	(IXPE SAT) Topical Working Group
UTC	Universal Time Coordinated

Appendix B: Definition of FITS format codes

The table below defines the data type codes used in the description of the FITS file formats in the main sections of this document.

Table B-1: FITS keyword format codes

FITS format code	Description	# 8-bit bytes
L	logical (Boolean)	1
X	bit	*
B	Unsigned byte	1
I	16-bit integer	2
J	32-bit integer	4
K	64-bit integer	8
A	character	1
E	single precision floating point	4
D	double precision floating point	8
C	single precision complex	8
M	double precision complex	16
P	array descriptor	8
Q	array descriptor	16

(from https://docs.astropy.org/en/stable/io/fits/usage/table.html)