ART-XC – Science Data Dictionary

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Abstract

This document provides a description of the *Astronomical Röntgen Telescope - X-ray Concentrator* (ART-XC) data format, content, and filename conventions and the data directory structure.

Revision History

Revision	Author	Date	Change
v.01	D.Swartz/USRA	06/11/2021	Initial Draft
v.02	D.Swartz/USRA	07/14/2021	Added new data format

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1 Introduction

1.1 Purpose

This document provides details of the *Astronomical Röntgen Telescope - X-ray Concentrator* (ART-XC) science data format, data content and filename conventions and the data file directory structure. Its purpose is to provide the data end user information needed to locate and identify data of interest for their particular research goals. Cross references to relevant CALDB files are included for completeness.

1.2 Scope

This document is intended as a reference guide for ART-XC data end users. This document applies to the calibration and survey phases of the ART-XC mission which commenced c. August 2019 and is planned to continue through December 2023 with final public data delivery c. March 2025.

1.3 Change Authority/Responsibility

The NASA Office of Primary Responsibility for this document is the MSFC ART-XC team Principal Investigator.

1.4 Applicable Documents

All ART-XC data are in Flexible Image Transport System (FITS) format. The following documents are relevant:

FITS format:	https://heasarc.gsfc.nasa.gov/docs/heasarc/fits.html
Guidelines for FITS formats for Event Lists:	OGIP Memo OGIP/94-003

The full contents of the ART-XC calibration database (CALDB) are documented in:

ART-XC Software Guide:	MSFC-DOC-SWGUIDE.pdf

2 Overview

All ART-XC data use the Flexible Image Transport System (FITS) format. Data are stored in two types of files. Fundamentally, the primary data are binary table event lists with one row for each event recording the time of arrival, position on the detector, and a measure of the energy deposited. The other type of data file records the spacecraft orientation represented by time-ordered attitude quaternions; also in binary table extensions. Level 1 data files contain calibrated, but unfiltered, science data. Level 2 data files contain cleaned (filtered) science data with the aspect solution applied so that Level 2 event lists also contain the celestial coordinates of each event.

In 2021 May, the content and filename conventions of ART-XC data provided by the Science Data and Operations Center at the Russian Space Research Institute (IKI) to the MSFC ART-XC (MART) team was modified. This document describes both Level 1 and Level 2 event lists and attitude files for both the new and original formats. The data end user will be primarily interested in the Level 2 files for scientific inquiry. Efforts have been made by the MART team to minimize the differences between old and new Level 2 file names and content.

ART-XC operates in two fundamental observing modes: Survey Mode and Pointed/Scan Mode. Data file content for these two modes are identical but the file naming conventions and data directory structures differ significantly.

Typographic conventions for this document are:

- *ITALIC CAPITALS* denote wildcards in file names.

- **boldface** denotes
- `typewriter font` denotes software tasks such as individual FTOOLS or MSFC-supplied scripts.
- < > are used to enclose data directory paths

2.1 Telescope Numbering

Seven co-aligned telescopes comprise the ART-XC instrument. The telescopes are variously referred to by their mirror module assembly production number, their detector (URD) production number, or simply by telescope number or hexadecimal equivalent as defined in table 1.

Table 1: ART-XC Telescope Identifiers

Telescope Number	Hexadecimal Equivalent	URD Number	MMA Production Number	Detector Number
T01	02	28	3-2	33
T02	04	22	5-6	34
T03	08	23	4-3	24
T04	10	24	1-4	25
T05	20	25	2-5	22
T06	40	26	8-9	26
T07	80	30	7-7	23
Corresponding FITS header keyword record				
DETNAM		URDN	MMA	DETN

This table is provided in the CALDB file artT00_TELMAP_20131001v0001.fits.

3 Survey Mode Science Data and Directory Structure

The primary data products in survey mode are Level 1 and Level 2 event lists and attitude quaternions gathered and processed during ART-XC's four year long all sky survey.

3.1 Tile Number Definition

At the highest level, data file names and/or data directories are organized by sky regions, or 'tiles', defined by their fundamental six-digit tile number, *RRRDDD* and referred to generically as 'sky tiles'. Tile numbers reflect the location on the sky of the tile center in degrees with the first 3 digits representing the R.A. and the last 3 digits 90−Decl. of the tile center in J2000 coordinates. For example, tile number $RRRDDD = 273024$ indicates a sky region centered at R.A. $= 273°$, Decl. $= 90 - 24 = 66°$. Tiles span three degrees in declination and a range in right ascension such that each tile subtends a nearly constant solid angle on the sky. There are 4700 tiles covering the full sky. The tile numbering convention and related information (minimum and maximum R.A. and Decl. and conversions of tile centers to other coordinate systems) is included in the CALDB file artT00_TILEMAP_20131001v0001.fits.

3.2 Epoch Definition

One all-sky survey is completed every six months. Therefore, daily Level 2 survey data are *merged* into epochs containing event lists spanning six-month intervals for each tile number and each telescope (§ 5.4). Similarly, the attitude files are merged into epochs containing quaternions spanning six-month intervals for each telescope (applicable to all tiles). The epoch temporal boundaries are listed in Table 2. The contents of this table are also included in the CALDB file artT00_EPOCHS_20131001v0001.fits.

Table 2: Sky Survey Epoch Definitions

Epoch Number	Start	End	Epoch Number	Start	End
1	2019-12-13	2020-06-12	5	2021-12-13	2022-06-12
2	2020-06-13	2020-12-12	6	2022-06-13	2022-12-12
3	2020-12-13	2021-06-12	7	2022-12-13	2023-06-12
4	2021-06-13	2021-12-12	8	2023-06-13	2023-12-12

3.3 Level 1

Following IKI conventions, Level 1 event list file names denote the date and time of file creation, typically spanning an interval of ∼one day between consecutive event lists for a given tile corresponding to a typical data downlink interval.

- **Old Format File Names:** Level 1 event list files are named srg_*YYYMMDD_HHMMSS*_00*N*.*TT*_urd.fits where *YYYMMDD_HHMMSS* denote the date and time of file creation, *N* is either 0 or 1 depending on whether telemetered data was processed directly (0) or required reprocessing (1) due to telemetry errors, and *TT* denotes the telescope number in hexadecimal (Table 2). It may be noted that the times referred to in the file names reflect the file creation time but do not necessarily correspond to valid GTIs within the data files. Corresponding Level 1 attitude files are named srg_*YYYMMDD_HHMMSS*_00*N*_gyro.fits.
- **New Format File Names:** Level 1 event list files are named art*DDDDDD*T*N*_uf.fits where *DDDDDD* denotes an integer day since 2000-01-01 00:00:00 UTC (1999-12-31 21:00:00 MSK), and *N* denotes the one-digit telescope number (Table 2). Corresponding Level 1 attitude files are named art*DDDDDD*_gyro.fits.

Level 1 event lists and attitude files are stored in directories named <*RRRDDD*/level1>. The number of individual Level 1 data files, up to one file per day (for tiles near the ecliptic poles) over the four year survey, can be large. Therefore, Level 1 event lists for each telescope (and each tile) will be combined using `gtar` into single 'epochs' where each epoch duration is six months corresponding to one full-sky survey. These files are named srg_*TTT*_*RRRDDD*_Epoch*J*.tar where *TTT* denotes the telescope as zero-padded integer (*TTT* = T01, T02, T03, T04, T05, T06, T07), *RRRDDD* corresponds to the six digit tile number, and *J* is a single digit integer corresponding to the survey epoch ($J = 1, 2, 3, 4, 5, 6, 7, 8$). Individual Level 1 attitude files will be similarly combined.

3.4 Level 2

Survey mode Level 2 event lists available to end users will consist of six-month accumulations of events for each tile and each telescope. These event lists are named artL2merged_*TTT*_*RRRDDD*_Epoch*J*.fits where *TTT* denotes the telescope as zero-padded integer (*TTT* = T01, T02, T03, T04, T05, T06, T07), *RRRDDD* corresponds to the six digit tile number, and *J* is a single digit integer corresponding to the survey epoch ($J = 1, 2, 3, 4, 5, 6, 7, 8$). Level 2 survey mode event lists are stored in a directory named <l2merged>. Thus this directory will contain one file for each of the seven telescopes and for each of up to 8 six-month epochs for each sky tile.

Appropriately accumulated Level 2 attitude files will accompany the Level 2 event lists and will be located in the same <l2merged> directory. These files are named artL2_GyroMerged_Epoch*J*.fits. They contain separate extensions for each of the seven telescopes and are applicable to all tiles.

4 Pointed & Scan Mode Science Data and Directory Structure

In addition to survey mode data, pointed and scan modes were used during the calibration and performance verification phase of the SRG mission which took place in the months before the all-sky survey

mode that began in Dec 2019. Additional pointed (and scan mode) observations are occasionally made during the all sky survey.

4.1 Observation Identification Numbers

Pointed and scan mode observations are assigned a unique 11-digit observation identification number. Pointed and scan mode event lists are organized into directories named by the identification number with individual subdirectories for Level 1 and Level 2 products, e.g., <*N*/level1> where *N* denotes the identification number.

4.2 Level 1

Level 1 science data (event lists and attitude files) file names also follow a convention using the identification number. Level 1 event list file names are art*N*T*T*_uf.fits where *N* denotes the 11-digit identification number and *T* denotes the single-digit telescope number ($T = 1, ..., 7$). Level 1 attitude file names are art*N*.e3_gyro.fits where *N* denotes the 11-digit identification number.

CAUTION **Attitude files are available only for some pointed observations.**

4.3 Level 2

Level 2 event list file names are artL2_*TTT*_*N*.fits where *N* denotes the 11-digit identification number and *TTT* denotes telescope number as zero-padded integer (T01, ...,T07). Corresponding spacecraft attitude files are named artL2_att_*N*.fits.

5 Data File Content

This section defines the contents of the Level 1 and Level 2 FITS files (i.e., the header keyword records and the table columns in the data units).

5.1 Universal Keywords & HDU Extensions

Keyword records of interest to data end users included in all Level 2 event lists are described in Table 3. This is not an exhaustive list.

All event lists and attitude files (Level 1 and Level 2) contain GTI and/or STDGTI extensions with START and STOP columns. When both extensions are present, the STDGTI is the more complete as it contains all the relevant good time intervals for that data file (the STDGTI extension is generated by the FTOOL task `ftmgtime`).

All data are in FITS format and all HDUs contain the standard FITS keywords CHECKSUM, a 16-character string, left justified starting in column 12, containing the ASCII-encoded complement of the checksum of the FITS HDU and DATASUM, the unsigned integer value of the checksum of the data records of the HDU. These are used to detect accidental modification such as corruption in stored data or errors in a communication channel.

In addition, all Level 2 event lists contain the following informational character string keywords helpful in the event data requires reprocessing:

- a SOFTVER string containing the version of the MART-specific software used during the processing. The version is defined as *YYYY.MM* where *YYYY* is the four-digit year and *DD* is the one or two-digit month denoting when the software version was released. For example, a relase in August of 2021 would be denoted as *2021.8*, whereas a release in November of that same year would be *2021.11*. This is in conformance with PEP 440 standards (`https://www.python.org/dev/peps/pep-0440/#final-releases`).

- a CALDBVER string containing the version of the calibration index file used during the processing. The format of the CALDBVER string is identical to the SOFTVER string given above, although the precise release dates may not necessarily be identical.

Table 3: Level 2 Event List Keyword Records

KEYNAME	Example Value	Description/Comment String
	Hardware Identification	
TELESCOP	SRG	mission name
INSTRUME	ART-XC	instrument name
MMA	7-7	Mirror module-spider combination
DETNAM	T07	telescope number
URDN	30	URD number
DETN	23	detector number
	Data Level / Mode Identification	
DATALVL	MSFCL2	Data processing level
OBSMODE	POINTED/SURVEY	Telescope observation mode
SMAPNR	273024	sky map tile number (None for pointed observations)
	Survey Mode Identification	
RA_MIN	270.0	sky map minimum Right Ascension
RA_CEN	273.4615384615385	sky map center Right Ascension
RA_MAX	276.9230769230769	sky map maximum Right Ascension
DE_MIN	64.5	sky map minimum Declination
DE_CEN	66.0	sky map center Declination
DE_MAX	67.5	sky map maximum Declination
SRGEPOCH	2	Survey Epoch in which the data were acquired
	Pointed/Scan Mode Identification	
OBSID	11910035000	Observation ID # created by IKI
	Version Numbers	
SOFTVER	2021.8	Identifier of the software release
CALDBVER	2021.8	Identifier of the CALDB release
HEAVER	heasoft-6.28	Identifier of the HEASOFT version used in processing
	Miscellaneous	
PIXRAND	T	pixel randomization applied in aspect determination (T/F)

- a HEAVER string containing the version of the HEASOFT software used to process the data. This currently has the format of heasoft-$X.YY$ where X and YY are the major and minor version number of HEASOFT as determined by HEASARC, respectively.

5.2 Level 1 Event Lists

Data retrieved from IKI by MSFC is in the form of FITS-formatted event lists and spacecraft attitudes. These files do not meet OGIP standards but are readable and have been processed by the MSFC team to produce OGIP-compliant Level 1 and Level 2 FITS data. This section describes the contents of the original Level 1 files as retrieved. Survey Mode and Pointed/Scan Mode observations have identical Level 1 data content.

5.2.1 EVENTS Extension

The EVENTS binary table primary extension contains the standard event list (Table 4) recording the time of arrival (TIME), position on the detector (RAW_X, RAW_Y; non-FITS standard), and a measure of the energy deposited (PHA*, ENERGY). Also included is the event GRADE and location identifier FLAG.

Event GRADEs are defined as follows: Events are *triggered* when both a top and a bottom strip electrode register charge (PHA) above a preset threshold. Events are *graded* according to whether or not the PHA values in adjacent strips (electrodes) are above or below their respective threshold according to

Table 4: Level 1 EVENT Extension Columns†

Column Name	Format	Unit	Description
TIME	1D	sec	Time of event since 2000-01-01 00:00:00 Moscow Time
TIME_I	1J	sec	Integer component of time
TIME_F	1D	sec	Floating point component of time
TIME_CORR	1D*	sec	Time correction (nominally 0.0)
KVEA_FRAME	1J*		Frame number
ENERGY	1D	keV	Energy of the event after gain corrected PHA
ENERGY_BOT	1D*	keV	Energy of the event in bottom plate
ENERGY_TOP	1D*	keV	Energy of the event in top plate
PI	1I *		Invariant pulse height
RA	1D	deg	Right Ascension of Event, in J2000 coordinates
DEC	1D	deg	Declination of Event, in J2000 coordinates
RAW_X	1I	pixel	X-Position of Event in detector coordinates (0−47)
RAW_Y	1I	pixel	Y-Position of Event in detector coordinates (0−47)
PHA_BOT	1I		PHA for bottom strip at RAW_X/Y position
PHA_BOT_ADD1	1I		PHA for first bottom strip adjacent to RAW_X/Y position
PHA_BOT_SUB1	1I		PHA for second bottom strip adjacent to RAW_X/Y position
PHA_TOP	1I		PHA for top strip at RAW_X/Y position
PHA_TOP_ADD1	1I		PHA for first top strip adjacent to RAW_X/Y position
PHA_TOP_SUB1	1I		PHA for second top strip adjacent to RAW_X/Y position
TRIGGER	1I		Identifier for which series of strips triggered event
TD	1D*	°C	Detector temperature reading
GRADE	1I		Identifier for combination of strips above/below PHA thresholds
FLAG	1I		Detector position identifier

†An asterisk in the format column indicates inclusion only in the new format event list.

Table 5. If the event registers in (RAWX,RAWY)= i, j, then PHA_TOP_ADD1 is the charge registered in electrode RAWY= $j+1$, etc. Event ENERGY is defined as a weighted combination of these six electrode PHA values (if above threshold as indicated by event GRADE). All six PHA values are recorded even if the 'side electrode' values are below their respective thresholds.

FLAG=0 events fall within the detector field of view of the sky. FLAG=2 events register in positions (RAW_X, RAW_Y) hidden under the thick, circular Al mask mounted over the square CdTe die. These positions are not exposed to the sky and such events should not be included in most analyses. FLAG=3 events register in the edges of the detector (RAW_X=0 or 47, or RAW_Y=0 or 47) and should also not be included in most analyses because they cannot properly be assigned a GRADE nor an accurate ENERGY.

5.2.2 HK Extension

Time-ordered housekeeping data are recorded in the binary table extension HK of the Level 1 event list at 10 second intervals. The data structure is listed in Table 6. The original (retrieved from IKI by MSFC) HK extension data is filtered by GTI to retain only those data relevant to the events in the Level 1 EVENT extension. This reduces the Level 1 event list file volume by ∼1/2.

The detector temperatures (TD1, 2, or 3) are used to derive the event ENERGY from the six PHA values included in the primary EVENTS extension. The detector high voltage (HV) values are used to filter events (if any) occurring while the detector is periodically switched off (HV= 0) to mitigate the polarization effect in CdTe Schottky devices (nominal HV∼ -100 V).

Table 5: Event GRADE Definitions†

GRADE	Top	Bot	GRADE	Top	Bot
0	OXO	OXO	8	OXX	OXX
1	XXO	OXO	9	XXX	OXO
2	OXX	OXO	10	XXX	XXO
3	OXO	XXO	11	XXX	OXX
4	OXO	OXX	12	OXO	XXX
5	XXO	XXO	13	XXO	XXX
6	XXO	OXX	14	OXX	XXX
7	OXX	XXO	15	XXX	XXX

†X denotes above PHA threshold, O denotes below threshold

5.3 Level 1 Attitude Files

Each Level 1 event list has a corresponding spacecraft orientation or attitude file containing quaternions representing the pointing direction of the spacecraft over the same GTIs as the Level 1 file. Survey Mode and Pointed/Scan Mode observations have identical Level 1 attitude file data structure. The structure of the primary extension are included here (Table 7) for reference but only merged (time-ordered) Level 2 attitude files are provided to the end user (§ 5.5).

The attitude files also contain housekeeping information documenting which of three star tracking cameras are in use (BOKZ on the ART-XC optical bench or SED26−1 or SED26−2 on the eROSITA optical bench) and related information. These data are not of practical use to end users.

5.4 Level 2 Event Lists

The contents of the Level 2 event list EVENTS extension is given in Table 8. All of the steps taken to convert a series of Level 1 event lists into a Level 2 event list are described in detail in the `martxc` Software Manual. The resulting Level 2 event list files conform to OGIP standards, and a few of the column names have been slightly modified to ensure such compliance. Additional columns are added and superfluous columns not useful for further science analysis are removed in this process as well. Furthermore, the HK extension in the Level 1 event lists is absent in the the Level 2 data. Mode and Pointed/Scan Mode observations have identical Level 2 data structure.

Events with FLARE = T are in time intervals contaminated by enhanced particle activity (flares) and should not be included in most astrophysical analyses. Flares are identified using a sigma-clipping algorithm and an absolute count rate cut as part of MSFC's standard pipeline processing described in the Software Manual. Observations of the particle background of the SRG spacecraft suggest that there are few significant flares at its Earth-Sun L2 orbit. Specific time intervals are rarely rejected due to the presence of flares.

5.5 Level 2 Attitude Files

There are slight differences in the orientation of each telescope relative to the instrument orientation. Therefore, there are seven HDU extensions in the Level 2 attitude files labeled ORIENTATIONT where T denotes telescope number. Each extension contains data listed in Table 9. There is also a GTI HDU included in the Level 2 attitude files. Survey Mode and Pointed/Scan Mode observations have identical Level 2 attitude file data structure.

Table 6: Level 1 HK Extension Columns[†]

Column Name	Format	Unit	Description
TIME	1D	sec	Time of event since 2000-01-01 00:00:00 Moscow Time
TSYNC	1B*		Time synchronization flag
TD1	1D	°C	Temperature as measured by sensor #1
TD2	1D	°C	Temperature as measured by sensor #2
TD3	1D	°C	Temperature as measured by sensor #3
TEMP_STAB	1B*		Temperature stabilization flag
P5V	1D		Current in +5V circuit
M5V	1D		Current in −5V circuit
HV	1D	V	Value of Charge Collection voltage
HV_STATE	1B*		High voltage state flag
LEAK_CURRENT*	1D	A	Leakage current
FRAMES	1J		Telemetry Frames Count
EVENTS	1J		
EVENTS_PROCESSED	1J		
FSM_STATE	1B*		FSM state flag
FSM_STATE_SPEC	1B*		Spectrum collecting state flag
FSM_STATE_NOISE	1B*		Noise spectrum collecting state flag
BKI_STATE	1B*		Calibration spectrum collecting state flag
BAD_TA_CNT	1J*		Error founter

[†]An asterisk in the format column indicates inclusion only in the new format HK extension.

Table 7: Level 1 ORIENTATION Extension Columns

Column Name	Format	Unit	Description
TIME	1D	sec	Time of event since 2000-01-01 00:00:00 Moscow Time
TIME_I	1J	sec	Integer component of time
TIME_F	1D	sec	Floating point component of time
STATUS	1I		
QORT_0	1D		Component 0 of the spacecraft's rotation quaternion
QORT_1	1D		Component 1 of the spacecraft's rotation quaternion
QORT_2	1D		Component 2 of the spacecraft's rotation quaternion
QORT_3	1D		Component 3 of the spacecraft's rotation quaternion
ST_SED1_ON	1B		Status flag of SED26−1 star tracker
ST_SED2_ON	1B		Status flag of SED26−2 star tracker
ST_BOKZ_ON	1B		Status flag of BOKZ star tracker
ST_SED1_MEAS	1B		SED26−1 usage flag
ST_SED2_MEAS	1B		SED26−1 usage flag
ST_BOKZ_MEAS	1B		BOKZ usage flag
ST_SCIREADY	1B		Scientific observation readiness flag
ST_PRECSTAB	1B		Precise stabilization flag

Table 8: Level 2 EVENT Extension Columns

Column Name	Format	Unit	Description
TIME	1D	sec	Time of event since 2013-10-01 00:00:00 Coordinated Universal Time
RAWX	1I	pixel	X-Position of Event in detector coordinates (0−47)
RAWY	1I	pixel	Y-Position of Event in detector coordinates (0−47)
ENERGY	1D	keV	Energy of the event after gain corrected PHA
RA	1D	deg	Right Ascension of Event, in J2000 coordinates
DEC	1D	deg	Declination of Event, in J2000 coordinates
GRADE	1I		Identifier for combination of strips above/below PHA thresholds
PI	1I		Pulse Invariant (gain corrected) energy scale
FLAG	1I		Identifier for where RAW position occurs relative to mask or edge
FLARE	1L		Identifier of events occurring during flare intervals
X	1I	pixel	Sky position X-coordinate (15″ pixels)
Y	1I	pixel	Sky position Y-coordinate (15″ pixels)

Table 9: Level 2 ORIENTATION Extension Columns

Column Name	Format	Unit	Description
TIME	1D	sec	Time of event since 2013-10-01 00:00:00 Coordinated Universal Time
STATUS	1I		
QORT_0	1D		Component 0 of the spacecraft's rotation quaternion
QORT_1	1D		Component 1 of the spacecraft's rotation quaternion
QORT_2	1D		Component 2 of the spacecraft's rotation quaternion
QORT_3	1D		Component 3 of the spacecraft's rotation quaternion
RA	1D		Right Ascension of telescope optical axis direction towards the sky
DEC	1D		Declination of telescope optical axis direction towards the sky