Chandra X-Ray Center

CXC Archive Interface Control Document

Analysis Reference Data for:

Exposure Maps and Grating Levels 1.5–2 Tools[1]

Revision 1.7 — 23 Sep 2004

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[1]Current DRAFT version can be found at: `http://space.mit.edu/ASC/docs/ARD_ICD.ps.gz`
The top-level ICD index is at `http://hea-www.harvard.edu/asclocal/sds/development/ICD/index.html`

Document and Change Control Log

Date	Version	Section	Status
3 March 98	0.0	all	Initial Draft
28 May 98	0.1	QE, HRMA chapters	Updated HRMA chapter; major update to QE: region gone, uniformity, mean, embedded function in.
10 June 98	1.0	all	added many new chapters;re-organized.
23 Sept 98	1.1	all	updated hrma func; updated PI tbl, added HESF effic., misc fixes.
22 Oct 98	1.1 DRAFT	all	updated as per comments from JHK, WLM, LPD, DD. Added change-bars.
15 Dec 98	1.2	6, 11;	Very minor revisions
10 Mar 99	1.3	all	Conformance to `caldb.txt`: Filename templates given; Added CALDB keywords; Updated misc. keywords: CONTENT, EXTNAME, HDUNAME, HDUCLASn. – Added ACIS QE-uniformity functional; – Deleted HRMA vignetting functional. – Deleted ACIS bad-pixel and acis-window section. Former is in ACIS ARD ICD; latter is a L1 product in ACIS L1 ICD. – Added new sections for basic instrument parameters.
25-29 Mar 99	1.3	two	added hrma axial effective area added hrma vignetting map changed rmf-limit table HDUNAME and CONTENT to conform to caldb.txt. Transposed hrma effa and vignet images so energy is first index.
June 1999	1.4	all	Many format revisions, primarily to adopt OGIP formats, and to implement array columns so grids and uncertainties do not have to be in seperate HDU's. Removed function coefficient tables for QE uniformity; instead, use array of images vs energy. Revised ACIS uniformity product: need preliminary products from IPI. (See Change Orders: implemented dph003.0019-0036.)
Sept 2001	1.5	2.3	Added explicit requirements on the order of the energy values in the QEU energy axis (which must be increasing).
Sept 2002	1.6	2.6	Added sub section defining ACIS contamination data; (bumped section 2.6 to 2.7).
Sept 2004	1.7	2.6	Added sub section defining ACIS spatial contamination data; (bumped section 2.6 to 2.7).

2.6 File Structure: ACIS Spatial Contamination Transmission Tables

New section, *Revision 1.7 — 23 Sep 2004*

Recent analysis of *Chandra* flight data has shown that the ACIS filter contaminant thickness varies significantly with position. This section defines files which contain tables describing the transmission as a function of position as well as energy and time. The file supercedes the spatially invariant file defined in Section 2.7.

The calibration model of spatial contamination is defined in detail in "Spatial structure in the ACIS OBF contamination" (A. Vikhlinin, 5/09/04; `http://cxc.harvard.edu/contrib/alexey/cont_spat.pdf`).

The transmission efficiency of N contaminants, i, in M partial covering regions, can be expressed as

$$\epsilon(E,t,x,y) = \sum_{j=1}^{M} F_j e^{-\kappa_j \sum_{i=1}^{N} \mu_{ij}(E)\,\tau_{ij}(t,x,y)} \tag{1}$$

in which the relative thickness as a function of position and time s

$$\tau_{ij}(t,x,y) = \tau_{0ij}(t-t_0) + \tau_{1ij}(t-t_0) f_{ij}(x,y). \tag{2}$$

Here E is photon energy in keV, t is time in seconds since the reference time, t_0, $\mu(E)$ is the relative absorption coefficient per unit thickness, and τ are the relative thicknesses of the contaminants, and $f(x,y)$ defines the spatial distribution. The reference time, t_0, is the *Chandra* `MJDREF`, 50814.0 (1998.0). The absorption coefficient and thicknesses are in relative units since their absolute values are not known. Their product yields and optical depth, which can be measured.

The total absorption optical depth for N contaminants is given by the sum of individual optical depths over index i. The sum over j allows an option for partial filling factors by different contaminants, with weights F_j and κ_j.

There is a dependence upon the ACIS CCD, primarily upon the read-out array, ACIS-I or ACIS-S (since they have different thermal loading). For generality in chip-to-chip differences, there will be one FITS binary table extension per CCD.

The calibration file will tabulate F, κ, $\mu(E)$, $\tau(t)$, $f(x,y)$, t, and E, as provided by the Calibration Group. Each contaminant's data will be stored as vector columns on one row of a FITS binary table. Variable length tables may be used to achieve more efficient storage (specifically, if $f(x,y)$ is the same for each i, only one image will be stored in the "heap"). The column widths will be as large as the longest array required, and additional columns will tabulate the number of points in each array.

To further minimize file size, both the time dependence and absorption coefficient energy dependence will tabulated to some *a priori* specified accuracy to linear interpolation. The calibration scientist will specify end points suitable for interpolation over the time of the mission, or indicate that linear extrapolation is reasonable.

Tabulation of the data supports arbitrary and multiple functional dependencies as determined by calibration. That is, no other parameterization is required in software beyond what is given by Equations 1 and 2.

The primary implementation of the file will be in `ardlib`, the *CIAO* software interface to the calibration database, and used by response programs such as `mkarf`, `mkgarf`, and `mkinstmap`.[7]

2.6.1 File Names

The `CALDB` type for the spatial contamination is `contam`. File names will be of the forms:

`acisD1996-11-01contamN0001.fits`

2.6.2 HDU Components

The following table describes the file structure by Header-Data Unit number, type, extension name, content, and HDU classes. An asterisk (*) denotes the principal HDU.

HDU	HDU Type	EXTNAME	EXTVER	CONTENT	HDUCLASS	Description
0	PRIMARY	N/A	N/A	N/A	N/A	NULL
1 (*)	BINTABLE	AXAF_CONTAM	1	CDB_ACIS_CONTAM	ASC DETCHAR CONTAM	Binary table extension listing contamination coefficients as a funciton of energy, time, and position.

[7] `http://cxc.harvard.edu/ciao/ahelp/mkarf.html, mkgarf.html, mkinstmap.html`

2.6.3 Columns and Coordinate Systems

Columns for ACIS contamination coefficients are given in the following table.

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	Description
COMPONENT		1I	1	N/A	Component index, j. All contaminants in a component's optical depth are summed (over i) before exponentiation, then components' transmissions are summed (over j).
WEIGHT		1E	0.0	1.0	Component weight, F_j.
KAPPA		1E	N/A	N/A	Component exponent weight, κ_j.
FEATURE		16A	N/A	N/A	Name of the feature, such as `CK` for carbon-K edge, `OK` for oxygen-K, `FK` for fluorine K, or `FF` for the "fluffium" empirical correction term for a bi-level contaminant.
N_ENERGY		1I	2	N/A	Number of entries in the `ENERGY` and `MU` vectors. At least two points are required for interpolation and extrapolation.
ENERGY	keV	nE	0.0	N/A	E vector of energies, of which the first `N_ENERGY` elements are to be used.
MU		nE	0.0	N/A	$\mu(E)$ vector of relative absorption per unit length vs energy, of which the first `N_ENERGY` elements are to be used.
N_TIME		1I	2	N/A	Number of entries in the `TIME`, `TAU_0`, and `TAU_1` vectors. At least two points are required for interpolation and extrapolation.
TIME	s	mD	0	N/A	t time vector, of which the first `N_TIME` elements are to be used. Units are seconds since `MJDREF`, as is used for event files. The default `MJDREF` is 50814, which corresponds to `1998-01-01T00:00:00 (TT)`, and $MJD = JD - 2400000.5$.
TAU_0		mE	0.0	N/A	Thickness coefficient of absorbing material, in arbitrary length units.
TAU_1		mE	0.0	N/A	Thickness coefficient of absorbing material, in arbitrary length units.
FXY		1048576E	0.0	N/A	Spatial weight map, 1024 × 1024 elements, in ACIS chip coordinates. The offset, i into the image, `FXY[i]` for $f(X,Y)$ is: $i = 1024 \times (Y-1) + (X-1)$.

Array elements of `ENERGY` and `MU` are in one-to-one correspondence and have the same width; `N_ENERGY` is less than or equal to the length of the widest row in those columns (if there are multiple rows). `ENERGY` is required to be monotonic and in ascending order.

Array elements of `TIME`, `TAU_0`, and `TAU_1` are in one-to-one correspondence and have the same width; `N_TIME` is less than or equal to the length of the widest row in those columns (if there are multiple rows). `TIME` is required to be monotonic and in ascending order.

2.6.4 Relevant Header Keywords

The device and mode may be obtained from standard AXAF header keywords in the "Observation" component of the header, as defined by the ASC FITS Guide (Document 4; note that many keywords are not relevant to non-flight observations). The `CALDB` architecture guide (Document 3) also lists required keywords.

Relevant keywords are:

`INSTRUME`: The only allowed value is `ACIS`.

`TIMEZERO`: This is the t_0 in Equation 2. It is a standard FITS keyword used for time table data offsets.

`NAXIS2`: This is a mandatory FITS binary table keyword. Here is is also used to determine the number of contaminant components times the number of contaminants per component whose data are tabulated, one per row. All present should be evaluated.

`CIP`n: For configuration control, this keyword (or list if n is present to enumerate several keywords) names the input CIP, or Calibration Interface Product files delivered by calibration and formatted into this ARD.

`CIPREF`: For configuration control, this keyword cites a relevant calibration memo (or preferably, URL).

`INTRPACC`: specifies the accuracy to linear interpolation, in percent (for both MU and TIME).

2.6.5 `CALDB` Keywords

The required `CALDB` keywords are as follows:

```
CCLS0001  'BCF'
CDTP0001  'DATA'
CCNM0001  'CONTAM'
CBD10001  'ENERG(0.06-12.0)keV'
CBD10002  'TIME(tbd-tbd)s'
CVSD0001  1996-11-01T00:00:00
CDES0001  'ACIS Filter Spatial Contamination Coefficients'
```

2.6.6 Size and File Number Estimates

There will be one ACIS contamination file which will cover the time of the mission. The energy vector will probably be about 1000 points, and the time vector 100. The spatial map is 1024×1024 real elements. Each row will be less than about 4 MB. If multiple rows share the same $f(x, y)$ in the heap, then subsequent rows use about 100 kB. Hence a 3-contaminant, one component file will be less than 5MB.

2.7 File Structure: ACIS Contamination Transmission Function

This mean contamination file format is superceded by the spatially dependent contamination. See Section 2.6

Analysis of *Chandra* flight data over the first three years of operation has revealed absorption features due to contamination build-up on the ACIS filter For details, see Plucinsky et al 2002 (SPIE proceedings, URL TBD). This section defines files which contain tables defining the transmission function as a function of wavelength and time.

The transmission efficiency of contaminant, i, can be expressed as

$$\epsilon_i(E,t) = e^{-\alpha_i(E)\beta_i(t-t_0)}, \tag{1}$$

where E is photon energy, t is time, α is the absorption coefficient per unit thickness, and β is the thickness of the contaminant (in arbitrary units). The total absorption optical depth for N contaminants is given by the sum of individual optical depths,

$$\tau(E,t) = \sum_{i=1}^{N} \alpha_i(E)\beta_i(t-t_0), \tag{2}$$

assuming that each α_i has been normalized to the same relative unit thickness at the same fiducial time, t_0. Thus, the net transmissivity is

$$\epsilon(E,t) = e^{-\tau(E,t)}. \tag{3}$$

There is weak but yet inconclusive evidence that there are multiple contaminants, and that their time dependencies may be different. Hence, we have explicitly allowed for individual β_i for each α_i.

There is no dependence upon the ACIS CCD, nor upon the ACIS clocking mode.

The calibration file defined below will tabulate $\alpha(E)$ and $\beta(t)$. Each contaminant's data (both the absorption coefficient *and* the time depencence) will be stored as vector columns on one row of a FITS binary table. In order to avoid variable length tables, the column widths will be as large as the longest array required, and additional columns will tabulate the number of points in each array. Initially, we will have a one-row table for the single contaminant quantified to date. As more are needed, more rows will be added.

Both the time dependence and absorption coefficient will tabulated to some *a priori* specified accuracy to linear interpolation. The calibration scientist will specify end points suitable for interpolation over the time of the mission, or indicate that linear extrapolation is reasonable. Tabulation of the data supports arbitrary and multiple functional dependencies as determined by calibration.

The primary implementation of the file will be in `ardlib`, the *CIAO* software interface to the calibration database, as implemented by response programs such as `mkarf`, `mkgarf`, and `mkinstmap`.

2.7.1 File Names

The `CALDB` type for the mean contamination is `contam`. File names will be of the forms:

`acisD1996-11-01contamN0001.fits`

2.7.2 HDU Components

The following table describes the file structure by Header-Data Unit number, type, extension name, content, and HDU classes. An asterisk (*) denotes the principal HDU.

HDU	HDU Type	EXTNAME	EXTVER	CONTENT	HDUCLASS	Description
0	PRIMARY	N/A	N/A	N/A	N/A	NULL
1 (*)	BINTABLE	AXAF_CONTAM	1	CDB_ACIS_CONTAM	ASC DETCHAR CONTAM	Binary table describing the absorption coefficients vs energy vs time.

2.7.3 Columns and Coordinate Systems

Columns for ACIS contamination coefficients are given in the following table.

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	Description
FEATURE		16A	N/A	N/A	Name of the feature, such as “CK” for Carbon-K-edge.
N_ENERGY		1I	2	N/A	Number of entries in the energy and α vectors. At least two points are required for interpolation and extrapolation.
ENERGY	keV	nE	0.0	N/A	Energy vector, of which the first *n_energy* elements are to be used.
ALPHA	invlength	nE	0.0	N/A	α vector, of which the first *n_energy* elements are to be used.
N_TIME		1I	2	N/A	Number of entries in the time and β vectors. At least two points are required for interpolation and extrapolation.
TIME	s	mD	TBD	N/A	Time vector, of which the first *n_time* elements are to be used. Units are seconds since `MJDREF`, as is used for event files. The default `MJDREF` is 50814, which corresponds to `1998-01-01T00:00:00 (TT)`, and $MJD = JD - 2400000.5$.
BETA	length	mE	0.0	N/A	Thickness of absorbing material, in arbitrary length units.

Array elements of `ENERGY` and `ALPHA` are in one-to-one correspondence and have the same width; n is less than or equal to the length of the widest row in those columns (if there are multiple rows). `ENERGY` is required to be monotonic and in ascending order.

Array elements of `TIME` and `BETA` are in one-to-one correspondence and have the same width; m is less than or equal to the length of the widest row in those columns (if there are multiple rows). `TIME` is required to be monotonic and in ascending order.

2.7.4 Relevant Header Keywords

The device and mode may be obtained from standard AXAF header keywords in the "Observation" component of the header, as defined by the ASC FITS Guide (Document 4; note that many keywords are not relevant to non-flight observations). The `CALDB` architecture guide (Document 3) also lists required keywords.

Relevant keywords are:

`INSTRUME:` The only allowed value is `ACIS`.

`TIMEZERO:` This is the t_0 in Equation 3. It is a standard FITS keyword used for time table data offsets.

`NAXIS2:` This is a mandatory FITS binary table keyword. Here is is also used to determine the number of contaminants whose data are tabulated, one per row.

`CIP`n`:` For configuration control, this keyword (or list if n is present to enumerate several keywords) names the input CIP, or Calibration Interface Product files delivered by calibration and formatted into this ARD.

`CIPREF:` For configuration control, this keyword cites a relevant calibration memo (or preferably, URL).

`INTRPACC:` specifies the accuracy to linear interpolation, in percent (for both α and β).

2.7.5 `CALDB` Keywords

The required `CALDB` keywords are as follows:

```
CCLS0001  'BCF'
CDTP0001  'DATA'
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CBD10001  'ENERG(0.06-12.0)keV'
CBD10002  'TIME(tbd-tbd)s'
CVSD0001  1996-11-01T00:00:00
CDES0001  'ACIS Filter Contamination Coefficients'
```

2.7.6 Size and File Number Estimates

There will be one ACIS contamination file which will cover the time of the mission. The energy vector will probably be about 1000 points, and the time vector 100. Each row will be less than about 10 kB. Initially, there will be one row for a single contaminant.