Chandra X-Ray Center

Analysis Reference Data for: Exposure Maps and Grating Levels 1.5–2 Pipelines

CXC Archive Interface Control Document

(`http://space.mit.edu/ASC/docs/ARD_ICD.ps.gz`)

Revision 1.3 — 29 Mar 1999

Submitted: ____________________ ________

David Huenemoerder — Date

Grating Scientist, CXC Science Data Systems Group

Concurred: ____________________ ________

Dale Graessle — Date

Calibration Archive Scientist, CXC Data Systems Group

Concurred: ____________________ ________

Adam Dobrzycki — Date

HRC Scientist, CXC Science Data Systems Group

Concurred: ____________________ ________

Joel Kastner — Date

ACIS Scientist, CXC Science Data Systems Group

Concurred: ____________________ ________

Kenny Glotfelty — Date

CXC Data Systems Group Leader, L1.5 Pipelines

Concurred: ____________________ ________

Arnold Rots — Date

Archive Scientist, CXC Data Systems

Concurred: ____________________ ________

Martin Elvis — Date

Manager, CXC Science Data Systems

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.

Unresolved Issues

The following is a list of unresolved, un-reviewed, or un-implemented items:

1. 990222 QE uniformity for HRC-S is still under cal analysis. Rumor says HRC-I is non-uniform, but energy independent, but HRC-S is non-uniform and energy dependent. In anticipation, defined uniformity as polynomial "image" for HRC-S, 2D image for HRC-I.

2. 990224 Form of ACIS BI QE uniformity is expected to be a depletion-depth image, plus a power-law to define the energy dependence. ACIS FI are expected to be uniform. Files have been defined in consideration of this.

3. 990305 The "RMF Energy Limit Table" should be converted to region format. (next revisions, 1.4)

4. 990309 Need to add more parameters — detector geometry.

Change-bar Markup

Changes from the previous version are marked with change-bars in the margin. They have been added to this paragraph as an example. In some cases — particularly over page-breaks — they fail, and produce a diagnonal line through some text. This is not a strike-out.

If an entire section is new, there will be a note after the section heading with a change-bar, but the bar will not cover the rest of the text.

Deletions of text from the previous version are indicated by a filled square in the margin. There should be one after this paragraph.

Contents

1 General Description

This document describes the interface to be employed in transferring the Analysis Reference Data (ARD) used in the CXC processing pipelines and analysis tools to or from the CXC Data Archive, according to the requirements stipulated in the "ASC Data System Requirements" (Applicable Document 1). The products described here are those used in Exposure Map or Grating Level 1.5–2 processing.

The ARD are typically derived calibration products or parameters used in Level 2 processing pipelines or in interactive analysis. ARD are derived from Calibration Interface Products (CIP[1].) ARD may be identical to CIP, may be derived by re-formatting (e.g., ASCII table to FITS BINTABLE), or by many-to-one processing. The primary distinction is that the ARD are necessary or convenient for *analysis*, and are a subset of the CIP, which define the detailed *calibration*.

Together with pipeline and interactive processing data products, the ARD form a Data Dictionary.

1.1 Purpose

AXAF processing, described in Applicable Document 1, consists of event processing of HRC or ACIS Level 1 products (which are described in Applicable Documents 5 and 6) to derive new products, such as images, spectra, light-curves, or exposure-maps. This document describes the structure and content of the reference data required for a subset of this processing and for further analysis, either via pipeline or interactive processing.

1.2 Scope

This interface shall apply to data products that are used by CXC Level 2 pipelines and distributed to the CXC Data Archive (see Applicable Document 1 and the "ASC Data System Software Design," Applicable Document 2) during the course of the AXAF mission.

1.3 Applicable Documents

The Applicable Documents required for background and detail on grating Level 1.5 products are as follows:

1. ASC AMO-2400 (SE03)
   ASC Data System Requirements (ASC.302.93.0008)

2. ASC AMO-2401 (DS01)
   ASC Data System Software Design (ASC.500.93.0006)

3. HEASARC FITS CALDB Standards:
   `http://heasarc.gsfc.nasa.gov/docs/heasarc/caldb/caldb_intro.html`
   (and references therein.)

4. ASC FITS File Designers' Guide
   `http://hea-www.harvard.edu/~arots/asc/fits/ascfits.ps` (and references therein).

[1] For a definition, see `http://space.mit.edu/HETG/xrcf_cal/cal_prods.html#Overview`.

5. HRC Data Products Guide:
   Level 1 to ASC Archive Interface Control Document
   `http://hea-www.harvard.edu/asclocal/sds/ICD/l1icd.ps.gz`

6. ACIS Data Products Guide:
   Level 1 to ASC Archive Interface Control Document
   Link to be on: `http://space.mit.edu/ASC/docs/docs.html`

7. ARF ICD and Tools:
   TBD to ASC Archive Interface Control Document
   `http://space.mit.edu/ASC/docs/TBD`

8. "Guide to AXAF Data Products" (`content.txt, v 1.5`)
   `http://hea-www.harvard.edu/~arots/asc/fits/content.txt`

1.4 Functional Description

1.4.1 Data Content Summary

Data sets read by the processing pipelines shall consist of data files conforming to the FITS format (See the "ASC FITS File Designers' Guide", Document 4) and references therein.) These files contain header keyword entries and binary table (BINTABLE) extensions. Following rules outlined in Document 4, all these files will contain a possibly null primary header followed by a main binary table (the "principal HDU") and auxiliary extensions ("auxiliary HDU"). Furthermore, FITS ARD files will conform to the HEASARC CALDB conventions (Document 3).

Any other types of files will either be of types in common use (e.g., PostScript), or fully described here (e.g., ASCII region files of IRAF/PROS), or parameter files conforming to the SAO parameter interface.

1.4.2 Recipients and Utilization

The primary recipients of reference data products, via distribution from the archive, are AXAF observers, who will utilize these data products for scientific data analysis.

1.4.3 Pertinent Relationships with Other Interfaces

Changes to the definition of HRC, ACIS, or HRMA Calibration Interface Products, as described in Document ??TBD, may affect the data products described in the current document.

TBD by Cal.: CIP doc reference.

1.4.4 Assumptions and Constraints

It is assumed that CXC pipeline processing uses ARD applicable to the time of the observations, and that the ARD is updated as necessary when CIP are revised. It is also assumed that these products are extracted from the CXC archive and placed into an exportable calibration database (CALDB) for users.

1.4.5 Products Not Covered

Products that are used for maintenance and diagnostic purposes (those that are not supplied to the user for scientific data analysis) are not currently included within the interface defined by this document.

1.4.6 Substructure Definition and Format

The "ASC FITS Designers' Guide" (Document 4) defines and lists header components for the primary header and for all binary table extensions. These will be used with appropriate modifications for non-flight data (e.g., many Observation and Timing Components' keywords are irrelevant). The modified components are listed in Appendix A. These will be used in accordance with Table 6 in the "ASC FITS Designers' Guide."

In general, when FITS headers are shown, column or row numbers are arbitrary unless otherwise indicated. It is the *column name and its attributes* which specify the requirement. **Additional columns or extensions not specified here are permitted in the file without violating the interface.** Processing software can ignore them, pass them through, or use them if they are "known" quantities. (Example usage of this are columns derived from simulation containing *a priori* known values, to be directly compared with specified columns containing derived values.) Likewise, **HDU order is arbitrary,** except for the primary HDU. HDU are intended to be referenced by name, not position.

Unless explicitly noted, the HDUNAME and EXTNAME header keywords will be identical. When there are multiple extensions with the same EXTNAME, EXTVER will be present and the HDUNAME will be the concatenation of EXTNAME and EXTVER.

1.5 File Naming

For reference data files which reside in the Calibration Database (CALDB), file names follow the conventions found in "AXAF CALDB Architecture" (caldb.txt, Document 3), which defines names of the form:
<instrument>[<detector>][<grating><order>]D<effective date><type>N<version>.fits. Terms in pointy brackets are to be replaced with an appropriate value from caldb.txt. Terms in square brackets are optional. The <type> will be specified in this document, and representative file-names given for each kind of product.

The nominal <effective date> will be given here as 1996-11-01 and the nominal <version> as 0001. This will both evolve as calibration products improve with age (particularly with the access of flight calibration data).

1.6 CALDB Configuration Keywords

New section, *Revision 1.3 — 29 Mar 1999*

There are several required keywords for any datafile to be kept in the CALDB, which specify fundamental file attributes used to organize and maintain the CALDB. These are listed in caldb.txt, and will be specified in this document for each product. The relevant keywords are:

CCLS*mmmm*: the class, which is usually BCF for "Basic Calibration File" (here and following, *mmmm* is to be substituted with a number starting at 0001, and will usually only have that value. Other values, 0002, 0003, etc., are used if one extension contains mixed classes (which is typically avoided);

CDTP*mmmm*: the type, which is usually DATA;

CCNM*mmmm*: the name, which describes the product (such as QE or PSF);

`CBD`*nmmmm*: specifies parameter, valid parameter boundaries, and units, if any are necessary. This keyword will not be included if there are no limits. The digit, n, indicates the parameter number (since there could be several for any product), and has permitted values from 1 to 9.

`CVSD`*mmmm*: is a date and time when the product becomes valid; and

`CDES`*mmmm*: is a descriptive string.

More details on these keywords can be found in references cited in `caldb.txt`. Explicit examples will be provided with each product.

1.7 Parameter Table File Format

New section, *Revision 1.3 — 29 Mar 1999*

Some information comes as a list of scalars, such as geometric parameters associated with the HRMA. This kind of data is not amenable to the usual FITS binary table in which each column has the same kind of information on each row. In order to accomodate such data, a more generic binary table format will be used. The table will have `HDUCLAS1='PARAMLIST'` and have some or all of the following columns:

TTYPE	TFORM	Description
NAME	16A	The name of the parameter.
DATATYPE	16A	The type of data, one of: ('SCALARVALUE' | 'STRINGVALUE' | 'VECTORVALUE' | 'FILENAME')
SCALARVALUE	1D	A value for scalar data.
ERROR	1D	The uncertainty of the scalar value.
UNITS	16A	The physical unit of the parameter.
STRINGVALUE	64A	If the data type is a string, this column is present and holds the value.
VECTORVALUE	1J	For vector values, a pointer is required.
VECTORLENGTH	1J	For vector values, a length is required (though redundant with FITS heap information).
FILENAME	128A	For data type, 'FILENAME', this will hold the file-name.
DESCRIPTION	64A	A short description of the parameter

The NAME, DATATYPE, and DESCRIPTION columns are required. At least one more column, as determined by DATATYPE, must be present. If any row contains a specific data type, then all rows of the HDU must contain the same columns, but will have null entries in columns which do not apply. This allows mixed-type content (such as numeric parameters and file-names), at the expense of a larger file. Field widths are representative and may be adjusted as necessary (provided all rows have the same width). Column order is arbitrary.

2 Quantum Efficiency Products: Mean, Spatial Variance, and Uniformity

Data Product Summary

Analysis Reference Data Product	Detector Mean QE
Instrument(s)	ACIS, HRC
Level	2
Scientist/SDS	D. Huenemoerder
Scientist/Cal	B. McNamara,
	H. Donnelly
Filetype	FITS Bintable
Created by tool	TBD
Used by tool(s)	expmap
Sample file	ACIS_QE.fits

Data Product Summary

Analysis Reference Data Product	Detector QE vs. position
Instrument(s)	ACIS, HRC
Level	2
Scientist/SDS	D. Huenemoerder
Scientist/Cal	B. McNamara,
	H. Donnelly
Filetype	FITS 3D Image
Created by tool	TBD
Used by tool(s)	expmap
Sample file	ACIS_QEXY.fits

Data Product Summary

Analysis Reference Data Product	Detector QE Uniformity
Instrument(s)	ACIS, HRC
Level	2
Scientist/SDS	D. Huenemoerder
Scientist/Cal	B. McNamara,
	H. Donnelly
Filetype	FITS Bintable
Created by tool	TBD
Used by tool(s)	expmap
Sample file	ACIS_QEU.fits

In order to make Exposure Maps which incorporate both the detector quantum efficiency (QE) as a function of energy for detailed spectral analysis, and the spatial dependence of the QE for both spatial and spectral analysis, we need the mean QE per device at high spectral resolution and the spatial variations in the QE. These are both crucial for Exposure Map computation and for derivation of the mean response for spectral analysis (the effective "ARF").

2.1 Quantum Efficiency Functions

In general, the quantum efficiency (QE) depends not only upon energy, E, but upon position, (x, y), where the coordinates represent some bins in detector coordinates (for ACIS, the granularity requirement is 32×32 pixels, and for HRC, 256×256 pixels). We will denote this function as $Q_n(E, x, y)$, where the subscript, n refers to a detector element. Q is known to be quite spatially variant in some cases (e.g., back-illuminated CCD, with peak-to-peak amplitude of 20%). The variations can also be energy-dependent. Hence, we must have a way of representing the spatial-spectral quantum efficiency.

We will define several QE reference data products:

$Q_n(E_i, x_j, y_k)$: The discretized absolute QE for device n as a function of energy, E_i, and detector bin (x_j, y_k). This array is sparse in energy (about 10-20 bins). This will be formatted as a FITS 3D image from basic calibration models.

$\overline{Q}_n(E)$: The spatially averaged QE for device n as a function of energy. In this case, we are assuming that E is essentially a continuous variable (~thousand bins).

$U_n(E, x_j, y_k)$: The QE *uniformity* of detector element n, as a function of position bin and energy. The energy here is a continuous variable.

This will be represented as a FITS table of function coefficients, and derived from the previous two items. The function coefficients may be considered as a "hidden" reference data product. In more compact notation, it will be called $U_{jk}(E)$, where jk refers to a spatial bin, (x_j, y_k), and the n is implicit.

Given these definitions, we can determine the QE at any position and energy to the desired resolution via

$$Q_{jk}(E) = U_{jk}(E)\,\overline{Q}(E). \tag{1}$$

2.1.1 Characteristics of U

As of February, 1999, the following are believed to be true:

1. The ACIS front-illuminated CCDs are uniform: $U(E_i, x_j, y_k) = 1$ for all i, j, k.
2. The ACIS back-illuminated CCDs are non-uniform, but U can be modeled in terms of the depletion-depth as a function of position, and a simple functional dependent on energy. Specifically:

   $$U_{jk} = e^{-\lambda(x,y)/\Lambda(E)} \tag{2}$$

   in which $\lambda(x, y)$ is the position-dependent depletion depth (which can be stored as an image), and $\Lambda(E)$ is the energy-dependent unit absorption length.
3. HRC-I is non-uniform, but energy-independent; hence, a 2D map will suffice: $U(E_i, x_j, y_k) \rightarrow U(x_j, y_k)$.
4. HRC-S is both non-uniform and energy-dependent, and will require empirical fitting of U (see next section - 2.1.2).

2.1.2 Generating U

Even though this is a reference data product document, I'm putting the tool specifications for the uniformity function here as well — at least in outline — since the processing is unlikely to be used for any other purpose than ARD generation.

Using an table of functional coefficients for U will result in a considerable savings in storage space for the spatially and energy dependent QE. We are assuming (but haven't yet proven; dph 980528) that at any position on the detector, that the uniformity function with energy is slowly varying and can be represented by a low-order polynomial. This means that it can be described by fewer energies than the desired resolution of the QE itself. We start with a discretized version of U:

$$U_n(E_i, x_j, y_k) = \frac{Q_n(E_i, x_j, y_k)}{\overline{Q}_n(E_i)}. \tag{3}$$

For each j, k, we fit U with a low-order polynomial in E to derive the coefficients. These coefficients are stored in a FITS binary table. Thus, for every position bin, we have a few numbers (of order 10 instead of order 1000) which allow us to describe the QE essentially continuously in energy. To do this, we access the embedded function with an arbitrary energy for the non-discrete permutation of the preceding equation:

$$Q_n(E, x_j, y_k) = \overline{Q}_n(E)\, U_n(E, x_j, y_k) \tag{4}$$

Smoothing in position, if desired, can be done by a subsequent interpolation.

In summary, the tool to produce the function table has the following interface:

`QEU_make_fcn`

```
Calculate the coefficients of the quantum
efficiency uniformity and store as a FITS
function table.  The function is parameterized
as a polynomial (possibly piecewise, if
necessary to describe edges) in energy, and
stored versus position.
```

`Inputs:`

$Q_n(E_i, x_j, y_k)$

$\overline{Q}_n(E)$

`Parameters:`

```
Polynomial type
Polynomial order
Energy range:  min..max
Spatial range:  xmin, xmax, ymin,ymax
```

`Output:`

$U_n(E, x_j, y_k)$ `FITS function table file`

`Restrictions:`

2.2 File Structure: Mean Absolute QE

The mean absolute QE, $\overline{Q}_n(E)$, is provided as a FITS binary table in which the QE versus energy is tabulated for each CCD or MCP in the successive extensions. It is important to note that:

- Separate extensions are used for detector array elements (`DETNAM`'s) or for regions of very different responses (such as for HRC-S filters).
- Any array element regions which are distinct, but very similar in responses (such as ACIS CCD quadrants) are included as additional columns in the extension. (It is expected that ACIS quadrants will be identical, and the per-quadrant columns won't be needed.)
- Each QE column has an associated extension containing the uncertainty on the QE.
- If filter tranmissivities are included in the QE, the `FILTER` keyword will be present and have a value other than `NONE`.
- Separate files are used to cover any multiplicity of QE with mode (e.g., as for ACIS timed exposure-faint, or continuous-clocking, each versus grade-set).

2.2.1 File Names

The `CALDB` type for the mean absolute QE is `qe`. File names will be of the forms:

```
acisD1996-11-01qeN0001.fits
hrcD1996-11-01qeN0001.fits.
```

No `<detector>` fields are required since all elements will be included in each file.

2.2.2 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_QE	1	CDB_ACIS_QE or CDB_HRC_QE	ASC DETCHAR QE MEAN	Binary table describing the QE vs. Energy for one device (CCD or MCP). Similar device regions (e.g., ACIS quadrants) are included, if appropriate, as separate columns.
2..n	BINTABLE	AXAF_QE	2..n	CDB_ACIS_QE or CDB_HRC_QE	ASC DETCHAR QE MEAN	Binary table describing the QE vs. Energy for additional devices or regions of very different response (e.g., HRC-S filters), as necessary. Keyword will indicate the device (`DETNAM`) and filter (`FILTER`) as necessary.
$n+1..2n$	BINTABLE	AXAF_QEERR	1..n	CDB_ACIS_QEERR or CDB_HRC_QEERR	ASC DETCHAR ERR MEAN	Binary table describing the uncertainty on the QE vs. Energy for each device or region; there is one extensions for each QE extension.

2.2.3 Explicit HDU/Column Enumeration

To make the file structure explicit, the following table defines the actual structure of ACIS or HRC files.

INSTRUME	DETNAM	EXTVER	FILTER	QE TTYPES
ACIS	ACIS-0	1	UVIS_ACISI	QE, QE0, QE1, QE2, QE3
"	ACIS-1	2	UVIS_ACISI	"
"	ACIS-2	3	UVIS_ACISI	"
"	ACIS-3	4	UVIS_ACISI	"
"	ACIS-4	5	UVIS_ACISS	"
"	ACIS-5	6	UVIS_ACISS	"
"	ACIS-6	7	UVIS_ACISS	"
"	ACIS-7	8	UVIS_ACISS	"
"	ACIS-8	9	UVIS_ACISS	"
"	ACIS-9	10	UVIS_ACISS	"
ACIS	ACIS-0	1	UVIS_ACISI	ERR, ERR0, ERR1, ERR2, ERR3
... etc., for acis 2-9 uncertainty extensions...				
HRC	HRC-I	1	UVIS_HRCI	QE
"	HRC-S0	2	UVIS_HRCS3	"
"	HRC-S0	3	UVIS_HRCS5	"
"	HRC-S1	4	UVIS_HRCS1	"
"	HRC-S1	5	UVIS_HRCS2	"
"	HRC-S2	6	UVIS_HRCS4	"
"	HRC-S2	7	UVIS_HRCS6	"
HRC	HRC-I	1	UVIS_HRCI	ERR
... etc., for hrc-s* uncertainty extensions...				

2.2.4 Columns and Coordinate Systems

Columns for Detector QE HDU are given in the following table. QEn columns are added as required for the number of device segments (e.g., 4 for ACIS quadrants on each chip, none for HRC).

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	Description
ENERGY	keV	1E	0.06	10.0	Energy
QE		1E	0.0	1.0	Mean Quantum efficiency for the device, averaged over all segments.
Optional columns — ACIS only:					
QE0		1E	0.0	1.0	Quantum efficiency for the device, first segment.
QE1		1E	0.0	1.0	Quantum efficiency for the device, second segment.
QE2		1E	0.0	1.0	Quantum efficiency for the device, third segment.
QE3		1E	0.0	1.0	Quantum efficiency for the device, fourth segment.

Columns for uncertainty HDUs are given in the following table. `ERR`n columns are added as required for the number of device segments (e.g., 4 for ACIS quadrants on each chip, none for HRC).

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	Description
ENERGY	keV	1E	0.06	10.0	Energy
ERR		1E	0.0	N/A	Uncertainty in mean Quantum efficiency for the device, averaged over all segments.
Optional columns — ACIS only:					
ERR0		1E	0.0	N/A	Uncertainty in quantum efficiency for the device, first segment.
ERR1		1E	0.0	N/A	Uncertainty in quantum efficiency for the device, second segment.
ERR2		1E	0.0	N/A	Uncertainty in quantum efficiency for the device, third segment.
ERR3	1	1E	0.0	N/A	Uncertainty in quantum efficiency for the device, fourth segment.

ACIS quadrants are numbered from 0-3 starting at `CHIPX`= 1 and proceeding to greater `CHIPX`:

```
     quadrants
   0   1   2   3
 +---+---+---+---+
 |   |   |   |   |
 |   |   |   |   |
 |   |   |   |   |
 |   |   |   |   |
 |   |   |   |   |
 |   |   |   |   |
 +---+---+---+---+
 CHIPX ---->
```

(Note: the direction of AXAF-y relative to `CHIPX` varies with chip on ACIS-I, but is parallel to it on ACIS-S.)

HRC-S segments are as indicated in the following figure:

```
        S0                     S1                    S2
+------------------+ +--------------------+ +--------------------+
|        5         | |          1         | |          6         |
+------------------+ +------+        +----+ +--------------------+
|                  | |      |        |    | |                    |
|                  | |      |    +   |    | |                    |
|                  | |      |        |    | |                    |
|        3         | |  2   |        |  2 | |          4         |
|                  | |      |        |    | |                    |
+------------------+ +------+--------+----+ +--------------------+
                         Left <----> Right
```

This is a schematic of the HRC-S MCP and filter geometry. The geometric center of the middle facet is marked by a "+". Regions labeled 1-6 represent different filter transmissivities, which will be stored in separate FITS binary table extensions and referenced with `FILTER` keywords with values `UVIS_HRCS`n, in which n is the index shown in the above figure.

The filter lies about 10 mm along the positive X axis from the center MCP, with the result that the QE boundaries will be vignetted and not be sharp as shown. The positive AXAF Y-axis is to the right, positive Z is up, and positive X is out of the page.

2.2.5 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`: HRC or ACIS; HRC-I and HRC-S are allowed, but the QE files contain each as extensions and use the `DETNAM` keyword to distinguish them.

`DETNAM`: ACIS-n (where n is replaced with the `CHIPID` value of 0-9), HRC-I, or HRC-Sn, in which the HRC-S chips are numbered 0-2.

`DATAMODE`: For ACIS only, this indicates whether timed or continuous mode.

`READMODE`: For ACIS only, this can have one of about a dozen values, but will usually be `FAINT`, `FAINT_BIAS`, or `GRADED` (see the ASC FITS Guide, Document 4, or the ACIS Level 1 ICD, Document 6).

`FILTER`: The detector filter, which may have values of

```
'NONE'
'UVIS_HRCI'
'UVIS_HRCS1'
'UVIS_HRCS2'
'UVIS_HRCS3'
'UVIS_HRCS4'
'UVIS_HRCS5'
'UVIS_HRCS6'
'UVIS_ACISI'
'UVIS_ACISS'
```

(in which "UVIS" is a mnemonic for Ultraviolet/Ion-Shield (HRC) or Ultraviolet/Visible (ACIS) blocking filter.

2.2.6 `CALDB` Keywords

The required `CALDB` keywords, for both HRC and ACIS mean QE files, are as follows:

```
CCLS0001   'BCF'
CDTP0001   'DATA'
CCNM0001   'QE'
CBD10001   'ENERG(0.06-10.0)keV'
CVSD0001   1996-11-01T00:00:00
CDES0001   'Mean Quantum Efficiency'
```

For the uncertainty extensions, we will use:

```
CCNM0001   'QEERR'
CDES0001   'Uncertainty in mean Quantum Efficiency'
```

The `CBD1` and `CVSD` keywords are subject to revision.

2.3 File Structure: HRC-S QE Uniformity Function

The QE uniformity is stored as a FITS function coefficient table. The independent variable is the energy, and the function value is the ratio of the QE at the specified position to the mean QE at the same energy. There will be at least one row for each cell (about 1000 cells per detector element); more rows will be necessary for each cell if piecewise functions of energy are required. There will be one extension per detector element. The `DETNAM` keyword can be used to discriminate the detector element.

2.3.1 File Names

The `CALDB` type for the QE uniformity is `qeu`. File names will be of the form:

`hrcsD1996-11-01qeuN0001.fits`.

The `<detector>` field (the 's') is required since HRC-S and ACIS have different forms for their unifomity data.

2.3.2 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_QEU	1	CDB_HRCS_QEU	ASC DETCHAR QE UNIF	Polynomial function table describing the QE uniformity vs. Energy at every position.
$2-n$	BINTABLE	AXAF_QEU	$2-n$	CDB_HRCS_QEU	ASC DETCHAR QE UNIF	Polynomial function table describing the QE uniformity vs. Energy at every position, for additional detector segments.

2.3.3 Columns and Coordinate Systems

The uniformity at any position is defined by a polynomial. The position is given in chip pixel coordinates and is specified by the cell center in real-valued pixels, and the cell size in integer pixels. The uniformity function is specified by the valid energy range, the central energy, the polynomial order, and the polynomial coefficients. In the event that piecewise polynomials are needed, there will be multiple rows for each cell with different energy ranges specified for the following parameters. In order to make the interface simpler, the byte-width of the table is held constant; if higher-order coefficients are not used, the coefficient values will be ignored. The following table describes the columns in terms of FITS keywords.

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	TDBIN	TNULL	Description
CHIPX	pixel	1E	1.0	16384.0	1	NaN	X-center of cell
CHIPY	pixel	1E	1.0	16384.0	1	NaN	Y-center of cell
DX	pixel	1I	1	16384	1	0	X-size of cell (if constant, this becomes a keyword)
DY	pixel	1I	1	16384	1	0	Y-size of cell (if constant, this becomes a keyword).
FLMIN	keV	1E	0.	20.	N/A	NaN	Minimum value of the independent variable (E) for the function described by this row. This is given as a column, in case piecewise polynomials are required. If the range is constant (i.e., one piece is sufficient), then this becomes a header keyword.
FLMAX	keV	1E	0.	20.	N/A	NaN	Maximum value of the independent variable (E) (see FLMIN).
E0	keV	1E	0.	20.	N/A	NaN	Central value of independent variable (E) for the function described in this row. This is a parameter of the function.
ORDER	N/A	1I	0	N/A	N/A	-1	Order of the polynomial function described in this row. The number of elements in the coefficient array columns to use is $ORDER+1$. Additional elements are to be ignored. If all rows have the same order, this becomes a header keyword.
COEF	N/A	16E	N/A	N/A	N/A	NaN	Polynomial coefficients

Additional keywords are required to specify the function, as follows:

```
COMMENT Polynomial function specification
FAXIS   = 1
FTYPE   = 'ENERGY'
FUNIT   = 'keV'
COMMENT The following example specifies a 3rd order polynomial.
FUNCTION= 'C0+C1*(E-E0)+C2*(E-E0)**2+C3*(E-E0)**3'
FUNCNAME= 'HRCS_QEUNIF'        / HRC-S QE uniformity polynomial
```

2.3.4 Relevant Header Keywords

The device 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:` `HRC`;

`DETNAM:` `HRC-S`n, in which the HRC-S chips are numbered 0-2.

`FILTER:` `NONE`; the HRC-S uniformities are given independently of the filter.

2.3.5 `CALDB` Keywords

The required `CALDB` keywords are as follows:

```
CCLS0001   'BCF'
CDTP0001   'DATA'
CCNM0001   'QE'
CBD10001   'ENERG(0.06-10.0)keV'
CVSD0001   1996-11-01T00:00:00
CDES0001   'Quantum Efficiency Uniformity'
```

The `CBD1` and `CVSD` keywords are subject to revision.

2.3.6 Explicit HDU/Column Enumeration

To make the file structure explicit, the following tables define the actual structure of the HRC-S file.

INSTRUME	DETNAM	EXTVER
HRCS	HRC-S1	1
"	HRC-S2	2
"	HRC-S3	3

2.4 File Structure: HRC-I Uniformity Image

Revision 1.3 — 29 Mar 1999 — New subsection

The HRC-I QE is non-uniform, but is independent of energy. Hence, we can represent the uniformity as a two-dimensional image, in which detector pixels may be blocked to some appropriate resolution, and whose values are the ratio of the bins integrated QE to the mean integrated QE.

2.4.1 File Names

The `CALDB` type for the QE uniformity is `qeu`. File names will be of the form:

`hrciD1996-11-01qeuN0001.fits`.

The `<detector>` field (the '`i`') is required since HRC-S and ACIS have different forms for their unifomity data.

2.4.2 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	0 (*)	1
HDU Type	PRIMARY	IMAGE
EXTNAME	N/A	AXAF_QEU_IMG
HDUNAME	AXAF_QEU_IMG	AXAF_QEU_IMG
EXTVER	N/A	N/A
CONTENT	CDB_HRC_QEU	CDB_HRC_QEU_ERR
HDUCLASS	ASC	ASC
	DETCHAR	DETCHAR
	QE	ERR
	UNIF	UNIF
Description	IMAGE of the HRC-I QE uniformity.	IMAGE of the uncertainty in HRC-I QE uniformity.

2.4.3 Columns, Axes, and Coordinate Systems

The logical coordinate of the image is a bin which each cell represents some number of detector pixels. The coordinate system keywords provide the coefficients to transform the logical pixel into the physical detector pixel. The image values are unitless, real values.

CTYPE	CNAME	CRPIX	CRVAL	CDELT	CUNIT	Description
pixel	CHIPX	1	$(N+1)/2.0$	N	pixel	First spatial axis.
pixel	CHIPY	1	$(N+1)/2.0$	N	pixel	Second spatial axis.

The blocking factor is arbitarily given as N, which should be replaced in the actual file the the value used for N. It is assumed that the x and y blocking factors will be identical.

2.4.4 Relevant Header Keywords

The device 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`: `HRC`;

`DETNAM`: `HRC-I`.

`FILTER`: `NONE` (the uniformity is provided independently of the filter).

2.4.5 `CALDB` Keywords

The required `CALDB` keywords are as follows:

```
CCLS0001  'BCF'
CDTP0001  'DATA'
CCNM0001  'QE'
CBD10001  'ENERG(0.06-10.0)keV'
CVSD0001  1996-11-01T00:00:00
CDES0001  'Quantum Efficiency Uniformity'
```

For the uncertainty extensions, we will use:

```
CCNM0001  'QEERR'
CDES0001  'Uncertainty in mean Quantum Efficiency'
```

The `CBD1` and `CVSD` keywords are subject to revision.

2.5 File Structure: ACIS BI Uniformity Function

Revision 1.3 — 29 Mar 1999 — New subsection

The ACIS QE uniformity is stored as a FITS images containing depletion depths vs position for each back-illuminated (BI) CCD, and as a table of function coefficients for the characteristic depletion depth as a function of energy. The function value is the ratio of the QE at the specified position to the mean QE at the same energy. There will be at least one row for each cell (about 1000 cells per detector element); more rows will be necessary for each cell if piecewise functions of energy are required (such as between absorption edges). There will be one image per detector element, and one coefficient table. The `DETNAM` keyword can be used to discriminate the detector element.

2.5.1 File Names

The `CALDB` type for the QE uniformity is `qeu`. File names will be of the form:

`acisD1996-11-01qeuN0001.fits`.

The `<detector>` field is not required since the file will contain extensions for different detector elements (the BI CCDs).

2.5.2 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	CDB_ACIS_QEU	ASC DETCHAR QE UNIF	An image of depletion-depth values for spatial bins as defined by the coordinate system keywords for the detector element named by `DETNAM`.
1	IMAGE	AXAF_QEU	1	CDB_ACIS_QEU	ASC DETCHAR QE UNIF	Same as PRIMARY, but for another detector element.
2	BINTABLE	AXAF_QEU	2	CDB_ACIS_QEU_FUNC	ASC DETCHAR QE UNIF	Power-law coefficient table describing the CCD characteristic depletion depth vs. Energy.

2.5.3 Columns and Coordinate Systems

The depletion depth in chip pixel coordinates and is specified by the cell center in real-valued pixels, and the cell size in integer pixels. The logical coordinate of the image is a bin which each cell represents some number of detector pixels. The coordinate system keywords provide the coefficients to transform the logical pixel into the physical detector pixel. The image values are real values of with units of length.

CTYPE	CNAME	CRPIX	CRVAL	CDELT	CUNIT	Description
pixel	CHIPX	1	$(N+1)/2.0$	N	pixel	First spatial axis.
pixel	CHIPY	1	$(N+1)/2.0$	N	pixel	Second spatial axis.

The blocking factor is arbitarily given as N, which should be replaced in the actual file the the value used for N. It is assumed that the x and y blocking factors will be identical.

The characteristic depth function is specified by the valid energy range, the central energy, and the polynomial coefficients. In the event that piecewise polynomials are needed, there will be multiple rows for each cell with different energy ranges specified for the following parameters. The following table describes the columns in terms of FITS keywords.

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	TNULL	Description
FLMIN	keV	1E	0.	20.	NaN	Minimum value of the independent variable (E) for the function described by this row. This is given as a column, in case piecewise power-laws are required. If the range is constant (i.e., one piece is sufficient), then this becomes a header keyword.
FLMAX	keV	1E	0.	20.	NaN	Maximum value of the independent variable (E) (see FLMIN).
E0	keV	1E	0.	20.	NaN	Central value of independent variable (E) for the function described in this row. This is a parameter of the function.
COEF	N/A	2E	0.0	N/A	NaN	Power law coefficients, C_i, for function $\Lambda(E) = C_0(E - E_0)^{C_1}$.

Additional keywords are required to specify the function, as follows:

```
COMMENT Power law function specification
FAXIS   = 1
FTYPE   = 'ENERGY'
FUNIT   = 'keV'                / unit of independent variable
BUNIT   = 'mm'                 / unit of result
COMMENT The following example specifies a power-law:
FUNCTION= 'C0*(E-E0)**C1'
FUNCNAME= 'ACIS_CHARDEPTH'     / characteristic depletion depth powrlaw
```

2.5.4 Relevant Header Keywords

The device 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. The data units are specified by the BUNIT keyword, and are nominally mm. Relevant keywords are:

```
BUNIT   = 'mm'            / units of image data
INSTRUME= 'ACIS'          / instrument
DETNAM  = 'ACIS-n'        / in which the BI chips have n=5 or 7
FILTER  = 'NONE'          / the uniformity is given independently of the filter.
```

2.5.5 CALDB Keywords

The required CALDB keywords are as follows:

```
CCLS0001  'BCF'
CDTP0001  'DATA'
CCNM0001  'QE'
CBD10001  'ENERG(0.06-10.0)keV'
CVSD0001  1996-11-01T00:00:00
CDES0001  'Quantum Efficiency Uniformity'
```

The CBD1 and CVSD keywords are subject to revision.

2.6 File Structure: Discrete QE vs Position and Energy

The QE of the detectors depends upon energy (E) and position (x, y). These data will be stored as three-dimensional images on these axes. Multiple 3D images are required in order to describe the efficiency for each detector element — 10 ACIS CCDs and 4 HRC micro-channel plates. The HRC-S micro-channel plates are further sub-divided into separate regions by the UV/ion shield and filter.

For each QE image, there is a corresponding extension containing a QE uncertainty image of the same structure.

For most analysis purposes, higher level products will be sufficient, since the uniformity and mean QE together provide the QE as a function of position and energy. The discrete form, however, is what those products are generated from, and it is provided as a more direct and fundamental product.

The order of axes is arbitrary, but preferred to be x, y, E, from most to least varying index. This is because common usage will retrieve a 2D image at constant energy. Since the energy axes may be non-linear, its coordinates are encoded in `EGRID` extensions. The spatial axes are linear and will have coordinate systems attached.

2.6.1 File Names

The `CALDB` type for the discrete QE is `qexye`. File names will be of the forms:

```
acisD1996-11-01qexyeN0001.fits
hrcD1996-11-01qexyeN0001.fits.
```

No `<detector>` fields are required since all elements will be included in each file as extensions.

2.6.2 HDU Components

The following table describes the file structure by Header-Data Unit number, HDU-type, extension name, content, and HDU classes. An asterisk (*) denotes the principal HDU. The principal HDU will contain a three-dimensional image of the QE, with two spatial dimensions and one energy dimension. The energies of each plane will be tabulated in an `EGRID` extension with a different `EXTNAME` but identical `EXTVER` (since there will be multiple extensions of the same kind). The spatial dimensions will be uniform and header keywords will define the cells in terms of detector pixel coordinates. Each device (such as ACIS CCDs or HRC MCPs) will have its data stored in a pair of seperate HDUs. The different HRC-S filter regions will be distinguishable by the `FILTER` keyword (if this keyword has the value, `NONE`, then no filter transmissivity has been included). Uncertainties are stored in associated extensions having the same structure as the QE, but with the string, "ERR", in the column, content, and HDU names.

HDU	HDU Type	EXTNAME	EXTVER	CONTENT	HDUCLASS	Description
0	PRIMARY	N/A	N/A	N/A	N/A	NULL
1 (*)	IMAGE	AXAF_QEXYE	1	CDB_QEXYE	ASC DETCHAR QE XY_ENERGY	3D image of detector QE vs position and energy for first segment.
2	BINTABLE	EGRID	1	EGRID	ASC GRID ENERGY	Energy grid for image energy axis for QEXYE image extension with the same EXTVER.
3	IMAGE	AXAF_QEXYE	2	CDB_QEXYE	ASC DETCHAR QE XY_ENERGY	3D image of detector QE vs position and energy for 2nd segment.
4	BINTABLE	EGRID	2	EGRID	ASC GRID ENERGY	Energy grid for image energy axis, for another segment (with matching `EXTVER` and `EXTNAME=AXAF_QEXYE`).
$5, 6, \ldots, 2n-2$						
$2n-1$	IMAGE	AXAF_QEXYE	n	CDB_QEXYE	ASC DETCHAR QE XY_ENERGY	3D image of detector QE vs position and energy for nth segment.
$2n$	BINTABLE	EGRID	n	EGRID	ASC GRID ENERGY	Energy grid for image energy axis, for another segment (with matching `EXTVER` and `EXTNAME=AXAF_QEXYE`).
etc.	IMAGE	AXAF_QEXYE_ERR	$1..n$	CDB_QEXYE_ERR	ASC DETCHAR ERR XY_ENERGY	3D image of uncertainty in detector QE vs position and energy for nth segment.
etc.	BINTABLE	EGRID	$1..n$	EGRID	ASC GRID ENERGY	Energy grid for image energy axis, for another segment (with matching `EXTVER` and `EXTNAME=AXAF_QEXYE`).

2.6.3 Explicit HDU/Column Enumeration

To make the files' structures more explicit, the following tables define the actual structure of ACIS and HRC files. Note that if the UV-blocking filter is *not* included in the response, that there will be fewer HRC-S extensions.

INSTRUME	DETNAM	EXTVER	EXTNAMEs	FILTER
ACIS	ACIS-0	1	AXAF_QEXYE, EGRID	UVIS_AI
"	ACIS-1	2	"	"
"	ACIS-2	3	"	"
"	ACIS-3	4	"	"
"	ACIS-4	5	"	UVIS_AS
"	ACIS-5	6	"	"
"	ACIS-6	7	"	"
"	ACIS-7	8	"	"
"	ACIS-8	9	"	"
"	ACIS-9	10	"	"
ACIS	ACIS-0	1	AXAF_QEXYE_ERR, EGRID	UVIS_AI
	. . . etc., for acis2-9 uncertainty extensions. . .			
HRC	HRC-I	1	AXAF_QEXYE, EGRID	UVIS_HRCI
"	HRC-S0	2	"	UVIS_HRCS3
"	HRC-S0	3	"	UVIS_HRCS1
"	HRC-S1	4	"	UVIS_HRCS0
"	HRC-S1	5	"	UVIS_HRCS2
"	HRC-S2	6	"	UVIS_HRCS4
"	HRC-S2	7	"	UVIS_HRCS6
HRC	HRC-I	1	AXAF_QEXYE_ERR, EGRID	UVIS_HRCI
	. . . etc., for hrcs* uncertainty extensions. . .			

2.6.4 Columns, Axes, and Coordinate Systems

The image axes will be in chip coordinates, and are binned by some number of pixels in both x and y. Coordinate keywords will specify this gridding. The following table specifies the image coordinates. The "n" in CRVAL and CDELT is to be replaced with the actual blocking factor. HRC is likely to have $n = 128$, which ACIS will be about $n = 32$ (to within factors of 2).

CTYPE	CNAME	CRPIX	CRVAL	CDELT	CUNIT	Description
pixel	CHIPX	1	$(N + 1)/2.$	N	pixel	First spatial axis.
pixel	CHIPY	1	$(N + 1)/2.$	N	pixel	Second spatial axis.
energy	ENERGY	N/A	N/A	N/A	keV	Energy axis (tabulated in `EGRID` extension).

The energy grid, which is discrete and not binned, is given in the auxiliary `EGRID` extension. The columns are given in the following table.

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	TNULL	Description
ENERGY	keV	1E	0.0	20.	NaN	energies of image planes

2.6.5 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:` HRC or ACIS; HRC-I and HRC-S are allowed, but the QE files contain each as extensions and use the `DETNAM` keyword to distinguish them.

`DETNAM:` ACIS-n (where n is replaced with the `CHIPID` value of 0-9), HRC-I, or HRC-Sn, in which the HRC-S chips are numbered 1-3 (HRC-I is chip 0).

`DATAMODE:` For ACIS only, this indicates whether timed or continuous mode.

`READMODE:` For ACIS only, this can have one of about a dozen values, but will usually be `FAINT`, `FAINT_BIAS`, or `GRADED` (see the ASC FITS Guide, Document 4, or the ACIS Level 1 ICD, Document 6).

`FILTER:` Indicates whether filter transmission is included in the QE (value other than `NONE`), and which filter, if included.

2.6.6 `CALDB` Keywords

The required `CALDB` keywords are as follows:

```
CCLS0001  'BCF'
CDTP0001  'DATA'
CCNM0001  'QE'
CBD10001  'ENERG(0.06-10.0)keV'
CVSD0001  1996-11-01T00:00:00
CDES0001  'Discrete Quantum Efficiency vs Position and Energy'
```

For the uncertainty extensions, we use

```
CCNM0001  'QEERR'
CDES0001  'Uncertainty in discrete quantum efficiency vs position and energy'
```

The `CBD1` and `CVSD` keywords are subject to revision.

2.7 Size and File Number Estimates

2.7.1 Mean Absolute QE

For ACIS, each of 10 QE extensions and 10 error has 6 columns of reals, and will have about 1024 rows. This yields about 480 kB per file. There will be one file for each mode of operation. At least three modes are expected: 2 grade sets in timed exposure, and one in continuous-clocking.

HRC will need a QE function for each MCP and filter combination. There will be 7 QE extensions and 7 error extensions, each with two columns. For 1024 energy points each, the final size will be about 56 kB.

2.7.2 Spatial QE

The discrete QE map is nominally provided on a spatial grid of about 32×32 bins, where each bin either represents 32×32 (ACIS) or 256×256 (HRC) detector pixels. There will nominally be about 20 energy bins (TBR). For 20 real-valued images of 1024 bins each requires 80 kB. There will be 10 image such extensions for ACIS making 800 kB, and 3 for HRC making 240 kB. The energy grid extensions are of negligible size relative to the QE images.

2.7.3 QE Uniformity

The uniformity map will have about 60 bytes per row, one row per spatial cell, and one extension per detector element. For about 1024 rows and 13 detector elements (10 ACIS, 3 HRC, in 2 files) we require about 1 MB. There will be one file for ACIS and one for HRC.

2.8 Unresolved Issues

3 HRMA On-axis Effective Area

New section, 990325.

Data Product Summary

Analysis Reference Data Product	HRMA On-Axis Effective Area
Instrument(s)	HRMA
Level	2
Scientist/SDS	D. Huenemoerder
Scientist/Cal	L. David
Filetype	FITS bintable
Created by tool	TBD
Used by tool(s)	expmap
Sample file	`hrmaD1996-11-01axeffaN0002.fits`

The on-axis mirror effective area is a function of energy and mirror shell. Imaging observations require the ensemble area, while grating observations require knowledge of individual shell areas, since each shell is weighted by the grating efficiencies for that shell. The on-axis area is modeled at high energy resolution. In conjunction with a low-resolution vignetting model, it can provide a high-resolution off-axis area function.

3.1 File Structure

The axial effective area will be stored a a FITS binary table. Multiple extensions will store the all-shell ensemble area and areas for each individual shell. For each table of the effective area, there is a corresponding table containing the uncertainty of the area.

3.1.1 File Names

The `CALDB` type for the HRMA axial effective area is `axeffa`. File names will be of the forms:

```
hrmaD1996-11-01axeffaN0001.fits
```

3.1.2 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 ASC principal HDU.

HDU	HDU TYPE	EXTNAME	CONTENT	HDUCLASS	Description
0 (*)	PRIMARY	N/A	N/A	N/A	NULL
1	BINTABLE	AXAF_AXEFFA	CDB_HRMA_AXEFFA	ASC RESPONSE EFF AXEFFA	binary table, cm^2 vs E, for all shells.
2	BINTABLE	AXAF_AXEFFA	CDB_HRMA_AXEFFA	ASC RESPONSE EFF AXEFFA	binary table, cm^2 vs E, for shell 1.
3	BINTABLE	AXAF_AXEFFA	CDB_HRMA_AXEFFA	ASC RESPONSE EFF AXEFFA	binary table, cm^2 vs E, for shell 3.
4	BINTABLE	AXAF_AXEFFA	CDB_HRMA_AXEFFA	ASC RESPONSE EFF AXEFFA	binary table, cm^2 vs E, for shell 4.
5	BINTABLE	AXAF_AXEFFA	CDB_HRMA_AXEFFA	ASC RESPONSE EFF AXEFFA	binary table, cm^2 vs E, for shell 6.
6	BINTABLE	AXAF_AXEFFA_ERR	CDB_HRMA_AXEFFAERR	ASC RESPONSE ERR AXEFFA	binary table, cm^2 vs E, for all shells.
7	BINTABLE	AXAF_AXEFFA_ERR	CDB_HRMA_AXEFFAERR	ASC RESPONSE ERR AXEFFA	binary table, cm^2 vs E, for shell 1.
8	BINTABLE	AXAF_AXEFFA_ERR	CDB_HRMA_AXEFFAERR	ASC RESPONSE ERR AXEFFA	binary table, cm^2 vs E, for shell 3.
8	BINTABLE	AXAF_AXEFFA_ERR	CDB_HRMA_AXEFFAERR	ASC RESPONSE ERR AXEFFA	binary table, cm^2 vs E, for shell 4.
8	BINTABLE	AXAF_AXEFFA_ERR	CDB_HRMA_AXEFFAERR	ASC RESPONSE ERR AXEFFA	binary table, cm^2 vs E, for shell 6.

3.1.3 Columns and Coordinate Systems

Columns for each area HDU are given in the following table.

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	Description
ENERGY	keV	1E	0.06	10.0	Energy
EFFA	`cm**2`	1E	0.0	N/A	Mirror efffective area

Columns for each uncertainty HDU are given in the following table.

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	Description
ENERGY	keV	1E	0.06	10.0	Energy
ERR	cm**2	1E	0.0	N/A	Uncertainty in mirror efffective area

3.2 Special Header Keywords

The shells included in the response are indicated with a bitmap, with one bit for each shell. If the place is a "1", then that shell's response is included. The bits correspond to shell 1346 in that order (1 being the outer shell). The example shows only shell 1 included. Typical values will be: 1111, 1000, 0100, 0010, and 0001.

```
SHELL   = '1000    '           /Shell 1346 bitmap; 1=>response included
```

3.2.1 `CALDB` Keywords

The required `CALDB` keywords are as follows:

```
CCLS0001  'BCF'
CDTP0001  'DATA'
CCNM0001  'AXEFFA'
CBD10001  'ENERG(0.05-10.0)keV'
CVSD0001  1996-11-01T00:00:00
CDES0001  'Telescope axial effective area'
```

For the uncertainty extensions, we will use:

```
CCNM0001  'AXEFFAERR'
CDES0001  'Uncertainty in axial HRMA effective area'
```

The `CBD1` and `CVSD` keywords are subject to revision.

3.3 Size Estimate

The nominal number energy points is 1000. Hence, the single HDU table size is about 8 kB. There are five such tavle HDUs for different shell combinations, and five for uncertainties. Hence the total size is of order 80 kB (plus headers). One file suffices to specify the HRMA effective area.

3.4 Unresolved Issues

1. (none)

4 HRMA Off-axis Effective Area

Data Product Summary

Analysis Reference Data Product	HRMA Effective Area
Instrument(s)	HRMA
Level	2
Scientist/SDS	D. Huenemoerder
Scientist/Cal	L. David
Filetype	FITS bintable
Created by tool	TBD
Used by tool(s)	expmap
Sample file	`hrmaD1996-11-01effaN0002.fits`

The effective area of the mirror depends on energy (E), off-axis angle (θ), and azimuthal angle (ϕ), in order of the magnitude of variation. The HRMA effective area is input to the exposure map creation, where it is combined with the detector QE (which is also spatially dependent), and possibly integrated over energy.

4.1 File Structure

The HRMA effective area will be stored as three-dimensional images. Multiple 3D images are required in order to store the effective area for the all-shell ensemble and for each individual shell. Imaging mode (non-grating observations or zero-order imaging) or LETG mode require the ensemble area, while HETG data require single-shell responses. For each image of the effective area, there is a corresponding image containing the uncertainty of the area.

Since the axes may be non-linear, the coordinates are encoded in a "`*GRID`" extension for each axis.

The order of axes is E, θ, and ϕ, from most to least varying index. This is because expected usage will retrieve a vector in energy at constant θ and ϕ.

4.1.1 File Names

The `CALDB` type for the HRMA effective area is `effa`. File names will be of the forms:

```
hrmaD1996-11-01effaN0001.fits
```

4.1.2 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 ASC principal HDU.

HDU	HDU TYPE	EXTNAME	CONTENT	HDUCLASS	Description
0 (*)	PRIMARY	AXAF_EFFAREA	CDB_HRMA_EFFA	ASC RESPONSE EFF EFFAREA	3D image, cm^2 vs θ, ϕ, E, for all shells.
1	IMAGE	AXAF_EFFAREA	CDB_HRMA_EFFA	ASC RESPONSE EFF EFFAREA	3D image, cm^2 vs θ, ϕ, E, for shell 1.
2	IMAGE	AXAF_EFFAREA	CDB_HRMA_EFFA	ASC RESPONSE EFF EFFAREA	3D image, cm^2 vs θ, ϕ, E, for shell 3.
3	IMAGE	AXAF_EFFAREA	CDB_HRMA_EFFA	ASC RESPONSE EFF EFFAREA	3D image, cm^2 vs θ, ϕ, E, for shells 4.
4	IMAGE	AXAF_EFFAREA	CDB_HRMA_EFFA	ASC RESPONSE EFF EFFAREA	3D image, cm^2 vs θ, ϕ, E, for shells 6.
5	BINTABLE	EGRID	EGRID	ASC GRID ENERGY	Energy grid for 3D images' 3rd axes (Energy)
6	BINTABLE	TGRID	TGRID	ASC GRID ANGLE	θ-grid for 3D images' 1st axis (off-axis angle)
7	BINTABLE	PGRID	PGRID	ASC GRID ANGLE	ϕ-grid for 3D images' 2nd axis (azimuthal angle)
8	IMAGE	AXAF_EFFA_ERR	CDB_HRMA_EFFAERR	ASC RESPONSE ERR EFFAREA	3D image, Uncertainty in effective area for all shells.
9	IMAGE	AXAF_EFFA_ERR	CDB_HRMA_EFFAERR	ASC RESPONSE ERR EFFAREA	3D image, Uncertainty in effective area for shell 1.
10	IMAGE	AXAF_EFFA_ERR	CDB_HRMA_EFFAERR	ASC RESPONSE ERR EFFAREA	3D image, Uncertainty in effective area for shell 3.
11	IMAGE	AXAF_EFFA_ERR	CDB_HRMA_EFFAERR	ASC RESPONSE ERR EFFAREA	3D image, Uncertainty in effective area for shell 4.
12	IMAGE	AXAF_EFFA_ERR	CDB_HRMA_EFFAERR	ASC RESPONSE ERR EFFAREA	3D image, Uncertainty in effective area for shell 6.

4.1.3 Column and Axis Descriptions

The axes of the images are:

ENERGY: the energy, measured in keV.

THETA: the off-axis angle measured in arcminutes,

PHI: the azimuthal angle, measured in degrees, and

These are specified by the `CTYPE`n keywords as follows:

CTYPE	CNAME	CRPIX	CRVAL	CDELT	CUNIT	Comment
energy	ENERGY	N/A (See auxiliary extension, EGRID)				Energy axis.
angle	THETA	N/A (See auxiliary extension, TGRID)				First spatial axis: off-axis angle.
angle	PHI	N/A (See auxiliary extension, PGRID)				Second spatial axis: azimuthal angle.

Each axis has its bin's coordinates tabulated in the following extensions:

EGRID for ENERGY,

TGRID for THETA, and

PGRID for PHI.

The "*GRID" extensions' columns are described in the following tables.

Columns for Auxiliary EGRID HDU:

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	TDBIN	TNULL	Comment
ENERGY	keV	1E	0.0	20.	0.001	*NaN*	energy of bin

Columns for Auxiliary TGRID HDU:

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	TDBIN	TNULL	Comment
THETA	arcmin	1E	0.0	60.	0.1	*NaN*	angle of bin

Columns for Auxiliary PGRID HDU:

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	TDBIN	TNULL	Comment
PHI	deg	1E	0.0	360.	1.0	*NaN*	azimuth of bin

Table Notes: "*NaN*" is the IEEE standard for "Not a Number". It is not actually encoded as a TNULL entry in the header, but is implicitly understood as such by the FITS standard.

4.2 Special Header Keywords

Since the image axes are enumerated explicitly in auxiliary extensions, the image HDUs do not have coordinate systems attached. The axes are treated such because they are nominally non-linear.

Each header does, however, require the units of the data to be specified with the `BUNIT` keyword. Missing data, as for unspecified regions of the (θ, ϕ, E) volume, have values specified by the `BLANK` keyword. If this is not present and the data are reals (as they are specified), then the IEEE NaN value is implied (since `BLANK = NaN` is not allowed in the FITS standard). The shells included in the response are indicated with a bitmap, with one bit for each shell. If the place is a "1", then that shell's response is included. The bits correspond to shell 1346 in that order (1 being the outer shell). The example shows only shell 1 included. Typical values will be: 1111, 1000, 0100, 0010, and 0001.

```
BUNIT   = 'cm**2'
BLANK   = -1
SHELL   = '1000    '           /Shell 1346 bitmap; 1=>response included
```

4.2.1 `CALDB` Keywords

The required `CALDB` keywords are as follows:

```
CCLS0001  'BCF'
CDTP0001  'DATA'
CCNM0001  'EFFAREA'
CBD10001  'ENERG(0.3-8.0)keV'
CBD20001  'THETA(0.0-15.0)arcmin'
CVSD0001  1996-11-01T00:00:00
CDES0001  'Telescope effective area map'
```

For the uncertainty extensions, we will use:

```
CCNM0001  'EFFAERR'
CDES0001  'Uncertainty in mean hrma effective area'
```

The `CBD1` and `CVSD` keywords are subject to revision.

4.3 Size Estimate

The nominal number of off-axis and azimuthal angular bins is about 100, with about 1024 energy bins. Hence, the image size is about 400 kB. There are five such image HDUs for different shell combinations. Hence the total size is of order 4 MB. One file suffices to specify the HRMA effective area.

4.4 Unresolved Issues

1. (none)

5 HRMA Vignetting

New section, 990325.

Data Product Summary

Analysis Reference Data Product	HRMA Vignetting
Instrument(s)	HRMA
Level	2
Scientist/SDS	D. Huenemoerder
Scientist/Cal	L. David
Filetype	FITS bintable
Created by tool	TBD
Used by tool(s)	expmap
Sample file	

The effective area of the mirror depends on energy (E), off-axis angle (θ), and azimuthal angle (ϕ), in order of the magnitude of variation. The HRMA effective area is input to the exposure map creation, where it is combined with the detector QE (which is also spatially dependent), and possibly integrated over energy. The area divided by the on-axis area defines the "vignetting" function. This is a useful quantity because it is smoother than the effective area and can be more easily modeled and interpolated.

The vignetting will be stored in the same 3-D image format as the effective area map. (See Section 4.)

5.1 File Structure

The HRMA vignetting will be stored as three-dimensional images. Multiple 3D images are required in order to store the vignetting for the all-shell ensemble and for each individual shell. Imaging mode (non-grating observations or zero-order imaging) or LETG mode require the ensemble, while HETG data require single-shell responses. For each image of the vignetting, there is a corresponding image containing the uncertainty.

Since the axes may be non-linear, the coordinates are encoded in a "`*GRID`" extension for each axis.

The order of axes is E, θ, and ϕ, from most to least varying index. This is because expected usage will retrieve a vector in energy at constant θ and ϕ.

5.1.1 File Names

The `CALDB` type for the HRMA vignetting is `vignet`. File names will be of the forms:

```
hrmaD1996-11-01vignetN0001.fits
```

5.1.2 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 ASC principal HDU.

HDU	HDU TYPE	EXTNAME	CONTENT	HDUCLASS	Description
0 (*)	PRIMARY	AXAF_VIGNET	CDB_HRMA_VIGNET	OGIP IMAGE VIGNETTING	3D image, V vs θ, ϕ, E, for all shells.
1	IMAGE	AXAF_VIGNET	CDB_HRMA_VIGNET	OGIP IMAGE VIGNETTING	3D image, V vs θ, ϕ, E, for shell 1.
2	IMAGE	AXAF_VIGNET	CDB_HRMA_VIGNET	OGIP IMAGE VIGNETTING	3D image, V vs θ, ϕ, E, for shell 3.
3	IMAGE	AXAF_VIGNET	CDB_HRMA_VIGNET	OGIP IMAGE VIGNETTING	3D image, V vs θ, ϕ, E, for shells 4.
4	IMAGE	AXAF_VIGNET	CDB_HRMA_VIGNET	OGIP IMAGE VIGNETTING	3D image, V vs θ, ϕ, E, for shells 6.
5	BINTABLE	EGRID	EGRID	ASC GRID ENERGY	Energy grid for 3D images' 3rd axes (Energy)
6	BINTABLE	TGRID	TGRID	ASC GRID ANGLE	θ-grid for 3D images' 1st axis (off-axis angle)
7	BINTABLE	PGRID	PGRID	ASC GRID ANGLE	ϕ-grid for 3D images' 2nd axis (azimuthal angle)
8	IMAGE	AXAF_VIGNET_ERR	CDB_HRMA_VIGNERR	OGIP IMAGE VIGNETTING ERR	3D image, Uncertainty in vignetting for all shells.
8	IMAGE	AXAF_VIGN_ERR	CDB_HRMA_VIGNERR	OGIP IMAGE VIGNETTING ERR	3D image, Uncertainty in vignetting for shell 1.
9	IMAGE	AXAF_VIGN_ERR	CDB_HRMA_VIGNERR	OGIP IMAGE VIGNETTING ERR	3D image, Uncertainty in vignetting for shell 3.
10	IMAGE	AXAF_VIGN_ERR	CDB_HRMA_VIGNERR	OGIP IMAGE VIGNETTING ERR	3D image, Uncertainty in vignetting for shell 4.
11	IMAGE	AXAF_VIGN_ERR	CDB_HRMA_VIGNERR	OGIP IMAGE VIGNETTING ERR	3D image, Uncertainty in vignetting for shell 6.

5.1.3 Column and Axis Descriptions

The axes of the images are:

ENERGY: the energy, measured in keV.

THETA: the off-axis angle measured in arcminutes,

PHI: the azimuthal angle, measured in degrees, and

These are specified by the `CTYPE`n keywords as follows:

CTYPE	CNAME	CRPIX	CRVAL	CDELT	CUNIT	Comment
energy	ENERGY	N/A (See auxiliary extension, EGRID)				Energy axis.
angle	THETA	N/A (See auxiliary extension, TGRID)				First spatial axis: off-axis angle.
angle	PHI	N/A (See auxiliary extension, PGRID)				Second spatial axis: azimuthal angle.

Each axis has its bin's coordinates tabulated in the following extensions:

EGRID for ENERGY,

TGRID for THETA, and

PGRID for PHI.

The "*GRID" extensions' columns are described in the following tables.

Columns for Auxiliary EGRID HDU:

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	TDBIN	TNULL	Comment
ENERGY	keV	1E	0.0	20.	0.001	*NaN*	energy of bin

Columns for Auxiliary TGRID HDU:

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	TDBIN	TNULL	Comment
THETA	arcmin	1E	0.0	60.	0.1	*NaN*	angle of bin

Columns for Auxiliary PGRID HDU:

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	TDBIN	TNULL	Comment
PHI	deg	1E	0.0	360.	1.0	*NaN*	azimuth of bin

Table Notes: "*NaN*" is the IEEE standard for "Not a Number". It is not actually encoded as a TNULL entry in the header, but is implicitly understood as such by the FITS standard.

5.2 Special Header Keywords

Since the image axes are enumerated explicitly in auxiliary extensions, the image HDUs do not have coordinate systems attached. The axes are treated such because they are nominally non-linear.

Since vignetting is a unit-less quantity, there is no `BUNIT` keyword. Missing data, as for unspecified regions of the (θ, ϕ, E) volume, have values specified by the `BLANK` keyword. If this is not present and the data are reals (as they are specified), then the IEEE NaN value is implied (since `BLANK = NaN` is not allowed in the FITS standard). The shells included in the response are indicated with a bitmap, with one bit for each shell. If the place is a "1", then that shell's response is included. The bits correspond to shell 1346 in that order (1 being the outer shell). The example shows only shell 1 included. Typical values will be: 1111, 1000, 0100, 0010, and 0001.

```
BLANK   = -1
SHELL   = '1000    '           /Shell 1346 bitmap; 1=>response included
```

5.2.1 `CALDB` Keywords

The required `CALDB` keywords are as follows:

```
CCLS0001  'BCF'
CDTP0001  'DATA'
CCNM0001  'VIGNET'
CBD10001  'ENERG(0.3-8.0)keV'
CBD20001  'THETA(0.0-45.0)arcmin'
CVSD0001  1996-11-01T00:00:00
CDES0001  'Telescope vignetting map'
```

For the uncertainty extensions, we will use:

```
CCNM0001  'VIGNERR'
CDES0001  'Uncertainty in mean HRMA vignetting'
```

The `CBD1` and `CVSD` keywords are subject to revision.

5.3 Size Estimate

There nominal number of off-axis and azimuthal angular bins is about 100, with about 1024 energy bins. Hence, the image size is about 400 kB. There are five such image HDUs for different shell combinations and five for uncertainties. Hence the total size is of order 4 MB. One file suffices to specify the HRMA effective area.

5.4 Unresolved Issues

1. (none)

6 Spectral Models

Data Product Summary

Analysis Reference Data Product	spectrum model file
Instrument(s)	N/A
Level	2
Scientist/SDS	D. Huenemoerder
	J. Houck
Scientist/Cal	N/A
Filetype	FITS Bintable, ASCII Table
Created by tool	TBD
Used by tool(s)	expmap, `MARX`, ASCFit (TBR)
Sample file	TBD

To make a spectrally weighted, integrated exposure map, a model spectrum is required. The spectrum is specified (typically) in units of [photons $\mathrm{cm^{-2}\,s^{-1}\,keV^{-1}}$].

6.1 File Structure

Several file-formats may be supported:

`MARX` **format,** which is simple and in common use for AXAF simulations. It is an ASCII table with two columns: energy in [keV], and differential flux (as given above). A detailed description is given in the `MARX` manual ("`MARX` User Guide"[2]). Each row should have two values: Energy (in [keV]), and photon flux (in [photons $\mathrm{cm^{-2}\,s^{-1}\,keV^{-1}}$]). Rows starting with a "#" character are treated as comments.

`XSPEC` **Table Model**[3]**:** This format allows a grid of models to be stored with associated parameters (such as temperature, abundances, or power-law index). (Note that this is *not* the same as the AXAF binned spectrum product!) The Table Model's units are [photons $\mathrm{cm^{-2}\,s^{-1}\,bin^{-1}}$].

Exposure Map ASCII Table, which is similar to the `MARX` file, but is in integrated units ([photons $\mathrm{cm^{-2}\,s^{-1}}$]). This is the flux integrated over a bandpass. The definition of the bandpass is up to the user.

Utilities (TBS) will provide conversion between these formats for use in different applicatons.

spectrum file conversion utilities

6.2 Size Estimate

Spectrum files will have sizes of order 1 MB times the number of spectra in the table, which is arbitrary (e.g., as for a grid of models). Low resolution models suitable for ACIS or HRC imaging observations will be considerably smaller.

6.3 Unresolved Issues

- use of XSPEC models elsewhere in ASCDS, such as ASCFit?

[2]ftp://asc.harvard.edu/pub/software/GO_cycle1/marx_2.04-dist.tar.gz

7 PSF Width Table

Data Product Summary

Analysis Reference Data Product	PSF Width Table
Instrument(s)	HETG, LETG
Level	1.5
Scientist/SDS	D.Huenemoerder
Scientist/Cal	L.David
Filetype	FITS bintable
Created by tool	TBD
Used by tool(s)	tg_create_mask
Sample file	TBD

In order to generate a region mask for extraction of grating spectra, an imaging PSF table is used to specify the mask dimensions, as affected by off-axis angle and defocus. The table is currently an approximate Gaussian sigma vs. off-axis angle.

7.0.1 File Names

The `CALDB` type for the PSF width table is `wpsf`. File names will be of the forms:

`hrmaD1996-11-01wpsfN0001.fits`

7.1 File Structure

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

HDU	HDU TYPE	EXTNAME	CONTENT	HDUCLASS	Description
0	PRIMARY	N/A	N/A	N/A	NULL
1 (*)	BINTABLE	AXAF_WPSF	CDB_HRMA_WPSF	ASC RESPONSE PSF WPSF	This is a table of the full-width-half-maximum of the HRMA PSF for shell 1, as appropriate for definition of the HETG or LETG zero-order source image size.

The structure of the HDUs, as specified by the ASC FITS Guide (Document 4), is

- Null Primary HDU:

  image mandatory
  null configuration control
  short timing
  short observation

- Principal table HDU:

  bintable mandatory
  table coordinates
  full configuration control
  full observation
  full timing

7.2 Column Descriptions

The table is comprised of two columns which specifies the FWHM in arcseconds vs. off-axis-angle in arcminutes.

Columns for primary HDU

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	TDBIN	TNULL	Comment
OFFAXIS	arcmin	1E	0.0	60.	N/A	*NaN*	Angular distance of the source from the optical axis.
FWHM	arcsec	1E	0.0	N/A	N/A	*NaN*	The full-width half-maximum of the PSF in arcseconds at the given off-axis angle.

7.3 Special Header Keywords

None.

7.3.1 CALDB Keywords

The required CALDB keywords are as follows:

```
CCLS0001  'CPF'
CDTP0001  'DATA'
CCNM0001  'WPSF'
CBD10001  'THETA(0.0-30.0)arcmin'
CVSD0001  1996-11-01T00:00:00
CDES0001  'Radial point spread function widths'
```

7.4 Size Estimate

For about a dozen off-axis angles, the file size is about 10 kB.

7.5 Unresolved Issues

None.

8 RMF Energy-Limit Table

Data Product Summary

Analysis Reference Data Product	PI Region Table
Instrument(s)	HETG/ACIS, LETG/ACIS
Level	1.5
Scientist/SDS	D.Huenemoerder
Scientist/Cal	B.McNamara
Filetype	FITS bintable
Created by tool	TBD
Used by tool(s)	tg_resolve_events
Sample file	TBD

In order to perform order-sorting during extraction of grating spectra detected with ACIS, a pulse-height region (in "pulse invariant" or PI bins, scaled to energy units) is used to specify energy offsets versus energy. The table is generated for a specified fractional enclosed power, and specifies the low and high energy offsets from the nominal energy for this power vs energy (i.e., the actual limits are $E - E\_LO$ to $E + E\_HI$). It is created using a detector response matrix function ("RMF").

The table is constructed for a specified enclosed fractional probability. That is, given the PHA distribution at some energy (in "pulse invariant" energy units), then for some fractional enclosed probability, f, energy limits about the nominal center (defined by the linearized gain to convert from PHA to PI to energy, accounting for CTI), are given by adjusting the high and low limits until the integral between them equals f. If the distribution were a Gaussian, we could give the Gaussian one-sigma width, which would be symmetric about the mean. Instead, the "sigma" has been generalized to refer to upper and lower differences from the mean.

8.1 Current Format

The following subsections describe the generalization to accomodate multiple responses, and change from PI to ENERGY units (since PI has become a linearized bin-number, and not scaled to eV). The multiplicity is required due to the different responses of each individual CCD (even after linearization). Grating spectral order-sorting selects photons from within a CCD response region. Using a table with a constant (or known) fractional flux is required for effective area calibration.

The extension name was changed from "RM" to "IRM", since the quantity tablulated comes from an "Integrated Redistribution Matrix".

8.1.1 File Names

The `CALDB` type for the RMF energy width table is **`irmf`** (which is very short for "integrated redistribution matrix function energy limits"). File names will be of the forms:

```
acisD1996-11-01irmfN0001.fits
```

8.1.2 File Structure

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

HDU	HDU Type	EXTNAME	EXTVER	CONTENT	HDUCLASS	Description
0	PRIMARY	N/A	N/A	N/A	N/A	NULL
1 (*)	BINTABLE	AXAF_IRM	0	CDB_ACIS_IRM	ASC RESPONSE CCD	Redistribution function energy limits vs energy for some fractional enclosed probability, chipid=0 (I0).
2	BINTABLE	AXAF_IRM	1	CDB_ACIS_IRM	ASC RESPONSE CCD	Redistribution function energy limits vs energy for some fractional enclosed probability, chipid=1 (I1).
3	BINTABLE	AXAF_IRM	2	CDB_ACIS_IRM	ASC RESPONSE CCD	Redistribution function energy limits vs energy for some fractional enclosed probability, chipid=2 (I2).
4	BINTABLE	AXAF_IRM	3	CDB_ACIS_IRM	ASC RESPONSE CCD	Redistribution function energy limits vs energy for some fractional enclosed probability, chipid=3 (I3).
5	BINTABLE	AXAF_IRM	4	CDB_ACIS_IRM	ASC RESPONSE CCD	Redistribution function energy limits vs energy for some fractional enclosed probability, chipid=4 (S0).
6	BINTABLE	AXAF_IRM	5	CDB_ACIS_IRM	ASC RESPONSE CCD	Redistribution function energy limits vs energy for some fractional enclosed probability, chipid=5 (S1).
7	BINTABLE	AXAF_IRM	6	CDB_ACIS_IRM	ASC RESPONSE CCD	Redistribution function energy limits vs energy for some fractional enclosed probability, chipid=6 (S2).
8	BINTABLE	AXAF_IRM	7	CDB_ACIS_IRM	ASC RESPONSE CCD	Redistribution function energy limits vs energy for some fractional enclosed probability, chipid=7 (S3).
9	BINTABLE	AXAF_IRM	8	CDB_ACIS_IRM	ASC RESPONSE CCD	Redistribution function energy limits vs energy for some fractional enclosed probability, chipid=8 (S4).
10	BINTABLE	AXAF_IRM	9	CDB_ACIS_IRM	ASC RESPONSE CCD	Redistribution function energy limits vs energy for some fractional enclosed probability, chipid=9 (S5).

8.1.3 Column Descriptions

Columns for *RM_** HDUs

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	TNULL	Comment
ENERGY	eV	1E	0	20000	*NaN*	Energy
ENERGY_LO	eV	1E	0	20000	*NaN*	Low boundary energy difference from central energy.
ENERGY_HI	eV	1E	0	20000	*NaN*	High boundary energy difference from central energy.

8.1.4 Special Header Keywords

In order to correctly calibrate the effective area, each extension must record the fractional probability implied by the table. The value shown is only representative. Its allowed values range from 0.0 to 1.0. Other keywords give the detector element (CCD) and the CCD-mode for the response.

```
FRACPROB=0.95                    / Fractional enclosed probability
DETNAM  ='ACIS-0'                / One of -0 to -9
GRD_SCHM='ACIS'                  / Grading scheme; ASCA|ACIS|USER
READMODE='TIMED'                 / For example. Other modes: FAINT
DATAMODE='FAINT_BIAS'            / For example.
```

8.1.5 `CALDB` Keywords

The required `CALDB` keywords are as follows:

```
CCLS0001  'CPF'
CDTP0001  'DATA'
CCNM0001  'IRM'
CBD10001  'ENERG(0.1-10.0)keV'
CVSD0001  1996-11-01T00:00:00
CDES0001  'ACIS integrated redistribution matrix'
```

8.1.6 Size Estimate

A file tabulating limits for about 4096 energies is about 40 kB. The size scales with the number of CCD's, hence, for 10, the size is about 400 kB.

8.2 Unresolved Issues

1. 990305 Should re-cast to a region format (especially for use in exposure map code).

8.3 Obsolete Format

The following subsections describe the prior implementation.

8.3.1 File Structure

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

This was the format prior to release 981207.

HDU	Type	EXTNAME	CONTENT	HDUCLASS	Description
1	NULL	N/A	N/A	N/A	null primary
2 (*)	RM	BINTABLE	ELIMITS	ASC RESPONSE CCD	PI (Energy) limits vs energy for some fractional enclosed probability.

8.3.2 Column Descriptions

Columns for *RM* HDU

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	TNULL	Comment
PI	eV	1E	0	20000	NaN	PI, in energy units
sigma_lo	eV	1E	0	20000	NaN	Low boundary difference from central PI.
sigma_hi	eV	1E	0	20000	NaN	Hi boundary difference from central PI.

8.3.3 Special Header Keywords

None.

8.3.4 Size Estimate

A file tabulating limits for about 4096 energies is about 40 kB.

9 Transmission Grating Efficiency

Data Product Summary

Analysis Reference Data Product	Grating Efficiency
Instrument(s)	HETG, LETG
Level	2
Scientist/SDS	D. Huenemoerder
Scientist/Cal	H. Marshall, J. Drake
Filetype	FITS Bintable
Created by tool	TBD
Used by tool(s)	tgarf (TBR)
Sample file	TBD

The grating efficiency versus order and energy is required for exposure map calculation and ultimately the generation of the "ARF" — the effective area versus wavelength. The efficiencies will be given for each shell as an facet-ensemble average. Typical use will involve weighting each shell by the HRMA shell effective area before combining shells. Efficiency as a function of energy are given for multiple orders.

9.1 File Names

The `CALDB` type for the grating efficiency table is `greff`. File names will be of the forms:

```
hetgD1996-11-01greffN0001.fits
letgD1996-11-01greffN0001.fits
```

9.2 File Structure

The grating efficiency will be stored as FITS binary tables. The Principal HDU will contain the efficiencies, and an auxiliary HDU (in the same format) will contain the uncertainties. Efficiencies vs order will be stored in a vector column. The row will specify the energy. Each of the HRMA shells (or grating rings, enumerated 1, 3, 4, and 6, outer to inner), willl have an extension for the efficiency and another for the uncertainty.

9.2.1 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	CONTENT*	HDUCLASS	Description
0	PRIMARY	N/A	N/A	N/A	NULL
1 (*)	BINTABLE	AXAF_GREFF	CDB_*_GREFF	ASC RESPONSE EFF GREFF	Efficiency vs energy (rows) and order (columns), shell 1 (outermost).
2	BINTABLE	AXAF_GREFF	CDB_*_GREFF	ASC RESPONSE EFF GREFF	Efficiency vs energy (rows) and order (columns), shell 3.
3	BINTABLE	AXAF_GREFF	CDB_*_GREFF	ASC RESPONSE EFF GREFF	Efficiency vs energy (rows) and order (columns), shell 4.
4	BINTABLE	AXAF_GREFF	CDB_*_GREFF	ASC RESPONSE EFF GREFF	Efficiency vs energy (rows) and order (columns), shell 6.
5	BINTABLE	AXAF_GREFF	CDB_*_GRERR	ASC RESPONSE ERR GREFF	Uncertainty of efficiency vs energy (rows) and order (columns), shell 1 (outermost).
6	BINTABLE	AXAF_GREFF	CDB_*_GRERR	ASC RESPONSE ERR GREFF	Uncertainty of efficiency vs energy (rows) and order (columns), shell 3.
7	BINTABLE	AXAF_GREFF	CDB_*_GRERR	ASC RESPONSE ERR GREFF	Uncertainty efficiency vs energy (rows) and order (columns), shell 4.
8	BINTABLE	AXAF_GREFF	CDB_*_GRERR	ASC RESPONSE ERR GREFF	Uncertainty efficiency vs energy (rows) and order (columns), shell 6.

* Replace with HETG or LETG as appropriate.

9.2.2 Columns and Coordinate Systems

Each efficiency HDU will have the following columns:

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	TDBIN	TNULL	Comment
ENERGY	keV	1E	0.0	20.0	0.001	NaN	energy coordinate
EFF	NONE	nE	0.0	1.0	N/A	NaN	Efficiency array, vs order. The first elements is for m= -(NORDERS-1)/2, and the NORDER-th is +(NORDERS-1/)2. Note that n is to be replaced with the actual number of orders, for efficient storage (see NORDERS column definition).

The "ERR" auxiliary extension hdu tables will have analogous structure, but the "EFF" column name will be replaced by "ERR".

9.2.3 Special Header Keywords

The headers will indicate the grating shell through a bitmap keyword. The grating type is specified by a keyword, as are the number of orders included on each row. The calibration data are compressed via a "pruning" algorithm, which deletes points which fall within a tolerance when linearly interpolated. This tolerance is given by `INTRPACC`. The keywords listed must have their values set to reflect the content; typical examples are shown here.

```
INTRPACC=0.5                        / percent accuracy of pruning
GRATING ='LETG'                     / HETG or LETG
NORDERS =                        23 / number of orders included in each row
SHELL   = '0001    '                /Shell 1346 bitmap; 1=>response included
```

9.2.4 `CALDB` Keywords

The required `CALDB` keywords are as follows:

```
CCLS0001   'BCF'
CDTP0001   'DATA'
CCNM0001   'GREFF'
CBD10001   'ENERG(0.1-10.0)keV'
CVSD0001   1996-11-01T00:00:00
CDES0001   'Grating efficiency'
```

For the uncertainty extensions, we will use:

```
CCNM0001   'GRERR'
CDES0001   'Uncertainty in grating efficiency'
```

9.3 Size and File Number Estimates

There will be 3 grating efficiency files: two for HETG (HEG and MEG), and one for LETG. Each file will have about 5000 rows per HDU, of about 200 bytes each, and have about 8 HDUs. Hence the total size is about 16 MB.

9.4 Unresolved Issues

1. none

10 High Energy Suppression Filter (HESF) Efficiency

Data Product Summary

Analysis Reference Data Product	HESF (Drake Flat) Efficiency
Instrument(s)	HRC-S
Level	2
Scientist/SDS	D. Huenemoerder
Scientist/Cal	J. Drake
Filetype	FITS Bintable
Created by tool	TBD
Used by tool(s)	tgarf (tbd)
Sample file	TBD

The High Energy Suppression Filter (HESF, also known as the Drake Flat) efficiency versus energy is required for exposure map calculation and ultimately the generation of the "ARF" — the effective area versus wavelength, in use with the LETG and HRC-S..

10.1 File Structure

The HESF efficiency will be stored as a FITS binary table.

10.2 File Names

The `CALDB` type for the HESF efficiency table is `hesf`. File names will be of the forms:

```
hrcsD1996-11-01hesfN0001.fits
```

10.2.1 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_HESF	1	CDB_HRCS_HESF	ASC RESPONSE FILTER HESF	Efficiency vs energy for the first segment of the flat. If an array column, then it is also vs incident angle.
2	BINTABLE	AXAF_HESF	2	CDB_HRCS_HESF	ASC RESPONSE FILTER HESF	Efficiency vs energy for the second segment of the flat. If an array column, then it is also vs incident angle.
3	BINTABLE	AXAF_HESF	1	CDB_HRCS_HESF_ERR	ASC RESPONSE ERR HESF	Uncertainty in efficiency vs energy for the first segment of the flat.
4	BINTABLE	AXAF_HESF	2	CDB_HRCS_HESF_ERR	ASC RESPONSE ERR HESF	Uncertainty of efficiency vs energy for second segment of the flat.
5	BINTABLE	AXAF_HESF	N/A	CDB_HRCS_HESF_TGRID	ASC RESPONSE TGRID HESF	Grid of incident angles, to map efficiency array column elements. (Optional; used only if principal HDU uses array column for the efficiency.)

10.2.2 Columns and Coordinate Systems

Each efficiency or error HDU will have two of the following types of columns: `ENERGY` and `EFF`, or `ENERGY` and `ERR`, depending on whether it is an efficiency or error HDU. If the efficiency is given as a function of incident angle, then the efficiency or error column will be an array column, and the coordinate grid will be stored in an extension. The value "n" below will be replaced by the actual width of the array.

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	TDBIN	TNULL	Comment
ENERGY	keV	1E	0.0	20.0	0.001	*NaN*	energy coordinate
EFF		nE	0.0	1.0	N/A	*NaN*	Efficiency.
ERR		nE	0.0	N/A	N/A	*NaN*	Uncertainty of efficiency.

The angular grid extension (if present) will have the following column.

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	TDBIN	TNULL	Comment
ANGLE	deg	1E	0.0	6.0	N/A	*NaN*	The angle of incicence of a ray on the HESF.

10.2.3 Special Header Keywords

The calibration data may be compressed via a "pruning" algorithm, which deletes points which fall within a specified tolerance when linearly interpolated. This tolerance is given by `INTRPACC`. The keywords listed must have their values set to reflect the content; typical examples are shown here.

```
INTRPACC=0.5                    / percent accuracy of pruning
FILTER  ='HESF'                 / High Energy Suppresion Filter
NANGLES = n                     / Number of angles; width of array column
```

10.2.4 `CALDB` Keywords

The required `CALDB` keywords are as follows:

```
CCLS0001  'BCF'
CDTP0001  'DATA'
CCNM0001  'HESF'
CBD10001  'ENERG(0.06-10.0)keV'
CVSD0001  1996-11-01T00:00:00
CDES0001  'High Energy Suppression Filter (Drake Flat)'
```

For the uncertainty extensions, we will use:

```
CCNM0001  'ERR'
CDES0001  'Uncertainty in HESF efficiency'
```

10.3 Size and File Number Estimates

There will be one HESF efficiency files. The file will have about 5000 rows per HDU, of about 12 bytes each, and have 2 HDUs. Hence the total size is about 120 kB.

10.4 Unresolved Issues

1. (none yet)

11 HRC and ACIS Filter Transmission Efficiencies

New Section, V1.3 (990308)

ACIS-I and ACIS-S each have UV/optical blocking filters which entirely cover each array. The filter efficiency can be combined with the detector QE for most analysis purposes. For completeness, however, filter transmission files will be produced.

HRC-I and HRC-S have several UV/Optical blocking filters (which also serve as ion-shields) preceding the micro-channel plates. In some cases, analysis requires knowledge of the filter transmissions independently of the MCP quantum efficiencies — the filter is offset towards the mirror, so the boundaries are not sharp, due to differential vignetting of the converting cone of rays.

One single filter covers all of HRC-I. HRC-S has six distinct filter regions as follows:

```
          S0                      S1                     S2
+-----------------+ +-------------------+ +--------------------+
|       5         | |          1        | |          6         |
+-----------------+ +------+        +----+ +--------------------+
|                 | |      |        |    | |                    |
|                 | |      |   +    |    | |                    |
|                 | |      |        |    | |                    |
|       3         | |  2   |        |  2 | |          4         |
|                 | |      |        |    | |                    |
+-----------------+ +------+--------+----+ +--------------------+
                            Left <----> Right
```

The transmission efficiencies of regions labeled 1-6 will be stored in separate FITS binary table extensions and referenced with `FILTER` keywords with values `UVIS_HRCS`n, in which n is the index shown in the above figure. For each efficiency HDU, there will be an accompanying extension holding uncertainties.

11.1 File Names

The `CALDB` type for the filter transmission efficiency table is `uvis`. File names will be of the forms:

```
hrciD1996-11-01uvisN0001.fits
hrcsD1996-11-01uvisN0001.fits
acisiD1996-11-01uvisN0001.fits
acissD1996-11-01uvisN0001.fits
```

11.2 File Structure

11.2.1 HDU Components

The following table describes the files' structures by Header-Data Unit number, type, extension name, content, and HDU classes for HRC-I, ACIS-I, and ACIS-S. An asterisk (*) denotes a principal HDU.

HDU	HDU Type	EXTNAME	EXTVER	CONTENT	HDUCLASS	Description
0	PRIMARY	N/A	N/A	N/A	N/A	NULL
1 (*)	BINTABLE	1	AXAF_UVIS	CDB_HRCI_UVIS	ASC RESPONSE EFF UVIS	Transmission efficiency HRC-I filter.
2	BINTABLE	1	AXAF_UVIS_ERR	CDB_HRCI_UVIS_ERR	ASC RESPONSE ERR UVIS	Uncertainty in transmission efficiency of HRC-I filter.
0	PRIMARY	N/A	N/A	N/A	N/A	NULL
1 (*)	BINTABLE	1	AXAF_UVIS	CDB_ACISI_UVIS	ASC RESPONSE EFF UVIS	Transmission efficiency ACIS-I filter.
2	BINTABLE	1	AXAF_UVIS_ERR	CDB_ACISI_UVIS_ERR	ASC RESPONSE ERR UVIS	Uncertainty in transmission efficiency of ACIS-I filter.
0	PRIMARY	N/A	N/A	N/A	N/A	NULL
1 (*)	BINTABLE	1	AXAF_UVIS	CDB_ACISS_UVIS	ASC RESPONSE EFF UVIS	Transmission efficiency ACIS-S filter.
2	BINTABLE	1	AXAF_UVIS_ERR	CDB_ACISS_UVIS_ERR	ASC RESPONSE ERR UVIS	Uncertainty in transmission efficiency of ACIS-S filter.

The following table describes the file structure by Header-Data Unit number, type, extension name, content, and HDU classes for HRC-S. 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	1	AXAF_UVIS	CDB_HRCS_UVIS	ASC RESPONSE EFF/UVIS	Transmission efficiency of HRC-S filter region 1.
2	BINTABLE	2	AXAF_UVIS	CDB_HRCS_UVIS	ASC RESPONSE EFF/UVIS	Transmission efficiency of HRC-S filter region 2.
3	BINTABLE	3	AXAF_UVIS	CDB_HRCS_UVIS	ASC RESPONSE EFF/UVIS	Transmission efficiency HRC-S filter region 3.
4	BINTABLE	4	AXAF_UVIS	CDB_HRCS_UVIS	ASC RESPONSE EFF/UVIS	Transmission efficiency of HRC-S filter region 4.
5	BINTABLE	5	AXAF_UVIS	CDB_HRCS_UVIS	ASC RESPONSE EFF/UVIS	Transmission efficiency of HRC-S filter region 5.
6	BINTABLE	6	AXAF_UVIS	CDB_HRCS_UVIS	ASC RESPONSE EFF/UVIS	Transmission efficiency of HRC-S filter region 6.
7	BINTABLE	1	AXAF_UVIS_ERR	CDB_HRCS_UVIS_ERR	ASC RESPONSE ERR/UVIS	Uncertainty in transmission efficiency of HRC-S filter region 1.
8	BINTABLE	2	AXAF_UVIS_ERR	CDB_HRCS_UVIS_ERR	ASC RESPONSE ERR/UVIS	Uncertainty in transmission efficiency HRC-S filter region 2.
9	BINTABLE	3	AXAF_UVIS_ERR	CDB_HRCS_UVIS_ERR	ASC RESPONSE ERR/UVIS	Uncertainty in transmission efficiency of HRC-S region 3.
10	BINTABLE	4	AXAF_UVIS_ERR	CDB_HRCS_UVIS_ERR	ASC RESPONSE ERR/UVIS	Uncertainty in transmission efficiency of HRC-S region 4.
11	BINTABLE	5	AXAF_UVIS_ERR	CDB_HRCS_UVIS_ERR	ASC RESPONSE ERR/UVIS	Uncertainty in transmission efficiency of HRC-S region 5.
12	BINTABLE	6	AXAF_UVIS_ERR	CDB_HRCS_UVIS_ERR	ASC RESPONSE ERR/UVIS	Uncertainty in transmission efficiency of HRC-S region 6.

11.2.2 Columns and Coordinate Systems

Each efficiency HDU will have the following columns:

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	TDBIN	TNULL	Comment
ENERGY	keV	1E	0.0	20.0	0.001	*NaN*	energy coordinate
EFF		1E	0.0	1.0	N/A	*NaN*	Filter transmission efficiency.

Each uncertainty HDU will have the following columns:

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	TDBIN	TNULL	Comment
ENERGY	keV	1E	0.0	20.0	0.001	*NaN*	energy coordinate
ERR		1E	0.0	N/A	N/A	*NaN*	Uncertainty in filter transmission efficiency.

11.2.3 Special Header Keywords

Keywords indicate the interpolation accuracy used to compress the arrays (if any) and the HRC-S filter region (the letter "n" should be replaced by a digit from 1–6).

```
INTRPACC=0.5                    / percent accuracy of pruning
FILTER  ='HRC-Sn'               / Filter for region n of HRC-S
```

11.2.4 `CALDB` Keywords

The required (one of each) `CALDB` keywords are as follows:

```
CCLS0001  'BCF'
CDTP0001  'DATA'
CCNM0001  'HRCS_UVIS'
CCNM0001  'HRCI_UVIS'
CCNM0001  'ACISS_UVIS'
CCNM0001  'ACISI_UVIS'
CBD10001  'ENERG(0.06-10.0)keV'
CVSD0001  1996-11-01T00:00:00
CDES0001  'HRC-S filter transmission efficiency.'
CDES0001  'HRC-I filter transmission efficiency.'
CDES0001  'ACIS-S filter transmission efficiency.'
CDES0001  'ACIS-S filter transmission efficiency.'
```

For the uncertainty extensions, we will use:

```
CCNM0001  'ERR'
CDES0001  'Uncertainty in filter HRC-S transmission efficiency'
```

12 HRMA Geometric Parameters

New section, *Revision 1.3 — 29 Mar 1999*

The HRMA geometry is given by several one-number items. They are useful, in particular, to define the cones of rays from the HRMA (front is furthest from the focus).

12.1 File Names

The `CALDB` type for the HRMA parameters is `PARAM`. Filenames will be of the form

```
hrmaD1996-11-01paramN0001.fits
```

12.2 HDU Components

Data are stored in a `PARAMLIST` HDU. 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	HRMA_PARAM	N/A	CDB_HRMA_PAR	ASC PARAMLIST HRMA	Binary table describing the several geometric parameters of the HRMA, useful for calculating cone angles.

12.3 Columns and Coordinate Systems

Columns for parameter list HDU are given in the following table.

TTYPE	TFORM	Description
NAME	16A	The name of the parameter.
DATATYPE	16A	The type of data.
SCALARVALUE	1D	A value for scalar data.
ERROR	1D	The uncertainty of the scalar value.
UNITS	16A	The physical unit of the parameter.
DESCRIPTION	64A	A short description of the parameter

The actual name and units values are as follows:

Name	Units	Description
HRMAfl	mm	Focal length (defined as inverse of plate scale?)
GeomArea$n$:	cm**2	HRMA effective area into 2π for on-axis point-source at infinity assuming mirror reflectivity= 1; note that this does include CAP obscuration, etc.
HnAf	mm	Axial location of the front of the shell-n hyperbola
HnAb	mm	Axial location of the back of the shell-n hyperbola.
HnRf	mm	Radius of the front of the shell-n hyperbola.
HnRb	mm	Radius of the back of the shell-n hyperbola.

The digit, n, takes the values 1, 3, 4, and 6 for the outer to inner HRMA shells.

12.3.1 `CALDB` Keywords

The required `CALDB` keywords are as follows:

```
CCLS0001  'BCF'
CDTP0001  'DATA'
CCNM0001  'HRMAPAR'
CVSD0001  1996-11-01T00:00:00
CDES0001  'HRMA scalar parameters'
```

13 Grating Parameters

New section, *Revision 1.3 — 29 Mar 1999*

13.1 HETG Parameters

Several grating parameters are given by one-number items. They are useful, in particular, for specifying the dispersion relation.

13.1.1 File Names

The `CALDB` type for the HETG parameters is `PARAM`. Filenames will be of the form

```
hetgD1996-11-01paramN0001.fits
```

13.1.2 HDU Components

Data are stored in a `PARAMLIST` HDU. 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	HETG_PARAM	N/A	CDB_HETG_PAR	ASC PARAMLIST HETG	Binary table describing the several parameters for the HETG, which are useful for calculating the dispersion relation.

13.1.3 Columns and Coordinate Systems

Columns for parameter list HDU are given in the following table.

TTYPE	TFORM	Description
NAME	16A	The name of the parameter.
DATATYPE	16A	The type of data.
SCALARVALUE	1D	A value for scalar data.
ERROR	1D	The uncertainty of the scalar value.
UNITS	16A	The physical unit of the parameter.
DESCRIPTION	64A	A short description of the parameter

The actual name and units values are as follows:

Name	Units	Description
HEGp	angstrom	Average period of the HEG gratings
MEGp	angstrom	Average period of the MEG gratings
HETGrsX	mm	HETG Rowland Spacing at XRCF
HETGrsF	mm	HETG Rowland Spacing in Flight
HETGopenX	deg	HETG opening angle at XRCF (HXDS coords)
HETGopenF	deg	HETG opening angle in Flight (ACIS coords)
HETGclockX	deg	HETG mean dispersion angle at XRCF
HETGclockF	deg	HETG mean dispersion angle in Flight
HEGangleX	deg	HEG dispersion angle relative to the y-axis, XRCF
HEGangleF	deg	HEG dispersion angle relative to the y-axis, Flight
MEGangleX	deg	MEG dispersion angle relative to the y-axis, XRCF
MEGangleF	deg	MEG dispersion angle relative to the y-axis, Flight

13.1.4 `CALDB` Keywords

The required `CALDB` keywords are as follows:

```
CCLS0001  'BCF'
CDTP0001  'DATA'
CCNM0001  'HETGPAR'
CVSD0001  1996-11-01T00:00:00
CDES0001  'HETG Grating scalar parameters'
```

13.2 LETG Parameters

The LETG parameters are given in a manner analogous to those of the HETG.

13.2.1 File Names

The `CALDB` type for the HETG parameters is `PARAM`. Filenames will be of the form

```
hetgD1996-11-01paramN0001.fits
```

13.2.2 HDU Components

Data are stored in a `PARAMLIST` HDU. 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	LETG_PARAM	N/A	CDB_LETG_PAR	ASC PARAMLIST LETG	Binary table describing the several parameters for the LETG, which are useful for calculating the dispersion relation.

13.2.3 Columns and Coordinate Systems

Columns for parameter list HDU are given in the following table.

TTYPE	TFORM	Description
NAME	16A	The name of the parameter.
DATATYPE	16A	The type of data.
SCALARVALUE	1D	A value for scalar data.
ERROR	1D	The uncertainty of the scalar value.
UNITS	16A	The physical unit of the parameter.
DESCRIPTION	64A	A short description of the parameter

The actual name and units values are as follows:

Name	Units	Description
LEGp	angstrom	Average period of the LETG gratings
LETGrsX	mm	LETG Rowland Spacing at XRCF
LETGrsF	mm	LETG Rowland Spacing in Flight
LETGclockX	deg	LETG mean dispersion angle at XRCF
LETGclockF	deg	LETG mean dispersion angle in Flight

13.2.4 CALDB Keywords

The required CALDB keywords are as follows:

```
CCLS0001  'BCF'
CDTP0001  'DATA'
CCNM0001  'LETGPAR'
CVSD0001  1996-11-01T00:00:00
CDES0001  'LETG Grating scalar parameters'
```

14 HRC-S Parameters

New section, *Revision 1.3 — 29 Mar 1999*

Several HRC-S geometric parameters are required for calculation of vignetting of the LETG spectrum by the filter boundaries.

14.1 File Names

The `CALDB` type for the HRC-S parameters is `PARAM`. Filenames will be of the form

```
hrcsD1996-11-01paramN0001.fits
```

14.2 HDU Components

Data are stored in a `PARAMLIST` HDU. 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	HETG_PARAM	N/A	CDB_HRCS_PAR	ASC PARAMLIST HRCS	Binary table describing the several parameters for the HRC-S, which are useful for calculating LETG spectral vignetting.

14.2.1 Columns and Coordinate Systems

Columns for parameter list HDU are given in the following table.

TTYPE	TFORM	Description
NAME	16A	The name of the parameter.
DATATYPE	16A	The type of data.
SCALARVALUE	1D	A value for scalar data.
ERROR	1D	The uncertainty of the scalar value.
UNITS	16A	The physical unit of the parameter.
DESCRIPTION	64A	A short description of the parameter

The actual name and units values are as follows:

Name	Units	Description
UVISoffX	mm	X-offset (towards HRMA) of filter from MCP.
UVISplusY	mm	Y-offset from array center of inner filter boundary on plus side.
UVISminusY	mm	Y-offset from array center of inner filter boundary on minus side.

14.2.2 CALDB Keywords

The required CALDB keywords are as follows:

```
CCLS0001  'BCF'
CDTP0001  'DATA'
CCNM0001  'HRCSPAR'
CVSD0001  1996-11-01T00:00:00
CDES0001  'HRC-S scalar parameters'
```

14.2.3 Issues

1. 990309 This product needs to be augmented with HRC-I and HRC-S geometric parameters.

15 ACIS Parameters

New section, *Revision 1.3 — 29 Mar 1999*

This table holds various ACIS scalar parameters.

15.1 File Names

The CALDB type for the ACIS parameters is PARAM. Filenames will be of the form

```
hrcsD1996-11-01paramN0001.fits
```

15.2 HDU Components

Data are stored in a PARAMLIST HDU. 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	ACIS_PARAM	N/A	CDB_ACIS_PAR	ASC PARAMLIST ACIS	Binary table describing the several parameters for the ACIS.

15.2.1 Columns and Coordinate Systems

Columns for parameter list HDU are given in the following table.

TTYPE	TFORM	Description
NAME	16A	The name of the parameter.
DATATYPE	16A	The type of data.
SCALARVALUE	1D	A value for scalar data.
ERROR	1D	The uncertainty of the scalar value.
UNITS	16A	The physical unit of the parameter.
DESCRIPTION	64A	A short description of the parameter

The actual name and units values are as follows:

Name	Units	Description
TBD	tbd	whatever

15.2.2 CALDB Keywords

The required CALDB keywords are as follows:

```
CCLS0001   'BCF'
CDTP0001   'DATA'
CCNM0001   'ACISPAR'
CVSD0001   1996-11-01T00:00:00
CDES0001   'ACIS scalar parameters'
```

15.2.3 Issues

1. 990309 This product needs to be filled in with ACIS geometric parameters: corner positions in 3D, pixel size, etc.

A FITS Header Templates

The following header sections have been taken from the ASC FITS file specifications, with slight modifications to make them appropriate for calibration data, as opposed to observational data. The changes are primarily the omission of observation-related keywords. *In all cases, column numbers, axis numbers, and keyword values are representative!* The order or value should not be taken literally unless explicitly stated.

A.1 Components With No Changes

Mandatory component for Image Primary Header (M)
Mandatory component for Null Primary Header (M)
Mandatory component for Binary Table extension (M)
Mandatory component for Image extension (M)
Full configuration control component (CC)
Short configuration control component (Short CC)
Configuration control component for null primary HDU (Null CC)

A.2 Components With Changes

A.2.1 Full timing component (T)

```
                               / Time information block-------------------------
DATE    = '1998-01-01T00:00:00'  / Date and time of file creation (UTC)
TIMEUNIT= 's       '
```

A.2.2 Short timing component (short T)

```
                               / Time information block-------------------------
DATE    = '1998-01-01T00:00:00'  / Date and time of file creation (UTC)
TIMEUNIT= 's       '
```

A.2.3 Full observation info component (O)

Only include those keywords which are determined by that stage of processing.

```
                               / Observation information block------------------
MISSION = 'AXAF    '           / Mission is AXAF
INSTRUME= '        '           / HRC, ACIS, EPHIN, S/C subsystems
DETNAM  = '        '           / Detector name
GRATING = 'NONE    '           / Grating
DATAMODE= '        '           / Datamode (varies only for science instr. data)
DATACLAS= 'SIMULATED'          / If fake data,
                               / include this (default is DATACLAS='OBSERVED')
```

A.3 Short observation info component (short O)

```
                               / Observation information block------------------
MISSION = 'AXAF    '           / Mission is AXAF
TELESCOP= 'AXAF    '           / Telescope is AXAF
INSTRUME= '        '           / HRC, ACIS, EPHIN, S/C subsystems
```

B FITS Header Template Usage

The templates' usage depends upon the file-type, specifically whether the principal HDU is a BINTABLE or an IMAGE, and whether the HDU is principal or auxiliary. The types of the HDUs for any case are specified by the ASC FITS Guide (Document 4).

Cases relevant to ARDs are:
All BINTABLE:

- Null Primary HDU:

  image mandatory
  null configuration control
  short timing
  short observation

- Principal table HDU:

  bintable mandatory
  table coordinates
  full configuration control
  full observation
  full timing

- Auxiliary table HDU:

  bintable mandatory
  table coordinates
  short configuration control
  short observation
  short timing

IMAGE, followed by IMAGEs and BINTABLEs

- IMAGE Primary HDU:

  image mandatory
  full configuration control
  full timing
  full observation
  image coordinates

- Auxiliary IMAGE HDU:

  image mandatory
  image coordinates
  short configuration control
  short observation
  short timing

- Auxiliary table HDU:

  bintable mandatory
  table coordinates
  short configuration control
  short observation
  short timing