Chandra X-Ray Center

CXC Archive Interface Control Document
Analysis Reference Data for:

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

Revision 1.4 — 22 June 1999

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

Document and Change Control Log

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

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. Uniformity has been defined as 3D images (dimensions of energy, chipx, chipy).

2. Proper use `DETNAM` for HRC-S MCP's needs to be resolved. This document currently uses HRC-Sn, where n is 0-3 from HRC-I to HRC-S. The `CHIP_ID` keyword is also included for redundancy.

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.

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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[2].) 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).

[2]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.

TNULL **keywords:** if not explicitly indicated and the quantity is a real number, it is assumed that missing data will have the IEEE value NaN.

Statistical and systematic uncertainties will follow the guidelines in OGIP Calibration Memo, CAL/GEN/92-003, version 1995 Jul 11, section 9) for naming and storing the uncertainties, i.e., we will use keywords (or columns) STAT_MIN, STAT_MAX, SYS_MIN, and SYS_MAX. If unknown, the column will be absent. If only the _MIN is present, it is assumed that uncertainties are symmetric. (We do not condone adding systematic and statistical uncertainties in quadrature, however, since systematic uncertainties are generally correlated).

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 — 26 March 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 — 26 March 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 may 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.

$U_n(E_i, x_j, y_k)$: This is the discretized (in energy) version of U, which corresponds more directly to $Q_n(E_i, x_j, y_k)$.

$B_n(x_j, y_k)$: The bad pixels are stored as a list, and specify single pixels (typically) which should be ignored (that is, any events in these locations are discarded, and QE is set to zero in the response). The bad-pixel format is not defined in this document, but is in the instrument Level 1 ICD's (see Documents 6, 5).

B is a function with values of 0.0 for a bad pixel, or 1.0 otherwise.

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

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

2.1.1 Characteristics of U

As of June, 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.

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 - **??**), or the discretized images.

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); regions of very different responses on the same device (such as for HRC-S filters) are stored in different rows in the same HDU.
- Any array element regions which are distinct, but very similar in responses (such as ACIS CCD quadrants) are *not explicitly included*, but are to be accounted for by the uniformity function. (It is expected that ACIS quadrants will be identical after CTI and gain corrections.)
- Asymmetric systematic and statistical uncertainties are stored, if known, in additional columns. If identical, they will be in header keywords (as per OGIP Calibration Memo, CAL/GEN/92-003, version 1995 Jul 11, section 9).
- If filter tranmissivities are included in the QE, the `FILTER` keyword will be present and have a value other than `NONE`. For HRC, regions of the same MCP (`CHIP_ID`) will be stored in the same HDU on separate rows, and the `FILTER` keyword will become a column.
- 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
hrciD1996-11-01qeN0001.fits
hrcsD1996-11-01qeN0001.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).
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. Keyword will indicate the device (`DETNAM`).

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	CCD_ID OR CHIP_ID
ACIS	ACIS-0	1	UVIS_ACISI	0
”	ACIS-1	2	UVIS_ACISI	1
”	ACIS-2	3	UVIS_ACISI	2
”	ACIS-3	4	UVIS_ACISI	3
”	ACIS-4	5	UVIS_ACISS	4
”	ACIS-5	6	UVIS_ACISS	5
”	ACIS-6	7	UVIS_ACISS	6
”	ACIS-7	8	UVIS_ACISS	7
”	ACIS-8	9	UVIS_ACISS	8
”	ACIS-9	10	UVIS_ACISS	9
HRC	HRC-I	1	UVIS_HRCI	0
”	HRC-S1	2	UVIS_HRCS3, UVIS_HRCS5	3
”	HRC-S2	3	UVIS_HRCS1, UVIS_HRCS2	2
”	HRC-S3	4	UVIS_HRCS4, UVIS_HRCS6	1

2.2.4 ACIS-I, ACIS-S, and HRC-I Columns and Coordinate Systems

Columns for Detector QE HDU are given in the following table. Each CCD and HRC-I can be described by a single region, and a standard FITS bintable columnar format is convenient.

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	Description
ENERGY	keV	1E	N/A	N/A	Energy
QE		1E	0.0	1.0	Mean Quantum efficiency for the device.
STAT_MIN		1E	0.0	n/a	Statistical uncertainty, low-side.
STAT_MAX		1E	0.0	n/a	Statistical uncertainty, high-side. If this column is absent, it is assumed that uncertainties are symmetric and STAT_MIN = STAT_MAX.
SYS_MIN		1E	0.0	1.0	Fractional systematic uncertainty, low-side. If unknown, this column may be omitted.
SYS_MAX		1E	0.0	1.0	Fractional systematic uncertainty, high-side. If unknown, this column may be omitted. If omitted, but SYS_MIN is present, then it is to be assumed that SYS_MAX = SYS_MIN.

2.2.5 HRC-S Columns and Coordinate Systems

New section in V1.4

Columns for Detector QE HDU are given in the following table. Since HRC-S has several distinct filter regions on each MCP, a row format with array columns is used so that other attributes of the region can be given with the QE array. This format will have identical attribute columns as the QE Uniformity table.

To provide a mnemonic for the region, an index is generated from $100\times$`CHIP_ID`$+n$, where n is a running index on each MCP counting each distinct region.

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	Description
REGIONID		1I	101	399	Region ID. The ID is $100 \times$ CHIP_ID $+ i$, where i is a serial index of regions on each MCP, starting at 1 for each MCP.
FILTER		32A	N/A	N/A	Filter identifier. This has the values UVIS_HRCI, or UVIS_HRCSj, where j is an index from 1 to 6.
ENERGY	keV	nE	N/A	N/A	Energy array. (It is assumed that all rows have the same length energy grid).
QE		nE	0.0	1.0	Mean Quantum efficiency for the region.
STAT_MIN		nE	0.0	n/a	Statistical uncertainty, low-side. (optional)
STAT_MAX		nE	0.0	n/a	Statistical uncertainty, high-side. If this column is absent, it is assumed that uncertainties are symmetric and STAT_MIN = STAT_MAX. (optional)
SYS_MIN		nE	0.0	1.0	Fractional systematic uncertainty, low-side. If unknown, this column may be omitted. (optional)
SYS_MAX		nE	0.0	1.0	Fractional systematic uncertainty, high-side. If unknown, this column may be omitted. If omitted, but SYS_MIN is present, then it is to be assumed that SYS_MAX = SYS_MIN. (opitonal)

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

```
          S3                    S2                    S1
CHIP_ID:  3                      2                     1
+-----------------+ +-------------------+ +-------------------+
|     5  (301)    | | (201)   1         | | (101)   6         |
+-----------------+ +-----+........+----+ +-------------------+
|                 | |     |        |    | |                   |
|        (302)    | |(202)|   +    |(204) |  (102)           |
|                 | |     |        |    | |                   |
|      3          | |  2  | (203)  |  2 | |         4         |
|                 | |     |        |    | |                   |
+-----------------+ +-----+--------+----+ +-------------------+
                        Left <----> Right
```

In this 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. The numbers in parentheses are the REGIONID tags. In order to have rectangular regions, the "T" (filter-1) region is further subdivided into two rectangles, as marked by the "...". Each row of the table will have both FILTER and REGIONID keywords; FILTER keywords will have values UVIS_HRCSn, in which n is the single-digid index as 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.

2.2.6 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; if the QE files contain each as extensions, the DETNAM keyword will be used 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.

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). For HRC-S, this keyword becomes a column.

2.2.7 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'
```

The CBD1 and CVSD keywords are subject to revision.

2.3 File Structure: Quantum Efficiency Uniformity Images

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.

HRC-S, however, is non-uniform, and may have some energy dependence. The format for both HRC-I and -S will be the same, in which the images are stored as a 3D-image (E, x, y) column of a binary table.

ACIS front-illuminated (FI) CCD's are uniform.

ACIS back-illuminated (BI) CCD's are non-uniform, and energy-dependent. Their non-uniformity will be stored in an identical format to the HRC data.

In order to provide a uniform interface, each chip's uniformity will stored in a separate FITS binary table extension. Each extension will have a row per each region, with array columns. The uniformity column will be a 3D image. The coordinate system keywords for each uniformity image, which maps blocked pixels to detector pixels, will be in columns. The uniformity column for HRC-S HDU's will be of variable length to accomodate the different sizes of HRC uniformity regions.

2.3.1 File Names

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

```
hrcD1996-11-01qeuN0001.fits
acisD1996-11-01qeuN0001.fits
```

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_IMG	1	CDB_HRC_QEU or CDB_ACIS_QEU	ASC DETCHAR QE UNIF	Binary table describing the QE uniformity for one device (chip) of a detector.
2..n	BINTABLE	AXAF_QEU_IMG	2..n	CDB_HRC_QEU or CDB_ACIS_QEU	ASC DETCHAR QE UNIF	Binary table describing the QE uniformity for additional devices (chips or mcps).

2.3.3 Columns, Axes, and Coordinate Systems

The logical coordinate of the image is a bin which each cell represents some rectangular region 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.

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	Description
REGIONID		1I	1	N/A	Region identifier. This is a mnemonic formed as 100*`chip_id` + i, (or `ccd_id` in the case of ACIS) where i is a serial index per chip. Only HRC-S currently has multiple regions per chip, but degradation in the future could make multiple regions necessary.
ENERGY	keV	nE	0.0	N/A	Energy grid, for first axis of uniformity image. If only one element long, then the `CBD` keyword should be checked for the valid range of validity.
TDIMk	N/A	32A	N/A	N/A	The dimensionality keyword of the QE uniformity image stored in column k. This is a string of the form, `'(`n_E, n_x, n_y`)'`.
2CRPXk	pixel	1J	1	N/A	Reference pixel for second axis (first spatial dimension) of the QE uniformity image in column k. This is typically 1, which is the lower left center of the logical pixel of the QEU image.
2CDLTk	pixel	1J	1	N/A	Increment, giving the number of detector pixels per QEU spatial pixel in the first spatial coordinate.
2CRVLk	PIXEL	1E	1	N/A	The value of the detector chip coordinate at the reference pixel in the first spatial coordinate for the QEU image in column k.
3CRPXk	pixel	1J	1	N/A	Reference pixel for third axis (second spatial dimension) of the QE uniformity image in column k. This is typically 1, which is the lower left center of the logical pixel of the QEU image.
3CDLTk	pixel	1E	1	N/A	Increment, giving the number of detector pixels per QEU spatial pixel in the second spatial coordinate.
3CRVLk	PIXEL	1J	1	N/A	The value of the detector chip coordinate at the reference pixel in the second spatial coordinate for the QEU image in column k.
QEU	N/A	*	0.0	N/A	Uniformity image. In the case of variable sized spatial regions, this will be a variable-length array, and use the "`1PE(`l`)`" form for `TFORM`, where l is the total number of bins in the 3D image.
STAT_MIN	N/A	*	0.0	N/A	Statistical uncertainty, low-side, for uniformity image. (optional)
STAT_MAX	N/A	*	0.0	N/A	Statistical uncertainty, high-side, for uniformity image. (optional)
SYS_MIN	N/A	*	0.0	1.0	Fractional systematic uncertainty, low-side, for uniformity image. (optional)
SYS_MAX	N/A	*	0.0	1.0	Fractional systematic uncertainty, high-side, for uniformity image. (optional)

* For variable-length arrays, the `TFORM` is of the form, `TFORM = '1PE(`l`)'`, in which l is the total length of the array, or $l = (n_E \times n_x \times n_y)$. If a single region, then `TFORM = '`l`E'`.

Special Coordinate Keywords

990710 new section Revision 1.4

The image column require several keywords in order to define its coordinate system and relation to other columns. These follow the conventions given in "Representation of celestial coordinates in FITS", by Greisen and Calabretta (Sept. 9, 1996)[3].

i`CTYP`*n*: These define the axes of the image column. In the current case of a 3D image with the energy axis being the most rapidly varying, we have:

```
1CTYPn = 'ENERGY',
2CTYPn = 'CHIPX',
3CTYPn = 'CHIPY'.
```

Here, n, is the column index. For variable-length arrays, these still belong in the header, since they are constant with table rows.

`TDIM`*n*: This specifies the dimensionality of each axis of the image column. It has the form, `'(`N_E, N_x, N_y`)'`. For example, for 8 energies, and 32 by 64 spatial bins, for an image in column 2 we would have: `TDIM2 = '(8, 32, 64)'`. For variable-length arrays, this becomes a column.

`CREF`*n*: This keyword has a string value which maps the image axes to `TTYPE`*n* keywords which specify grids for those axes. For example, with an image in column $n = 3$, the first axis being energy, and the other two being spatial coords, we would have:

$$\mathtt{CREF3} =' (\mathtt{ENERGY}, \mathtt{CHIPX}, \mathtt{CHIPY})'$$

For non-enumerated axes, the coordinate strings are what the WCS mapping provides (i.e., 2CRPX, 2CDLT, and 2CRVL scale QEU bins to CHIPX).

The `CREF` syntax is not specified by the OGIP memos for a case where one or more axes are not enumerated by explicit columns. What is to be done?

What is CREF for non-enumerated axes?

i`CRVL`*n*, *i*`CRPX`*n*, *i*`CLDT`*n*, *i*`CUNI`*n*: keywords to specify the image columns' spatial coordinates system.

For example, if the image is of `CHIPX`, `CHIPY` pixels blocked by 32, and `CHIPX` is the second axis of array column 12, (`ENERGY` is the first axis, then we could have:

```
2CRVL12 = 16.5
2CRPX12 = 1
2CDLT12 = 32
2CUNI12 = 'pixel'
```

This maps the blocked pixels in the image to the full-resolution detector pixels.

For variable-length arrays, these become columns of the table.

[3] `http://www.cv.nrao.edu/fits/documents/wcs/wcs.all.ps`

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 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.

`CCD_ID:` For ACIS, this is redundant with `DETNAM`, but is given for completeness and an explicit cross-reference.

`CHIP_ID:` For HRC, this is redundant with `DETNAM`, but is given for completeness and an explicit cross-reference.

`FILTER:` `NONE` (the uniformity is provided 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.

2.4 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 column containing a QE uncertainty image in the same format.

For most analysis purposes, higher level (uniformity and mean QE) 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 E, x, y, from most to least varying index. Since the energy axes may be non-linear, its coordinates are stored in an array column. The spatial axes are linear and will have coordinate systems attached.

The format will be the same as for the uniformity tables, with the addition of `FILTER` keywords (or columns) as appropriate.

2.4.1 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.

2.4.2 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 spatial dimensions will be uniform and header keywords will define the cells in terms of detector pixel coordinates. 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).

HDU	HDU Type	EXTNAME	EXTVER	CONTENT	HDUCLASS	Description
0	PRIMARY	N/A	N/A	N/A	N/A	NULL
1 (*)	BINTABLE	AXAF_QEXYE	1	CDB_QEXYE	ASC DETCHAR QE XY_ENERGY	3D image of detector QE vs position and energy for first segment.
$2-n$	BINTABLE	AXAF_QEXYE	2	CDB_QEXYE	ASC DETCHAR QE XY_ENERGY	3D image of detector QE vs position and energy for 2nd to n^{th} segments.

2.4.3 Explicit HDU/Column Enumeration

To make the files' structures more explicit, the following tables define the actual structure of ACIS and HRC files.

INSTRUME	DETNAM	EXTVER	EXTNAME
ACIS	ACIS-0	1	AXAF_QEXYE
"	ACIS-1	2	"
"	ACIS-2	3	"
"	ACIS-3	4	"
"	ACIS-4	5	"
"	ACIS-5	6	"
"	ACIS-6	7	"
"	ACIS-7	8	"
"	ACIS-8	9	"
"	ACIS-9	10	"
HRC	HRC-I	1	AXAF_QEXYE
"	HRC-S1	2	"
"	HRC-S2	3	"
"	HRC-S3	4	"

2.4.4 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. HRC is likely to have $n = 128$, which ACIS will be about $n = 32$ (to within factors of 2).

The columns are given for multiple regions. Chips for which a single region is sufficient will have one row, and columns with coordinate system or filter keywords may be promoted to header keywords. The multiple-region and variable length arrays are needed for HRC-S, but may be needed for other devices if degradation occurs with age.

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	Description
REGIONID		1I	1	N/A	Region identifier. The is a mnemonic formed as 100*`chip_id` + i, (or `ccd_id` in the case of ACIS) where i is a serial index per chip. Only HRC-S currently has multiple regions per chip, but degradation in the future could make multiple regions necessary.
FILTER		32A	N/A	N/A	Filter name. For HRC-S, this ia column. For ACIS and HRC-I, it can be a header keyword, since it is constant per chip.
ENERGY	keV	nE	0.0	N/A	Energy grid, for first axis of uniformity image. If only one element long, then the `CBD` keyword should be checked for the valid range of validity.
TDIMk	N/A	32A	N/A	N/A	The dimensionality keyword of the QE uniformity image stored in column k. This is a string of the form, `'(`n_E, n_x, n_y`)'`.
2CRPXk	pixel	1J	1	N/A	Reference pixel for second axis (first spatial dimension) of the QE uniformity image in column k. This is typically 1, which is the lower left center of the logical pixel of the QEU image.
2CDLTk	pixel	1J	1	N/A	Increment, giving the number of detector pixels per QEU spatial pixel in the first spatial coordinate.
2CRVLk	PIXEL	1J	1	N/A	The value of the detector chip coordinate at the reference pixel in the first spatial coordinate for the QEU image in column k.
3CRPXk	pixel	1J	1	N/A	Reference pixel for third axis (second spatial dimension) of the QE uniformity image in column k. This is typically 1, which is the lower left center of the logical pixel of the QEU image.
3CDLTk	pixel	1J	1	N/A	Increment, giving the number of detector pixels per QEU spatial pixel in the second spatial coordinate.
3CRVLk	PIXEL	1J	1	N/A	The value of the detector chip coordinate at the reference pixel in the second spatial coordinate for the QEU image in column k.
QEXYE	N/A	*	0.0	N/A	Uniformity image. In the case of variable sized spatial regions, this will be a variable-length array, and use the "`1PE(`l`)`" form for `TFORM`, where l is the total number of bins in the 3D image.
STAT_MIN	N/A	*	0.0	N/A	Statistical uncertainty, low-side, for uniformity image. (optional)
STAT_MAX	N/A	*	0.0	N/A	Statistical uncertainty, high-side, for uniformity image. (optional)
SYS_MIN	N/A	*	0.0	1.0	Fractional systematic uncertainty, low-side, for uniformity image. (optional)
SYS_MAX	N/A	*	0.0	1.0	Fractional systematic uncertainty, high-side, for uniformity image. (optional)

* For variable-length arrays, the `TFORM` is of the form, `TFORM = '1PE(`l`)'`, in which l is the total length of the array, or $l = (n_E \times n_x \times n_y)$. If a single region, then `TFORM = '`l`E'`.

Special Coordinate Keywords

~~990710 new section *Revision 1.4 — 22 June 1999*~~

The image column require several keywords in order to define its coordinate system and relation to other columns. These follow the conventions given in "Representation of celestial coordinates in FITS", by Greisen and Calabretta (Sept. 9, 1996)[4].

`i`CTYP`n`: These define the axes of the image column. In the current case of a 3D image with the energy axis being the most rapidly varying, we have:

```
1CTYPn = 'ENERGY',
2CTYPn = 'CHIPX',
3CTYPn = 'CHIPY'.
```

Here, n, is the column index. For variable-length arrays, these still belong in the header, since they are constant with table rows.

TDIM`n`: This specifies the dimensionality of each axis of the image column. It has the form, '(N_E, N_x, N_y)'. For example, for 8 energies, and 32 by 64 spatial bins, for an image in column 2 we would have: `TDIM2 = '(8, 32, 64)'`. For variable-length arrays, this becomes a column.

CREF`n`: This keyword has a string value which maps the image axes to TTYPEn keywords which specify grids for those axes. For example, with an image in column $n = 3$, the first axis being energy, and the other two being spatial coords, we would have:

$$\mathtt{CREF3} =' (\mathtt{ENERGY}, \mathtt{CHIPX}, \mathtt{CHIPY})'$$

For non-enumerated axes, the coordinate strings are what the WCS mapping provides (i.e., 2CRPX, 2CDLT, and 2CRVL scale QEU bins to CHIPX).

The CREF syntax is not specified by the OGIP memos for a case where one or more axes are not enumerated by explicit columns. What is to be done?

What is CREF for non-enumerated axes?

`i`CRVL`n`, `i`CRPX`n`, `i`CLDT`n`, `i`CUNI`n`: keywords to specify the image columns' spatial coordinates system.

For example, if the image is of CHIPX, CHIPY pixels blocked by 32, and CHIPX is the second axis of array column 12, (ENERGY is the first axis, then we could have:

```
2CRVL12 = 16.5
2CRPX12 = 1
2CDLT12 = 32
2CUNI12 = 'pixel'
```

This maps the blocked pixels in the image to the full-resolution detector pixels.

For variable-length arrays, these become columns of the table.

[4] http://www.cv.nrao.edu/fits/documents/wcs/wcs.all.ps

2.4.5 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.

`CCD_ID`: For ACIS, this is redundant with `DETNAM`, but is given for completeness and an explicit cross-reference.

`CHIP_ID`: For HRC, this is redundant with `DETNAM`, but is given for completeness and an explicit cross-reference.

`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. For multiple regions per chip, this becomes a column.

2.4.6 `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'
```

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

2.5 File Structure: Supplementary ACIS "Raw" QE Uniformity Data

New section, *Revision 1.4 — 22 June 1999*

The ACIS Instrument Principal Investigator team provides several low-level calibration data products from which the QE uniformity is derived. They will be converted to FITS tables and documented here. Routine analyses will not use them directly, but will use the derived uniformity. Hence, these product are referred to as "raw QE uniformity".

The ACIS uniformity is derived from three types of files:

1. Reference CCD flat-field counts images,
2. Flight CCD flat-field counts images, and a
3. bad counts list.

The ratios of the flight images to reference images, when converted to count-rates and factoring in bad-pixels, gives the QE uniformity (and statistical uncertainties).

Counts images are spatially blocked to provide adequate statistics per cell. The reference counts image is corrected for defects (that is, the counts in a cell have been normalized for any dead pixels). The flight counts images have not been corrected for bad pixels. The bad counts list gives the number of low and hot pixels in each cell, and allow adequate normalization and statistics to be computed (but they do not explicitly indicate which detector pixels are bad or hot). The bad-counts table is sparse and will not be stored as an image.

2.5.1 File Structure: Reference Chip Raw Quantum Efficiency Uniformity

File Names The `CALDB` type for the reference chip Raw QE uniformity is `rqeu`. File names will be of the form:

`acis_ccdnamD1996-11-01rqeuN0001.fits`

The `<detector>` field is required to encode the reference chip name ("`ccdnam`" will be replaced with the device ID).

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_RQEU_IMG	1	CDB_ACIS_RQEU	ASC DETCHAR RQE UNIF	Binary table describing the raw QE uniformity for one device (chip) of a detector.

Columns, Axes, and Coordinate Systems The logical coordinate of the image is a bin which each cell represents some rectangular region 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.

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	Description
ENERGY	keV	nE	N/A	N/A	Energy grid, for image column.
RQEU	COUNT	$(n_E \times n_x \times n_y)$E	0.0	N/A	Raw counts uniformity image.
STAT_MIN	COUNT	$(n_E \times n_x \times n_y)$E	0.0	N/A	Statistical uncertainty, low-side, for uniformity image.
STAT_MAX	COUNT	$(n_E \times n_x \times n_y)$E	0.0	N/A	Statistical uncertainty, high-side, for uniformity image.
SYS_MIN	N/A	$(n_E \times n_x \times n_y)$E	0.0	1.0	Fractional systematic uncertainty, low-side, for uniformity image.
SYS_MAX	N/A	$(n_E \times n_x \times n_y)$E	0.0	1.0	Fractional systematic uncertainty, high-side, for uniformity image.

Special Coordinate Keywords The image column require several keywords in order to define its coordinate system and relation to other columns. These follow the conventions given in "Representation of celestial coordinates in FITS", by Greisen and Calabretta (Sept. 9, 1996). [5]

i`CTYP`n: This defines the axes of the image column. In the current case of a 3D image with the energy axis being the most rapidly varying, we have:

```
1CTYPn = 'ENERGY',
2CTYPn = 'CHIPX',
3CTYPn = 'CHIPY'.
```

Here, n, is the column index.

`TDIM`n: This specifies the dimensionality of each axis of the image column. It has the form, `'`(N_E, N_x, N_y)`'`. For example, for 8 energies, and 32 by 64 spatial bins, for an image in column 2 we would have: `TDIM2 = '(8, 32, 64)'`.

`CREF`n: This keyword has a string value which maps the image axes to `TTYPE`n keywords which specify grids for those axes. For example, with an image in column $n = 3$, the first axis being energy, and the other two being spatial coords, we would have:

$$\texttt{CREF3} =' (\texttt{ENERGY}, \texttt{CHIPX}, \texttt{CHIPY})'$$

The `CREF` syntax is not specified by the OGIP memos for a case where one or more axes are not enumerated by explicit columns. What is to be done?

What is CREF for non-enumerated axes?

[5] `http://www.cv.nrao.edu/fits/documents/wcs/wcs.all.ps`

*i*CRVL*n*, *i*CRPX*n*, *i*CLDT*n*, *i*CUNI*n*: keywords to specify the image columns' spatial coordinates system.

For example, if the image is of CHIPX, CHIPY pixels blocked by 32, and CHIPX is the second axis of array column 12, (ENERGY is the first axis, then we could have:

```
2CRVL12 = 16.5
2CRPX12 = 1
2CDLT12 = 32
2CUNI12 = 'pixel'
```

This maps the blocked pixels in the image to the full-resolution detector pixels.

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: ACIS.

DETNAM: TBD - this will be the identifier for the reference chip.

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

CALDB **Keywords** The required CALDB keywords are as follows:

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

The CBD1 and CVSD keywords are subject to revision.

2.5.2 File Structure: Flight Chips Raw Quantum Efficiency Uniformity

File Names The CALDB type for the reference chip Raw QE uniformity is rqeu. File names will be of the form:

```
acisD1996-11-01rqeuN0001.fits
```

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_RQEU_IMG	1	CDB_ACIS_RQEU	ASC DETCHAR RQE UNIF	Binary table describing the raw QE uniformity for one device (chip) of a detector.
2-n	BINTABLE	AXAF_RQEU_IMG	2-n	CDB_ACIS_RQEU	ASC DETCHAR RQE UNIF	Binary table describing the raw QE uniformity for one device (chip) of a detector, one HDU per CCD.

Columns, Axes, and Coordinate Systems The logical coordinate of the image is a bin which each cell represents some rectangular region 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.

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	Description
ENERGY	keV	nE	N/A	N/A	Energy grid, for image column.
RQEU	COUNT	$(n_E \times n_x \times n_y)$E	0.0	N/A	Raw counts uniformity image.
STAT_MIN	COUNT	$(n_E \times n_x \times n_y)$E	0.0	N/A	Statistical uncertainty, low-side, for uniformity image.
STAT_MAX	COUNT	$(n_E \times n_x \times n_y)$E	0.0	N/A	Statistical uncertainty, high-side, for uniformity image.
SYS_MIN	N/A	$(n_E \times n_x \times n_y)$E	0.0	1.0	Fractional systematic uncertainty, low-side, for uniformity image.
SYS_MAX	N/A	$(n_E \times n_x \times n_y)$E	0.0	1.0	Fractional systematic uncertainty, high-side, for uniformity image.
X	bin	mI	1	1024	Bad-pixel table x-coordinates. This is an x-bin-coordinate of the `RQEU` image column.
Y	bin	mI	1	1024	Bad-pixel table y-coordinates. This is a y-bin-coordinate of the `RQEU` image column.
CTS_LOW	NONE	mI	0	N/A	Bad-pixel table, counts from pixels with low counts in the cell referenced by x and y.
NUM_LOW	NONE	mI	0	N/A	Bad-pixel table, number of pixels with low counts in the cell referenced by x and y.
CTS_HOT	NONE	mI	0	N/A	Bad-pixel table, counts from pixels with high counts in the cell referenced by x and y.
NUM_HOT	NONE	mI	0	N/A	Bad-pixel table, number of pixels with high counts in the cell referenced by x and y.
CTS_TOTAL	NONE	mI	0	N/A	Bad-pixel table, total number of counts in the cell referenced by x and y.

Special Coordinate Keywords The image column require several keywords in order to define its coordinate system and relation to other columns. These follow the conventions given in "Representation of celestial coordinates in FITS", by Greisen and Calabretta (Sept. 9, 1996)[6].

i`CTYP`*n*: This defines the axes of the image column. In the current case of a 3D image with the energy axis being the most rapidly varying, we have:

> `1CTYP`*n* `= 'ENERGY'`,
> `2CTYP`*n* `= 'CHIPX'`,
> `3CTYP`*n* `= 'CHIPY'`.

Here, n, is the column index.

`TDIM`*n*: This specifies the dimensionality of each axis of the image column. It has the form, `'`(N_E, N_x, N_y)`'`. For example, for 8 energies, and 32 by 64 spatial bins, for an image in column 2 we would have: `TDIM2 = '(8, 32, 64)'`.

`CREF`*n*: This keyword has a string value which maps the image axes to `TTYPE`*n* keywords which specify grids for those axes. For example, with an image in column $n = 3$, the first axis being energy, and the other two being spatial coords, we would have:

$$\texttt{CREF3} =' (\texttt{ENERGY}, \texttt{CHIPX}, \texttt{CHIPY})'$$

The `CREF` syntax is not specified by the OGIP memos for a case where one or more axes are not enumerated by explicit columns. What is to be done?

What is CREF for non-enumerated axes?

i`CRVL`*n*, *i*`CRPX`*n*, *i*`CLDT`*n*, *i*`CUNI`*n*: keywords to specify the image columns' spatial coordinates system.

For example, if the image is of `CHIPX`, `CHIPY` pixels blocked by 32, and `CHIPX` is the second axis of array column 12, (`ENERGY` is the first axis, then we could have:

```
2CRVL12 = 16.5
2CRPX12 = 1
2CDLT12 = 32
2CUNI12 = 'pixel'
```

This maps the blocked pixels in the image to the full-resolution detector pixels.

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`: ACIS.

[6] `http://www.cv.nrao.edu/fits/documents/wcs/wcs.all.ps`

`DETNAM:` ACIS-n (where n is replaced with the `CHIPID` value of 0-9).

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

`CALDB` **Keywords** The required `CALDB` keywords are as follows:

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

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

2.6 Size and File Number Estimates

2.6.1 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.

2.6.2 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 128×128 (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 960 kB. The energy grid extensions are of negligible size relative to the QE images.

2.6.3 QE Uniformity

The uniformity images have the same format, and hence, the same volume as the spatial QE.

2.6.4 Raw QE Uniformity

The raw uniformity images have the same format, and hence, the same volume as the spatial QE.

2.7 Unresolved Issues

1. Format of `CREF` keyword for image columns with non-tabulated axes.
2. Raw QE uniformity bad-pixel table columns needs to be reviewed. Should information be number of pixels, or counts from hot or low pixels in each cell? As defined, does not look like enough information to define average QE of active pixels (need both number of pixels of each kind, and counts from each kind).

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's response will be weighted by the correspoding grating efficiencies. 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 as specified by OGIP Memo, "CAL/GEN/92-019" (George and Zellar; Version: 1995 Jul 31). Multiple extensions will store the all-shell ensemble area and areas for each individual shell.

The OGIP document provides two alternatives for the file format, one for on-axis, and one for off-axis. In order to have a uniform interface, we will adopt the off-axis format for the on-axis case, omit the θ and ϕ grids, and indicate the on-axis-only via the `CBD`-keywords as described in CAL/GEN/92-019.

Note that there will also be an off-axis effective area file in the same format (with non-null θ, ϕ axes). The motivation for separate on-axis and off-axis files is that the on-axis case is modeled to much higher energy resolution. The on-axis data will typically be used to interpolate the off-axis vignetting function, derived from the off-axis area.

A peculiarity of the format is that the energy grid has both high and low bounds. This implies that the area is integrated over a bin. However, our data are differential, since they represent the value at a discrete point. For compatibility, both `ENERG_LO` and `ENERG_HI` arrays will be included, but their values will be identical.

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.

3.1.3 Columns and Coordinate Systems

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

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	Description
ENERG_LO	keV	nE	N/A	N/A	Energy grid, low edge of bin (but note: point data implies low and high are identical).
ENERG_HI	keV	nE	N/A	N/A	Energy grid, high edge of bin (but note: point data implies low and high are identical).
EFFAREA	`cm**2`	nE	0.0	N/A	Mirror efffective area
STAT_MIN	`cm**2`	nE	0.0	N/A	Statistical uncertainty in Mirror efffective area, low side.
STAT_MAX	`cm**2`	nE	0.0	N/A	Statistical uncertainty in Mirror efffective area, high side.
SYS_MIN	N/A	nE	0.0	1.0	Fractional systemacic uncertainty in Mirror efffective area, low side.
SYS_MAX	N/A	nE	0.0	1.0	Fractional systematic uncertainty in Mirror efffective area, high side.

The values in the energy columns must be monotonically increasing.

Special Coordinate Keywords

990710 new section *Revision 1.4 — 22 June 1999*

An array column generally requires several keywords in order to define its coordinate system and relation to other columns. These follow the conventions given in "Representation of celestial coordinates in FITS", by Greisen and Calabretta (Sept. 9, 1996). [7]

iCTYPn: This defines the axes of the image column. In the current case of a 1D image with the one energy axis, we have:

1CTYPn = 'ENERG_LO',

Here, n, is the column index.

TDIMn: This specifies the dimensionality of each axis of the image column. It has the form, '(N_E)'.

CREFn: This keyword has a string value which maps the image axes to TTYPEn keywords which specify grids for those axes. For example, with an array in column $n = 3$, the first (and only) axis being energy, we would have:

$$\mathrm{CREF3} ='\ (\mathrm{ENERG\_LO})'$$

iCRVLn, iCRPXn, iCLDTn, iCUNIn: keywords to specify the image columns spatial coordinate system. These are not needed for the on-axis effective 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_LO(0.05-10.0)keV'
CBD20001  'THETA(0)arcmin'
CBD30001  'PHI(0)deg'
CBD40001  'SHELL(nnnn)'     /Shell 1346 bitmap; 1=>response included
CVSD0001  1996-11-01T00:00:00
CDES0001  'Telescope axial effective area'
```

The CBD1 and CVSD keywords are subject to revision.

[7] http://www.cv.nrao.edu/fits/documents/wcs/wcs.all.ps

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 table HDUs for different shell combinations. The total size is of order 80 kB (plus headers). One file suffices to specify the on-axis 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 in a FITS binary table. 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) mode require the ensemble area, while HETG or LETG 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 array columns.

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.

The format is specified by OGIP Memo, "CAL/GEN/92-019" (George and Zellar; Version: 1995 Jul 31). Multiple extensions will store the all-shell ensemble area and areas for each individual shell.

The OGIP document provides two alternatives for the file format, one for on-axis, and one for off-axis; this uses the off-axis format.

Note that there will also be an on-axis effective area file in the same format (with null θ, ϕ axes). The motivation for separate on-axis and off-axis files is that the on-axis case is modeled to much higher energy resolution. The on-axis data will typically be used to interpolate the off-axis area or vignetting function derived from the off-axis area.

A peculiarity of the format is that the energy grid has both high and low bounds. This implies that the area is integrated over a bin. However, our data are differential, since they represent the value at a discrete point. For compatibility, both `ENERG_LO` and `ENERG_HI` arrays will be included, but their values will be identical.

In order to ease downstream use, the off-axis area file will have a regular grid in which each cell has a reasonable value. This may entail some interpolation and extrapolation of the input calibration data prior to producing the off-axis area file.

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	N/A	N/A	N/A	NULL
1(*)	BINTABLE	AXAF_EFFAREA	CDB_HRMA_EFFA	ASC RESPONSE EFF EFFAREA	binary table, cm^2 vs E, fo all shells.
2	BINTABLE	AXAF_EFFAREA	CDB_HRMA_EFFA	ASC RESPONSE EFF EFFAREA	binary table, cm^2 vs E, fo shell 1.
3	BINTABLE	AXAF_EFFAREA	CDB_HRMA_EFFA	ASC RESPONSE EFF EFFAREA	binary table, cm^2 vs E, fo shell 3.
4	BINTABLE	AXAF_EFFAREA	CDB_HRMA_EFFA	ASC RESPONSE EFF EFFAREA	binary table, cm^2 vs E, fo shell 4.
5	BINTABLE	AXAF_EFFAREA	CDB_HRMA_EFFA	ASC RESPONSE EFF EFFAREA	binary table, cm^2 vs E, fo 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.

Each coordinate grid must be monotonically increasing. These are stored in array columns. For historical reasons, the energy is stored as low and high bin values.

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

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	Description
ENERG_LO	keV	nE	N/A	N/A	Energy grid, low edge of bin (but note: point data implies low and high are identical).
ENERG_HI	keV	nE	N/A	N/A	Energy grid, high edge of bin (but note: point data implies low and high are identical).
THETA	arcmin	jE	0.0	45.0	Off-axis angle of polar coordinate system.
PHI	deg	kE	0.0	360.0	Azimuthal angle in polar coordinate system.
EFFAREA	`cm**2`	$(n \times j \times k)$E	0.0	N/A	Mirror effective area
STAT_MIN	`cm**2`	$(n \times j \times k)$E	0.0	N/A	Statistical uncertainty in Mirror effective area, low side.
STAT_MAX	`cm**2`	$(n \times j \times k)$E	0.0	N/A	Statistical uncertainty in Mirror effective area, high side.
SYS_MIN	N/A	$(n \times j \times k)$E	0.0	1.0	Fractional systemacic uncertainty in Mirror effective area, low side.
SYS_MAX	N/A	$(n \times j \times k)$E	0.0	1.0	Fractional systematic uncertainty in Mirror effective area, high side.

Special Coordinate Keywords

990710 new section *Revision 1.4 — 22 June 1999*

An array column for the area generally requires several keywords in order to define its coordinate system and relation to other columns. These follow the conventions given in "Representation of celestial coordinates in FITS", by Greisen and Calabretta (Sept. 9, 1996). [8]

`i`CTYPn: This defines the axes of the image column. In the current case of a 3D image with the one energy axis, and two spatial axes, we have:

> 1CTYPn = 'ENERG_LO',
> 2CTYPn = 'THETA',
> 3CTYPn = 'PHI',

Here, n, is the column index.

TDIMn: This specifies the dimensionality of each axis of the image column. It has the form, '(N_E, N_θ, N_ϕ)'.

CREFn: This keyword has a string value which maps the image axes to TTYPEn keywords which specify grids for those axes. For example, with an array in column $n = 3$, the first axis being energy, the second off-axis angle, and third azimuthal angle, we would have:

[8] `http://www.cv.nrao.edu/fits/documents/wcs/wcs.all.ps`

$$\texttt{CREF3} =' (\texttt{ENERG\_LO}, \texttt{THETA}, \texttt{PHI})'$$

*i*CRVL*n*, *i*CRPX*n*, *i*CLDT*n*, *i*CUNI*n*: keywords to specify the image columns spatial coordinate system. These are not needed for the off-axis effective area, since the coordinate grids are explicitly tabulated.

CSYSNAME: This keyword gives the type of coordinate system. The only value supported here is XMA_POL.

4.2 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
```

4.2.1 CALDB Keywords

The required CALDB keywords are as follows:

```
CCLS0001  'BCF'
CDTP0001  'DATA'
CCNM0001  'EFFAREA'
CBD10001  'ENERG_LO(0.06-10.0)keV'
CBD20001  'THETA(0.0-45.0)arcmin'
CBD30001  'PHI(0.0-360.0)deg'
CBD40001  'SHELL(nnnn)'     /Shell 1346 bitmap; 1=>response included
CVSD0001  1996-11-01T00:00:00
CDES0001  'Telescope effective area map'
```

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 off-axis effective area.

4.4 Unresolved Issues

1. (none)

5 HRMA Vignetting

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) mode require the ensemble, while HETG or LETG data require single-shell responses.

Since the axes may be non-linear, the coordinates are encoded in array columns.

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.

The format is specified by OGIP Memo, "CAL/GEN/92-021" (George and Zellar; Version: 1994 Aug 09). Multiple extensions will store the all-shell ensemble area and areas for each individual shell.

The OGIP document provides two alternatives for the file format, one with and the other without an obscuration factor. Here we require obscuration to be included, and define the vignetting to be the ratio of the off-axis area to the on-axis area with all factors included. (For single-shell vignetting tables, the ratio is still to the ensemble on-axis area.)

Note that there will also be on-axis and off-axis effective area files in a similar format. The motivation for separate on-axis and off-axis files is that the on-axis case is modeled to much higher energy resolution. The on-axis data will typically be used to interpolate the off-axis area or vignetting function derived from the off-axis area.

A peculiarity of the format is that the energy grid has both high and low bounds. This implies that the area is integrated over a bin. However, our data are differential, since they represent the value at a discrete point. For compatibility, both `ENERG_LO` and `ENERG_HI` arrays will be included, but their values will be identical.

In order to ease downstream use, the vignetting file will have a regular grid in which each cell has a reasonable value. This may entail some interpolation and extrapolation of the input calibration data prior to producing the vignetting file.

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	N/A	N/A	N/A	NULL
1 (*)	BINTABLE	AXAF_VIGNET	CDB_HRMA_VIGNET	OGIP RESPONSE VIGNET	binary table, vignetting vs E, θ, ϕ, for all shells.
2	BINTABLE	AXAF_VIGNET	CDB_HRMA_VIGNET	ASC RESPONSE VIGNET	binary table, vignetting vs E, θ, ϕ, for shell 1.
3	BINTABLE	AXAF_VIGNET	CDB_HRMA_VIGNET	ASC RESPONSE VIGNET	binary table, vignetting vs E, θ, ϕ, for shell 3.
4	BINTABLE	AXAF_VIGNET	CDB_HRMA_VIGNET	ASC RESPONSE VIGNET	binary table, vignetting vs E, θ, ϕ, for shell 4.
5	BINTABLE	AXAF_VIGNET	CDB_HRMA_VIGNET	ASC RESPONSE VIGNET	binary table, vignetting vs E, θ, ϕ, 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

Each coordinate grid must be monotonically increasing.

These are stored in array columns. For historical reasons, the energy is stored as low and high bin values.

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

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	Description
ENERG_LO	keV	nE	N/A	N/A	Energy grid, low edge of bin (but note: point data implies low and high are identical).
ENERG_HI	keV	nE	N/A	N/A	Energy grid, high edge of bin (but note: point data implies low and high are identical).
THETA	arcmin	jE	0.0	45.0	Off-axis angle of polar coordinate system.
PHI	deg	kE	0.0	360.0	Azimuthal angle in polar coordinate system.
VIGNET	N/A	$(n \times j \times k)$E	0.0	1.0	Mirror vignetting.
STAT_MIN	N/A	$(n \times j \times k)$E	0.0	N/A	Statistical uncertainty in Mirror vignetting, low side.
STAT_MAX	N/A	$(n \times j \times k)$E	0.0	N/A	Statistical uncertainty in Mirror vignetting, high side.
SYS_MIN	N/A	$(n \times j \times k)$E	0.0	1.0	Fractional systemacic uncertainty in Mirror effective area, low side.
SYS_MAX	N/A	$(n \times j \times k)$E	0.0	1.0	Fractional systematic uncertainty in Mirror effective area, high side.

Special Coordinate Keywords

990710 new section *Revision 1.4 — 22 June 1999*

An array column for the area generally requires several keywords in order to define its coordinate system and relation to other columns. These follow the conventions given in “Representation of celestial coordinates in FITS”, by Greisen and Calabretta (Sept. 9, 1996). [9]

`i`CTYPn: This defines the axes of the image column. In the current case of a 3D image with the one energy axis, and two spatial axes, we have:

```
1CTYPn = 'ENERG_LO',
2CTYPn = 'THETA',
3CTYPn = 'PHI',
```

Here, n, is the column index.

TDIMn: This specifies the dimensionality of each axis of the image column. It has the form, `'(`N_E, N_θ, N_ϕ`)'`.

CREFn: This keyword has a string value which maps the image axes to TTYPEn keywords which specify grids for those axes. For example, with an array in column $n = 3$, the first axis being energy, the second off-axis angle, and third azimuthal angle, we would have:

[9] http://www.cv.nrao.edu/fits/documents/wcs/wcs.all.ps

$$\texttt{CREF3} = '(\texttt{ENERG\_LO}, \texttt{THETA}, \texttt{PHI})'$$

*i*CRVL*n*, *i*CRPX*n*, *i*CLDT*n*, *i*CUNI*n*: keywords to specify the image columns spatial coordinate system. These are not needed for the vignetting, since the coordinate grids are explicitly tabulated.

CSYSNAME: This keyword gives the type of coordinate system. The only value supported here is XMA_POL.

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.

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
```

5.2.1 CALDB Keywords

The required CALDB keywords are as follows:

```
CCLS0001  'BCF'
CDTP0001  'DATA'
CCNM0001  'TVIGNET'
CBD10001  'ENERG_LO(0.06-10.0)keV'
CBD20001  'THETA(0.0-45.0)arcmin'
CBD30001  'PHI(0.0-360.0)deg
CBD40001  'SHELL(nnnn)'     /Shell 1346 bitmap; 1=>response included
CVSD0001  1996-11-01T00:00:00
CDES0001  'Telescope vignetting map'
```

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 vignetting map.

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"[10]). 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[11]:** 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?

[10] 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:

```
hetghegD1996-11-01greffN0001.fits
hetgmegD1996-11-01greffN0001.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 as an array column. Uncertainties will also be stored in an array 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 one extension.

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.

* Replace the "*" 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	Comment
ENERGY	keV	1E	N/A	N/A	energy coordinate
EFF	NONE	nE	0.0	1.0	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).
STAT_MIN	NONE	nE	0.0	N/A	Statistical uncertainty 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).
STAT_MAX	NONE	nE	0.0	N/A	Statistical uncertainty 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).
SYS_MIN	NONE	nE	0.0	N/A	Fractional systematic uncertainty 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).
SYS_MAX	NONE	nE	0.0	N/A	Fractional systematic uncertainty 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).

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'
CBD20001  'SHELL('nnnn')     /Shell 1346 bitmap; 1=>response included
CVSD0001  1996-11-01T00:00:00
CDES0001  '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. file name conventions: `caldb.txt` does not specify how separate HEG and MEG files get named.

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.
2	BINTABLE	AXAF_HESF	2	CDB_HRCS_HESF	ASC RESPONSE FILTER HESF	Efficiency vs energy for the second segment of the flat.

10.2.2 Columns and Coordinate Systems

Each efficiency or error HDU will have columns for `ENERGY`, `EFF`, and uncertainties (both statistical and systematic). If uncertainties aren't known, corresponding columns will be omitted. If constant, they will be promoted to keywords. The value "n" below will be replaced by the actual width of the array, which is the number of energy bins. Multiple rows will hold the efficiency as a function of angle.

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	Comment
THETA	deg	1E	-10.	10.	angle of incidence
ENERGY	keV	nE	N/A	N/A	energy coordinate
EFF		nE	0.0	1.0	Efficiency array, as a function of energy.
STAT_MIN		nE	0.0	N/A	Statistical uncertainty of efficiency.
STAT_MAX		nE	0.0	N/A	Statistical uncertainty of efficiency.
SYS_MIN		nE	0.0	1.0	Fractional systematic uncertainty of efficiency.
SYS_MAX		nE	0.0	1.0	Fractional systematic uncertainty of efficiency.

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
```

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'
CBD20001   'THETA(3.0-10.0)deg'
CVSD0001   1996-11-01T00:00:00
CDES0001   'High Energy Suppression Filter (Drake Flat)'
```

10.3 Size and File Number Estimates

There will be one HESF efficiency files. The file will have about 5000 energies 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

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 converging cone of rays.

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

```
          S3                     S2                     S1
 CHIP_ID:  3                      2                      1
 +------------------+ +--------------------+ +--------------------+
 |       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.

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.
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.
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.

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.

11.2.2 Columns and Coordinate Systems

Each efficiency HDU will have the following columns:

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	Comment
ENERGY	keV	nE	N/A	N/A	energy coordinate array
EFF		nE	0.0	1.0	Filter transmission efficiency.
STAT_MIN		nE	0.0	N/A	Statistical uncertainty in filter transmission efficiency.
STAT_MAX		nE	0.0	N/A	Statistical uncertainty in filter transmission efficiency.
SYS_MIN		nE	0.0	1.0	Fractional systematic uncertainty in filter transmission efficiency.
SYS_MAX		nE	0.0	1.0	Fractional systematic 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.'
```

12 HRMA Geometric Parameters

New section, Revision 1.3

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

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

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.
HESFOffsetZ	mm	The distance in the z-axis between the center of the HRC-S and the lower edge of the filter.
HESFTheta1	deg	the angle in the $x - z$ plane between the optical axis (x) and the plane of the upper facet.
HESFTheta2	deg	The angle in the $x - z$ plane between the optical axis (x) and the plane of the lower facet.
HESFHeight1	mm	The x axis distance between the lower edge of the upper facet (nearest the HRMA) and the lower edge of the lower facet.
HESFOffsetX	mm	The x axis distance (or "height") of the lower edge of the lower facet (furthest from the HRMA) above the MCP surface, at $y = 0$.
HRCS_Y0_MINUS HRCS_Y0_PLUS	mm	The "boundaries" of MCP segments, relative to optical axis (which is different from the array centerline). These mark the locations at which the MCP tilts begin.
HRCS_TILT_MINUS HRCS_TILT_CENTER HRCS_TILT_PLUS	deg	The tilt angle of the MCP.
HESFGapY2	mm	The HESF central gap limit on the minus-y side.
HESFGapY1	mm	The HESF central gap limit on the plus-y side.
HRCS_YMIN	mm	The minimum extent of the HRC-S on the AXAF y-axis.
HRCS_YMAX	mm	The maximum extent of the HRC-S on the AXAF y-axis.

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.
2. 990611 Augmented w/ HESF params. But: these may become separate ARD files via pixlib par file conversion.

15 ACIS Parameters

New section, Revision 1.3

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