AXAF Science Center

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

ASC Archive Interface Control Document

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

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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;reorganized.
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.

Unresolved Issues

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

1. Specified data need CALDB compliance keywords added.
2. Calibration may not be able to fit single shell HRMA areas. Hence, the vignetting function coefficient and vignetting energy coefficient tables for single shells may not exist as specified.

Contents

1 Introduction

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

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

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

Formatting NOTE: Text formatted between horizontal rules (like this block) provide some historical context regarding alternative choices considered, which may still be debated.

Items boxed in the right margin (like this) are questions to be answered or TBD's to be replaced.

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 ASC Level 2 pipelines and distributed to the ASC Data Archive (see Applicable Document 1 and the "ASC Data System Software Design," Applicable Document 2) during the course of the AXAF mission.

2 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)

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

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/ãrots/asc/fits/ascfits.ps` (and references therein).

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`

3 Functional Description

3.1 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).

CALDB compliance TBD.

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.

3.2 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.

3.3 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.

3.4 Assumptions and Constraints

It is assumed that ASC 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 ASC archive and placed into an exportable calibration database (CALDB) for users.

3.5 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.

3.6 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.

4 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. Donnely
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. Donnely
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. Donnely
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").

4.1 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.

What is the CIP reference?

$\overline{Q}_n(E)$: 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 ($\sim$thousand bins).

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

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

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

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

4.1.1 Generating U

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

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

$$U_n(E_i, x_j, y_k) = \frac{Q_n(E_i, x_j, y_k)}{\overline{Q}_n(E_i)}. \tag{2}$$

For each j, k, we fit U with a low-order polynomial in E to derive the coefficients. These coefficients are stored in a FITS embedded function file.[2] Thus, for every

[2] "FITS Embedded Function Proposal: ASC-FITS-FUNCTION-1.0 (SDS-11.1)", J.McDowell and A.Rots (`http://hea-www.harvard.edu/asclocal/sds/docs/jcmdocs/ps/SDS11.1.ps`)

position bin, we have a few numbers (of order 10 instead of order 1000) which allow us to describe the QE essentially continuously in energy. To do this, we access the embedded function with an arbitrary energy for the non-discrete permutation of the preceding equation:

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

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

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

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

$Q_n(E_i, x_j, y_k)$

$\overline{Q}_n(E)$

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

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

```
Restrictions:
```

4.2 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:

- Any device segments (such as ACIS CCD quadrants or HRC-S filter regions) are included as additional columns in the extension. Uncertainty values are also included as columns, for each segment.
- Filter tranmissivities are included in the QE.
- 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).

4.2.1 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	Type	EXTNAME	EXTVER	CONTENT	HDUCLASS	Description
1	NULL	N/A	N/A	N/A	N/A	NULL primary
2 (*)	BINTABLE	QE	1	QE	ASC QE	Binary table describing the QE vs. Energy for one device (CCD or MCP). Device segments (e.g., ACIS quadrants) are included, if appropriate.
$3-n$	BINTABLE	QE	$2-(n-1)$	QE	ASC QE	Binary table describing the QE vs. Energy for additional devices, as necessary. The EXTVER key will indicate the `chipid`.

Fix HDUCLASS, CONTENT keywords!

4.2.2 Columns and Coordinate Systems

Columns for Detector QE HDU are given in the following table. QEn and DQEn columns are added as requred for the number of device segments (e.g., 4 for ACIS quadrants, 1 for HRC-I, 6 for HRC-S filter sections).

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	Comment
ENERGY	keV	1E	0.0	14.0	Energy
QE	1	1E	0.0	1.0	Mean Quantum efficiency for the device, averaged over all segments. (detector times filter)
DQE	1	1E	0.0	N/A	Uncertainty in QE.
QE1	1	1E	0.0	1.0	Quantum efficiency for the device (detector times filter), segment 1.
DQE1	1	1E	0.0	N/A	Uncertainty in QE.
QE2	1	1E	0.0	1.0	Quantum efficiency for the device (detector times filter), segment 2.
DQE2	1	1E	0.0	N/A	Uncertainty in QE.
QE3	1	1E	0.0	1.0	Quantum efficiency for the device (detector times filter), segment 3.
DQE3	1	1E	0.0	N/A	Uncertainty in QE.
QE4	1	1E	0.0	1.0	Quantum efficiency for the device (detector times filter), segment 4.
DQE4	1	1E	0.0	N/A	Uncertainty in QE.

4.2.3 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). Relevant keywords are:

```
INSTRUME= '        '          / HRC, ACIS, EPHIN, S/C subsystems
DETNAM  = '        '          / Detector name
DATAMODE= '        '          / Datamode (varies only for science instr. data)
```

4.3 File Structure: QE Uniformity Embedded Function

The QE uniformity is stored as a FITS embedded function. The independent variable is the energy, and the function value is the ratio of the QE at the specified position to the mean QE at the same energy. There will be one row for each cell (about 1000 cells per detector element). There will be one extension per detector element. The `extver` keyword can be used to discriminate the CHIPID.

4.3.1 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	Type	EXTNAME	EXTVER	CONTENT	HDUCLASS	Description
1	NULL	N/A	N/A	N/A	N/A	NULL primary
2 (*)	BINTABLE	QEUNIFORM	1	FUNCTION	ASC FUNCTION	Polynomial function table describing the QE uniformity vs. Energy at every position.
$3-n$	BINTABLE	QEUNIFORM	$2-(n-1)$	FUNCTION	ASC FUNCTION	Polynomial function table describing the QE uniformity vs. Energy at every position.

4.3.2 Columns and Coordinate Systems

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

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

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

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

4.4 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 may be sub-divided into separate regions by filter (TBD)). Since the energy axis may be non-linear, its coordinates are encoded in "EGRID" extension. The spatial axes are linear and will have coordinate systems attached.

TBD: HRC-S filter sections.

The order of axes is arbitrary, but preferred to be x, y, E, from most to least varying index. This is because common usage will retrieve a 2D image at constant energy. The energy axis grid extension must be matched with its corresponding image via the TBD header keywords.

TBD: keywords to match image energy axis w/ its corresponding grid extension.

4.4.1 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. The principal HDU will contain a three-dimensional image of the QE, with two spatial dimensions and one energy dimension. The energies of each plane will be tabulated in an extension. The spatial dimensions will be uniform and header keywords will define the cells in terms of detector pixel coordinates. Each device (such as ACIS CCDs or HRC MCPs) will have its data stored in a pair of seperate HDUs, with unique EXTVER keywords.

HDU	Type	EXTNAME	EXTVER	CONTENT	HDUCLASS	Description
1 (*)	IMAGE	QE	1	QE	ASC IMAGE STANDARD	Detector QE vs position and energy.
2	BINTABLE	EGRID	1	EGRID	ASC	Energy grid for image energy axis.
3	IMAGE	QE	$2-n$	QE	ASC IMAGE STANDARD	Detector QE vs position and energy.
4	BINTABLE	EGRID	$2-n$	EGRID	ASC	Energy grid for image energy axis.

4.4.2 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. Note that the CRVAL and CDELT values are *representative only!* They may be gridded differently. In particular, HRC is likely to have values for the pair of order 128.5, 256.

CTYPE	CNAME	CRPIX	CRVAL	CDELT	CUNIT	Comment
pixel	CHIPX	1	16.5	32	pixel	First spatial axis.
pixel	CHIPY	1	16.5	32	pixel	Second spatial axis.
energy	ENERGY	N/A	N/A	N/A	keV	Energy axis (tabulated in EGRID extension).

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

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	TDBIN	TNULL	Comment
BIN	bin	1I	1	16384	1	0	energy bin number
E	keV	1E	0.0	20.	N/A	NaN	energy of bin

4.5 Size and File Number Estimates

4.5.1 Mean Absolute QE

For ACIS, each extension has 11 columns of reals, and will have about 1024 rows. There are 10 such extensions (one for each CCD), yielding about 440 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, but has fewer regions per device. There will be 4 QE extensions (one for each MCP), and the HRC-S MCP extensions will have columns for the different filter regions. The final size will be about 64 kB.

4.5.2 Spatial QE

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

4.5.3 QE Uniformity

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

4.6 Unresolved Issues

1. HEASARC CALDB-compliance keywords have not yet been added.

2. ACIS IPI may provide non-uniformity as a function of spatially variant depletion-depth coefficients. This is pending review for inclusion in Rev. 1.2 of this document.

5 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	HRMA_aeff.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.

This format may be deprecated in favor of a functional description, in which the vignetting at any energy is parameterized as a 2D surface, and the coefficients are further decomposed into another parameterization with energy. In this case, only the on-axis vector versus energy component of this file will be needed.

5.1 File Structure

The HRMA effective area will be stored as a three-dimensional images. Multiple 3D images are required in order to store the effective area for all shells, shells 1 & 3 (MEG), and shells 4 & 6 (HEG). Imaging mode (non-grating observations or zero-order imaging) or LETG mode require the ensemble area, while HETG data require shell-pair response.

Since the axes may be non-linear, the coordinates are encoded in a "*GRID" extension for each axis. (The quantities are differential, so bin boundaries are not required.)

The order of axes is arbitrary, but preferred to be θ, ϕ, E, from most to least varying index. This is because expected usage will retrieve a 2D image at constant energy, and θ and ϕ are the spatial dimensions.

5.1.1 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 ASC principal HDU.

HDU	TYPE	EXTNAME	CONTENT	HDUCLASS	Description
1 (*)	IMAGE	AEFF	IMAGE	ASC IMAGE STANDARD	3D image, cm^2 vs θ, ϕ, E, for all shells.
2	BINTABLE	EGRID	EGRID	ASC	Energy grid for 3D images' 3rd axes (Energy)
3	BINTABLE	TGRID	TGRID	ASC	θ-grid for 3D images' 1st axis (off-axis angle)
4	BINTABLE	PGRID	PGRID	ASC	ϕ-grid for 3D images' 2nd axis (azimuthal angle)
5	IMAGE	DAEFF	IMAGE	ASC IMAGE STANDARD	3D image, Uncertainty in effective area (AEFF) for all shells.

5.1.2 Column and Axis Descriptions

The axes of the images are:

θ: the off-axis angle measured in arcminutes,

ϕ: the azimuthal angle, measured in degrees, and

E: the energy, measured in keV.

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

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

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

EGRID for E,

TGRID for θ, and

PGRID for ϕ.

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

Columns for Auxiliary EGRID HDU:

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	TDBIN	TNULL	Comment
BIN	bin	1I	1	16384	1	0	energy bin number
E	keV	1E	0.0	20.	0.001	NaN	energy of bin

Columns for Auxiliary TGRID HDU:

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	TDBIN	TNULL	Comment
BIN	bin	1I	1	16384	1	0	θ bin number (off-axis angle)
THETA	arcmin	1E	0.0	60.	0.1	NaN	angle of bin

Columns for Auxiliary PGRID HDU:

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	TDBIN	TNULL	Comment
BIN	bin	1I	1	16384	1	0	ϕ bin number (azimuthal angle)
PHI	deg	1E	0.0	360.	1.0	NaN	azimuth of bin

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

5.2 Special Header Keywords

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

Each header does, however, require the units of the data to be specified with the `BUNIT` keyword. Missing data, as for unspecified regions of the (θ, ϕ, E) volume, have values specified by the `BLANK` keyword. If this is not present and the data are reals (as they are specified), then the IEEE NaN value is implied (since `BLANK = NaN` is not allowed in the FITS standard).

```
BUNIT   = 'cm**2'
BLANK   = -1
```

5.3 Size Estimate

The nominal number of off-axis and azimuthal angular bins are about 8×12, respectively, with about 1024 energy bins. Hence, the image size is about 750 kB. There are three such image HDUs for different shell combinations. Hence the total size is of order 2 MB. One file suffices to specify the HRMA effective area.

5.4 Unresolved Issues

1. HEASARC CALDB compliant keywords have not yet been added.

6 HRMA Vignetting Parameterized Function File

Data Product Summary

Analysis Reference Data Product	Effective Area Function
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	TBS

In order to assist computation of Exposure Maps effective areas derived from Exposure Maps, it is desireable to have a parameterized function which allows the mirror's effective area to be computed at arbitrary energy and position. The mirror vignetting (ratio of the off-axis area to the on-axis area) has been parameterized as a two-dimensional surface at specific energies. The surface is defined by the sum of a Lorentzian and a Gaussian. At each energy, there are six coefficients.

coef function TBD, but probably a spline

Since the vignetting surfaces are only specified at a few energies, but the area is desired at arbitrary energies, the fit is further characterized by parameterization of each model coefficient as a function of energy. The coefficients will be provided for the 4-shell ensemble, and for shell-pairs (1&3, and 4&6 for HETG support).

6.1 File Structure

The vignetting surface coefficients will be represented as a FITS table Each row of the file will contain the energy and the coefficients. The function itself will be commented in the header.[3]

Review EXTNAME, CONTENT, HDUCLASS, w/ A.R.

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.

[3] Migration to ASC FITS embedded functions may occur later.

HDU	Type	EXTNAME	CONTENT	HDUCLASS	Description
1	NULL	N/A	N/A	N/A	
2 (*)	BINTABLE	HRMAVIG1	COEF	ASC, CAL MODEL COEF	HRMA Vignetting model coefficient table: coefficients vs energy, for shell 1.
3	BINTABLE	HRMAVIG3	COEF	ASC, CAL MODEL COEF	HRMA Vignetting model coefficient table: coefficients vs energy, for shell 3. q
4	BINTABLE	HRMAVIG4	COEF	ASC, CAL MODEL COEF	HRMA Vignetting model coefficient table: coefficients vs energy, for shell 4.
5	BINTABLE	HRMAVIG6	COEF	ASC, CAL MODEL COEF	HRMA Vignetting model coefficient table: coefficients vs energy, for shell 6.
6	BINTABLE	HRMAVIG1346	COEF	ASC, CAL MODEL COEF	HRMA Vignetting model coefficient table: coefficients vs energy, for all-shell ensemble.
7	BINTABLE	HRMAVCOEF1	COEF	ASC, CAL MODEL COEF	HRMA Vignetting model coefficient parameterization vs. energy, for shell 1.
8	BINTABLE	HRMAVCOEF3	COEF	ASC, CAL MODEL COEF	HRMA Vignetting model coefficient parameterization vs. energy, for shell 3.
9	BINTABLE	HRMAVCOEF4	COEF	ASC, CAL MODEL COEF	HRMA Vignetting model coefficient parameterization vs. energy, for shell 4.
10	BINTABLE	HRMAVCOEF6	COEF	ASC, CAL MODEL COEF	HRMA Vignetting model coefficient parameterization vs. energy, for shell 6.
11	BINTABLE	HRMAVCOEF1346	COEF	ASC, CAL MODEL COEF	HRMA Vignetting model coefficient parameterization vs. energy, for all-shell ensemble.

6.2 Column and Axis Descriptions

The vignetting model coefficient extension columns are described in the following table. The function is currently an off-center Gaussian plus Lorentzian, and is defined at about 9 energies.

coefficients TBD: tentatively 6 for off-center Gauss+Lorentz, but coord sys may change.

Columns for Auxiliary HRMAVIG HDU

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	TNULL	Comment
ENERGY	keV	1E	0	14	*NaN*	Energy to which the coefficients on this row apply.
GAUSAMP	NONE	1E	N/A	N/A	*NaN*	Gaussian amplitude
GAUSSIG	deg	1E	0	N/A	*NaN*	Gaussian sigma
LORAMP	NONE	1E	N/A	N/A	*NaN*	Lorentzian amplitude
LORWID	deg	1E	0	N/A	*NaN*	Lorentzian width
ALTOFFSET	deg	1E	N/A	N/A	*NaN*	"Altitude" offset
AZIOFFSET	deg	1E	N/A	N/A	*NaN*	"Azimuth" Offset
dGAUSAMP	NONE	1E	N/A	N/A	*NaN*	delta (1-sigma uncertainty) in Gaussian amplitude
dGAUSSIG	deg	1E	0	N/A	*NaN*	1-sigma uncertainty in Gaussian sigma
dLORAMP	NONE	1E	N/A	N/A	*NaN*	1-sigma uncertainty in Lorentzian amplitude
dLORWID	deg	1E	0	N/A	*NaN*	1-sigma uncertainty in Lorentzian width
dALTOFFSET	deg	1E	N/A	N/A	*NaN*	1-sigma uncertainty in "Altitude" offset
dAZIOFFSET	deg	1E	N/A	N/A	*NaN*	1-sigma uncertainty in "Azimuth" Offset

The following table defines the columns for the parameterization of the coefficients with energy. They are tentatively defined as a piecewise polynomial (such as a cubic spline). Hence, there may be more than one row at each energy to store the individual polynomial pieces.

Columns for Auxiliary HRMAVCOEF HDU

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	TNULL	Comment
CNAME	NONE	16A	N/A	N/A	N/A	Coefficient name (e.g., GAUSAMP, LORWID)
FLMIN	keV	1E	0	20	*NaN*	Minimum applicable value of the independent variable (Energy).
FLMAX	keV	1E	0	20	*NaN*	Maximum applicable value of the independent variable (Energy).
FLREF	keV	1E	0	20	*NaN*	Reference value of independent variable (e.g., function of x-FLREF)
ORDER	NONE	1I	0	9	-1	Polynomial order; maximum tentatively set to 9.
COEF	NONE	10E	N/A	N/A	*NaN*	Coefficient array, of which the first ORDER+1 are required to be valid. (The length should be equal to the (TLMAX of ORDER)+1.)

6.3 Special Header Keywords

The vignetting function will be defined by header comments. The file format may eventually migrate to a FITS embedded function which will allow the function to be formally named and parsed by software, and possibly modified in *implementation* by changing the file header and contents. For now, the implementation is explicit in the application program. The function will be handled by comments as follows.

For the vignetting surface coefficients:

```
COMMENT VIGNETTING = GAUSS(GAUSAMP,GAUSSIG,ALTOFFSET,AZIOFFSET) +
COMMENT              LOR(LORAMP,LORWID,ALTOFFSET,AZIOFFSET)
COMMENT r(x,y;c,d) = sqrt(  (x-c*cos(d))^2 + (y-c*sin(d))^2 )
COMMENT GAUSS(x,y;a,b,c,d) = a * exp( -0.5 * r(x,y;c,d)^2  / b^2 )
COMMENT LOR(x,y;a,b,c,d) = a / (1 + 2 * r(x,y;c,d)^2  / b^2 )
```

For the coefficient parameterization:

```
COMMENT POLY= sum_i(COEF_i*(x-FLREF)^i), i=0..ORDER; FLMIN <x<= FLMAX
COMMENT POLY= 0; x <= FLMIN, x > FLMAX
```

6.4 Size Estimate

TBD

6.5 Unresolved Issues

1. HEASARC CALDB compliant keywords have not yet been added.
2. Final form of the vignetting function is TBD by Cal.
3. Form of the coefficient parameterization is TBD by Cal. If done as a spline, then the application may re-determine the spline fit vignetting coefficients instead of using the tabulated coefficient parameterization.
4. Calibration may not be able to fit single shell HRMA areas. Hence, the vignetting function coefficient and vignetting energy coefficient tables for single shells may not exist.

7 Detector Bad Pixel Files

Data Product Summary

Analysis Reference Data Product	badpix
Instrument(s)	ACIS, HRC
Level	2
Scientist/SDS	J.Kastner, A.Dobrzycki
Scientist/Cal	B.McNamara
	H.Donnely
Filetype	FITS bintable
Created by tool	TBD
Used by tool(s)	inst_scale_map
Sample file	TBD

Bad pixel lists are required for masking the Instrument Map prior to making an exposure map. They are pixels which are dead or "hot". Their locations will be set to zero QE in the Instrument Map.

7.1 File Structure

TBS: bad-pixel reference, for HRC

The bad pixel format for ACIS is defined by the ACIS Level 1 ICD (Document 6). For HRC, bad pixel definition can be found at TBS.

7.2 Unresolved Issues

1. HRC bad pixel specification

8 ACIS Spatial Window Files

Data Product Summary

Analysis Reference Data Product	ACIS Windows
Instrument(s)	ACIS
Level	2
Scientist/SDS	J. Kastner
Scientist/Cal	B.McNamara
Filetype	FITS bintable
Created by tool	TBD
Used by tool(s)	inst_scale_map
Sample file	TBD

ACIS may have rectangular "windows" defined. Events falling within these window boundaries can be accepted or rejected before telemetry. This essentially changes the effective active region of the detector. The Instrument Map must be masked by these windows prior to creation of an Exposure Map.[4]

8.1 File Structure

The window format is defined in the "ACIS Data Products: Level 1 to ASC ARchive Interface Control Document"[5] (Document 6).

8.2 Unresolved Issues

1.

[4] In addition, ACIS can operate in subarray mode, in which only a portion of the CCD is non-destructively read out. Even if the entire CCD is read out, however, events will only be detected between rows/columns 2–1023, inclusive. The ACIS spatial window ("mask") file describes both of these limitations on the effective active regions of ACIS, as well as any PHA and grade filters applied during on-board event processing.

[5] http://space.mit.edu/ASC/docs/acis_l1.ps.gz

9 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 $\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{keV}^{-1}$].

9.1 File Structure

Several file-formats will 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"[6]). Each row should have two values: Energy (in [keV]), and photon flux (in [photons $\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{keV}^{-1}$]). Rows starting with a "#" character are treated as comments.

`XSPEC` **Table Model[7]:** 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!)

Exposure Map ASCII Table, which is similar to the `MARX` file, but is in integrated units ([photons $\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{bin}^{-1}$]). These units are the same as in the `XSPEC` Table Model definition.

spectrum file conversion utilities

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

9.2 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.

9.3 Unresolved Issues

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

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

10 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.

10.1 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	TYPE	EXTNAME	CONTENT	HDUCLASS	Description
1	NULL	N/A	N/A	N/A	null primary
2 *	BINTABLE	PSF_FWHM	FWHM	ASC PSF FWHM	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

10.2 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: PSF_FWHM

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.

10.3 Special Header Keywords

None.

10.4 Size Estimate

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

10.5 Unresolved Issues

None.

11 RMF Energy-Limit Table

Renamed from "RMF PI-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 space) is used to specify PI limits versus energy. The table is generated for a specified fractional enclosed power, and specifies the low and high PI offsets from the nominal PI for this power vs energy (i.e., the actual limits are $PI - PI\_LO$ to $PI + PI\_HI$). It is created using a detector response matrix ("RMF"), or the equivalent functional form.

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.

11.1 Current Formats

The following subsections describe the current implementation.

11.1.1 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 is (or is close to) the current, in-use, format, as of 980923.

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.

11.1.2 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.

11.1.3 Special Header Keywords

None.

11.1.4 Size Estimate

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

11.2 Future Format

The following subsections describe the intended generalization to accomodate multiple responses, and change from PI to ENERGY units (since PI will 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 change from "RM" to "IRM", since the quantity tablulated comes from an "Integrated Redistribution Matrix".

981021 Note: pending discussion — this file is almost an `EBOUNDS` type, but for the low and high columns being deltas instead of absolutes. Conversion to actual `EBOUNDS` will be discussed, but would require changes to application s/w.

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

11.2.2 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.

Note: Columns "energy_lo" and "energy_hi" were previously called "pi_lo" and "pi_hi".

11.2.3 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.

```
FRACPROB=0.95                    / Fractional enclosed probability
```

11.2.4 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.

11.3 Unresolved Issues

1. Must migrate from a single table to 10 tables, one for each CCD.
2. Must migrate to "ENERGY" instead of "PI" as the independent variable.
3. If absolute energy limits were given instead of differences from the nominal, then this file would be of the kind, "`EBOUNDS`", and existing, common format. Whether to migrate is TBD. One tool would be affected (`tg_resolve_events`).

12 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.

12.1 File Structure

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

12.1.1 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	TYPE	EXTNAME	CONTENT	HDUCLASS	Description
1	NULL	N/A	N/A	N/A	Null primary.
2	BINTABLE	EFFIC_1	EFFIC	ASC RESPONSE TG	Efficiency vs energy (rows) and order (columns), shell 1 (outermost).
3	BINTABLE	EFFIC_3	EFFIC	ASC RESPONSE TG	Efficiency vs energy (rows) and order (columns), shell 3.
4	BINTABLE	EFFIC_4	EFFIC	ASC RESPONSE TG	Efficiency vs energy (rows) and order (columns), shell 4.
5	BINTABLE	EFFIC_6	EFFIC	ASC RESPONSE TG	Efficiency vs energy (rows) and order (columns), shell 6.
6	BINTABLE	UNCERT_1	EFFIC	ASC RESPONSE TG	Uncertainty of efficiency vs energy (rows) and order (columns), shell 1 (outermost).
7	BINTABLE	UNCERT_3	EFFIC	ASC RESPONSE TG	Uncertainty of efficiency vs energy (rows) and order (columns), shell 3.
8	BINTABLE	UNCERT_4	EFFIC	ASC RESPONSE TG	Uncertainty efficiency vs energy (rows) and order (columns), shell 4.
9	BINTABLE	UNCERT_6	EFFIC	ASC RESPONSE TG	Uncertainty efficiency vs energy (rows) and order (columns), shell 6.

12.1.2 Columns and Coordinate Systems

Each efficiency HDU will have the following columns:

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	TDBIN	TNULL	Comment
E	keV	1E	0.0	20.0	0.001	NaN	energy coordinate
NORDERS		1I	1	n	N/A	-1	Number of orders in efficiency array column. The actual orders range from -(NORDERS-1)/2 to (NORDERS+1)/2 (inclusive, including zero-order). NORDERS may be adjusted to minimize null-padding. Typical values for n will be 23 for HETG and 51 for LETG.
EFFICIENCY	NONE	nE	0.0	1.0	N/A	NaN	Efficiency array, vs order. The first elements is for m= -(NORDERS-1)/2, and the NORDER-th is +(NORDERS-1/)2. Note that n is to be replaced with the actual number of orders, for efficient storage (see NORDERS column definition).

The "UNCERT_*" auxiliary extension hdu tables will have analogous structure, but the "EFFICIENCY" column name will be replaced by "UNCERTAINTY".

12.2 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.

12.3 Unresolved Issues

1. CALDB keywords required.

13 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..

13.1 File Structure

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

13.1.1 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	Type	EXTNAME	EXTVER	CONTENT	HDUCLASS	Description
1	NULL	N/A	N/A	N/A	N/A	
2 (*)	BINTABLE	EFFIC	1	EFFIC	ASC RESPONSE	Efficiency vs energy for the first segment of the flat.
3	BINTABLE	EFFIC	2	EFFIC	ASC RESPONSE	Uncertainty of efficiency vs energy for second segment of the flat.

13.1.2 Columns and Coordinate Systems

Each HDU will have the following columns:

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

The "UNCERT*" auxiliary extension hdu tables will have analogous structure, but the "EFFICIENCY" column name will be replaced by "UNCERTAINTY".

13.2 Size and File Number Estimates

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

13.3 Unresolved Issues

1. CALDB keywords required.
2. Are there additional dependencies, such as z-offset?
3. Are there additional dependencies, such as angle-of-incidence?

14 Miscellaneous Products

There are a few miscellaneous parameters which should be considered Analysis Reference Data. They are presently contained both in `pixlib` and in grating tool parameter files.

```
  what                    inst

grating_angles          hetg/letg
grating_periods         hetg/letg
grating_radii           hetg/letg
rowland_spacing         hetg/letg

mirror_geometrical_area  hrma
```

Each of these is specified by a few numbers.

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