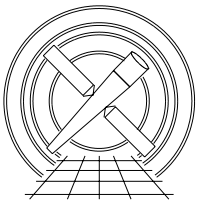
# AXAF Science Center



# Grating PSF Library:
# Data Product Interface Document:

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# Unresolved Issues

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

1. CBD keywords are not valid for the whole dataset (eg large values of $\phi$ are not allowed for all $\theta$).
2. The CDB keywords do not distinguish between HEG and MEG.
3. Normalization of the cross dispersion profiles for small extraction regions needs to be more explicit.

# Contents

**1 Introduction** **1**
1.1 Purpose . . . 1
1.2 Scope . . . 1
1.3 Applicable Documents . . . 1
1.4 Functional Description . . . 1
1.4.1 Data Content Summary . . . 1
1.4.2 Source and Transfer Method . . . 1
1.4.3 Recipients and Utilization . . . 1
1.4.4 Pertinent Relationships with Other Interfaces . . . 2
1.5 Assumptions and Constraints . . . 2
1.6 Products Not Covered . . . 2

**2 Access** **3**
2.1 Access Tools; Input/Output Protocol . . . 3

**3 Detailed Interface Specifications** **4**
3.1 Labeling and Identification . . . 4
3.2 PSF Library structure Definition . . . 4
3.3 1-D PSF Library Format . . . 4

**4 1-D File Structure for Grating Data** **5**
4.1 Enumerated Axis Definitions . . . 6
4.2 Image Hypercube coordinate Definitions . . . 9
4.3 Column and Axis Descriptions . . . 9
4.4 Additional Required Keywords . . . 10
4.5 Coordinate Keywords . . . 10

# List of Tables

1 PSF Data Product Files . . . . . 4
2 Table describing the REEF file structure . . . . . 6
3 Table describing the RPSF file structure for in the dispersion direction . . . . . 6
4 Table describing the RPSF file structure for the cross-dispersion direction . . . . . 7
5 FITS Enumerated Axis binary table contents for the radial axis . . . . . 7
6 FITS Enumerated Axis binary table contents for the energy axis . . . . . 7
7 FITS Enumerated Axis binary table contents for the $\theta$ axis . . . . . 7
8 FITS Enumerated Axis binary table contents for the $\phi$ axis . . . . . 7
9 FITS Enumerated Axis binary table contents for the Order axis . . . . . 8
10 FITS Enumerated Axis binary table contents for the DEFOCUS axis . . . . . 8
11 The principal HDU for the the PSF containing the 1-dimensional PSF data for the gratings. 9
12 The SUMRCTS HDU for the the PSF containing the total counts in the 1-dimensional PSF data for the gratings. . . . . 9

# 1 Introduction

This document describes the interface to be employed in accessing the PSF Library products, according to the requirements stipulated in Applicable Document 3.

## 1.1 Purpose

The purpose of this document is to define the Point Spread Function (generically referring to PSF) Library to be used in Level 2 processing for the grating products, as described in PSF Tool ICD. This consists of reading the task specific calibration data file and returning the user specified product (e.g. PSF image, characteristic size, psf fraction).

## 1.2 Scope

This interface shall apply to all Grating specific PSF and LSF (Line Spread Function) data products that need the PSF Library and distributed to the CXC Data Archive (see Applicable Documents TBD) 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. AXAF Data Products Guide
   `http://hea-www.harvard.edu/asclocal/sds/CDR2/dp.ps`
2. AXAF Coordinate Systems
   `http://hea-www.harvard.edu/ jcm/asc/coords`
3. ASC AMO-2400 (SE03)
   ASC Data System Requirements (ASC.302.93.0008)
4. ASC AMO-2401 (DS01)
   ASC Data System Software Design (ASC.500.93.0006)
5. HEASARC FITS Standards:
   `http://legacy.gsfc.nasa.gov/docs/heasarc/ofwg/`
   `docs/summary/ogip_93_001_summary.html`
6. ASC FITS File Designers' Guide
   `http:// http://hea-www.harvard.edu/~arots/asc/fits/ascfits.ps`

## 1.4 Functional Description

### 1.4.1 Data Content Summary

All Grating PSF Library files shall consist of data files conforming to the FITS format (Applicable Document 6). These files contain header keyword entries and binary table (BINTABLE) extensions.

### 1.4.2 Source and Transfer Method

PSF Library shall be created by TBD as described in Applicable Document 3.

### 1.4.3 Recipients and Utilization

The primary recipients, via distribution from the archive, of the PSF Library are AXAF observers, who will utilize these data products for scientific data analysis. The CXC may also make use of specific PSF Library data products for instrument calibration, instrument and/or spacecraft monitoring and trends analysis, and validation and verification of the Level 0, Level 1, and Level 1.5 software and of the data products themselves.

### 1.4.4 Pertinent Relationships with Other Interfaces

Changes to the definition of CXC FITS, as described in Applicable Documents 6, may affect the format of the PSF data products described in the current document.

## 1.5 Assumptions and Constraints

Besides the position of the primary HDU the order of the extensions arbitrary. The column order for any binary table appended to the data file is also arbitrary. The primary HDU should have the PSF spatial dimension as the first axis, the others may occur in any order.

## 1.6 Products Not Covered

PSF products that are used for maintenance and diagnostic purposes (those that are not supplied to the user for scientific data analysis), or which are generic AXAF Level 2 products, are not currently included within the interface defined by this document.

# 2 Access

## 2.1 Access Tools; Input/Output Protocol

Since PSF Library products obey the formatting rules described in Applicable Documents 6, they may be accessed by any software that conforms to those standards, including all versions of the FITSIO libraries that support the BINTABLE extension. In addition, since they adhere to HEASARC standards (Applicable Document 5), PSF data product files are compatible with the input/output routines that constitute the CXC data interface.

# 3 Detailed Interface Specifications

## 3.1 Labeling and Identification

The data files in the PSF Library shall be assigned external names as shown in Table 1. The names obey the convention described in `http://hea-www.harvard.edu/ arots/asc/fits/content.txt`. Where `INST`

| **Title** | **File name** |
|---|---|
| 1-d lsf data | `INST_GRAT_Dyyyy-mm-ddtypeNXXXX.fits` |

Table 1: PSF Data Product Files

is HETG or LETG. `GRAT` is a string indicating the grating type with allowed values of heg, meg, or leg. The PSF library file can contain either Encircled Energy (`type`=reef) data or the Line Spread Function (`type`=lsf). Each type of data can also be from the dispersion `type`=lsf or cross-dispersion data and is denoted by `type`= xdsf. NXXXX gives the version number with XXXX being a four digit integer. This file will contain the PSF's for that position and all the energies as a data cube in the primary HDU (Header Data Units) as described below. `yyyy-mm-dd` is the effective date.

No additional non-instrument-specific data products are output by the PSF processing pipeline.

## 3.2 PSF Library structure Definition

The primary HDU for the PSF library shall be a hypercube with the (n-dimensional images) that extend along the coordinates below. For two dimensional data the r coordinate is not required. For LSF data the l and m coordinate should be omitted. All others are required.

```
l - spatial x-direction of the PSF image
m - spatial y-direction of the PSF image
r - spatial radial direction of PSF image
X - spatial x-direction offset coordinate
Y - spatial y-direction offset coordinate
E - energy
f - focus
O - order
```

Each coordinate may be regularly sampled, in which case the sample points are defined by the usual CTYPEi, etc., keywords; or irregularly, in which case the sample points are defined in a table extension *in the same file*. Each coordinate has to have one or more pixels, but one is expressly allowed. If there is only one point along any of the required axes, the axis still needs to be present and its coordinate value shall be defined in the usual way (CTYPEi, etc.). A number of coordinate axes (most notably the spatial ones) will have several aliases defined in the header. The headers of these images will contain the required CalDB keywords.

The SUMRCTS images should match the PSF hypercubes exactly, except that the the (l,m) or (r) axes are missing. The image pixels indicate the number of counts used for each one dimensional PSF image. These images should be kept in IMAGE extensions, they should be numbered by EXTVER, and the value of EXTVER should correspond to the value of EXTVER in the PSF hypercube that it is associated with. Obviously, if there is only one hypercube in the file, EXTVER = 1 for the SUMRCTS image and the association is obvious.

The irregularly sampled coordinate definition tables are defined in Section 2.2 of Applicable Document 6.

## 3.3 1-D PSF Library Format

All PSF Library data products shall consist of files in FITS format, as defined in Applicable Document 6. The FITS file is constructed via the description in § 4. This is followed by the error component. The error

file shall have the same dimensions as the primary data array. The ETERMXX keyword will be added for each additional error term added. XX shall be the number of the error term starting at 01 and going to 99.

# 4 1-D File Structure for Grating Data

This section describes a 1-D PSF Library which is a FITS file with up to four types of HDU's. The first HDU will contain the normalized PSF images (1-d or 2-d) with the coordinate axes defined below. The * in table 2 or 3 denotes the principal HDU. The PSF images are normalized to a peak of one. To preserve the original information in the dataset and to derive accurate statistical errors an HDU containing the total counts for the data in the PSF is constructed as an image for the next HDU. The next four HDUs will contain an empty primary HDU and a binary table to define the irregularly sampled coordinate axis. The final HDU is optional but can contain an index table to reference additional PSF's not contained in the current file. We do not curretly use an index table so it is not described here (but see the ARD for the Spatial PSF Library `http://hea-www.harvard.edu/asclocal/sds/development/ICD/index.html` for a description).

- Principal Image HDU:
  - image mandatory
  - table coordinates
  - full configuration control
  - full timing
  - full observation
- SUMRCTS Image Extn HDU:
  - image mandatory
  - table coordinates
  - short CC
  - short timing
- Coordinate Tables
  - bintable mandatory
  - short CC
  - short timing
  - short Observation

The description of the required keywords (eg. image mandatory) can be found in Applicable Document 6.

| HDU | Type | EXTNAME | CONTENT | HDUNAME | HDUCLAS1 | HDUCLAS3 | Description |
|---|---|---|---|---|---|---|---|
| 0 (*) | IMAGE | HETG_REEF | CDB_HETG_REEF | AXAF_REEF | RESPONSE | REEF | 1-d PSF data |
| 1 | IMAGE | SUMRCTS | HETG_REEF_CTS | AXAF_REEF_CTS | RESPONSE | SUMRCTS | Normalization |
| 2 | BINTABLE | GROUPING | | | N/A | N/A | Optional table containing grouping information if the PSF spans multiple HDU's |
| 3 | BINTABLE | RADIUS | | | COORD | N/A | Contains radial coordinate information |
| 4 | BINTABLE | WAVELENGTH | | | COORD | N/A | Contains energy coordinate information |
| 5 | BINTABLE | THETA | | | COORD | N/A | Contains theta coordinate information |
| 6 | BINTABLE | PHI | | | COORD | N/A | Contains phi coordinate information |
| 7 | BINTABLE | ORDER | | | COORD | N/A | Contains order coordinate information |
| 8 | BINTABLE | DEFOCUS | | | COORD | N/A | Contains order focus information |

Table 2: Table describing the REEF file structure

| HDU | Type | EXTNAME | CONTENT | HDUNAME | HDUCLAS1 | HDUCLAS3 | Description |
|---|---|---|---|---|---|---|---|
| 0 (*) | IMAGE | AXAF_LSF | CDB_HETG_LSF | AXAF_LSF | RESPONSE | LSF | 1-d PSF data |
| 1 | IMAGE | SUMRCTS | HETG_RPSF_CTS | AXAF_LSF_CTS | RESPONSE | SUMRCTS | Normalization |
| 2 | BINTABLE | GROUPING | | | N/A | N/A | Optional table containing grouping information if the PSF spans multiple HDU's |
| 3 | BINTABLE | RADIUS | | | COORD | N/A | Contains radial coordinate information |
| 4 | BINTABLE | WAVELENGTH | | | COORD | N/A | Contains energy coordinate information |
| 5 | BINTABLE | THETA | | | COORD | N/A | Contains theta coordinate information |
| 6 | BINTABLE | PHI | | | COORD | N/A | Contains phi coordinate information |
| 7 | BINTABLE | ORDER | | | COORD | N/A | Contains order coordinate information |
| 8 | BINTABLE | DEFOCUS | | | COORD | N/A | Contains defocus coordinate information |

Table 3: Table describing the RPSF file structure for in the dispersion direction

## 4.1 Enumerated Axis Definitions

These tables list the binary tables which give the coordinate information for each enumerated axis and are defined in applicable document 6. The radial coordinate will specify the angle from the center of the image with respect to the grating node (see Applicable Document 2 §3).

| HDU | Type | EXTNAME | CONTENT | HDUNAME | HDUCLAS1 | HDUCLAS3 | Description |
|---|---|---|---|---|---|---|---|
| 0 (*) | IMAGE | AXAF_XPSF | CDB_HETG_XDSF | AXAF_XPSF | RESPONSE | XPSF | 1-d PSF data |
| 1 | IMAGE | SUMRCTS | CDB_SUMRCTS | AXAF_XPSF_CTS | RESPONSE | SUMRCTS | Normalization |
| 2 | BINTABLE | GROUPING | | | N/A | N/A | Optional table containing grouping information if the PSF spans multiple HDU's |
| 3 | BINTABLE | RADIUS | | | COORD | N/A | Contains radial coordinate information |
| 4 | BINTABLE | WAVELENGTH | | | COORD | N/A | Contains wavelength coordinate information |
| 5 | BINTABLE | THETA | | | COORD | N/A | Contains theta coordinate information |
| 6 | BINTABLE | PHI | | | COORD | N/A | Contains phi coordinate information |
| 7 | BINTABLE | ORDER | | | COORD | N/A | Contains order coordinate information |
| 8 | BINTABLE | DEFOCUS | | | COORD | N/A | Contains defocus coordinate information |

Table 4: Table describing the RPSF file structure for the cross-dispersion direction

| # | TTYPE | TUNIT | TFORM | TLMIN | TLMAX | Comment |
|---|---|---|---|---|---|---|
| 1 | RADIUS_AXIS | | 1I | 1 | TBD | Radius Bin |
| 2 | RAD_LO | degrees | 1D | 0.0 | TBD | Low radius of the bin |
| 3 | RAD_HI | degrees | 1D | 0.0 | TBD | Hi radius of the bin |

Table 5: FITS Enumerated Axis binary table contents for the radial axis

| # | TTYPE | TUNIT | TFORM | TLMIN | TLMAX | Comment |
|---|---|---|---|---|---|---|
| 1 | WAVELENGTH_AXIS | | 1I | 1 | TBD | Wavelength Bin |
| 2 | WAVE_LO | Angstroms | 1D | 0.0 | 10.0 | Low wavelength of the bin |
| 3 | WAVE_HI | Angstroms | 1D | 0.0 | 10.0 | Hi wavelength of the bin |

Table 6: FITS Enumerated Axis binary table contents for the energy axis

| # | TTYPE | TUNIT | TFORM | TLMIN | TLMAX | Comment |
|---|---|---|---|---|---|---|
| 1 | THETA_AXIS | | 1I | 1 | TBD | THETA Bin |
| 2 | THETA | deg | 1D | 0.0 | 360.0 | The Angle at the center of the bin |

Table 7: FITS Enumerated Axis binary table contents for the $\theta$ axis

| # | TTYPE | TUNIT | TFORM | TLMIN | TLMAX | Comment |
|---|---|---|---|---|---|---|
| 1 | PHI_AXIS | | 1I | 1 | TBD | PHI Bin |
| 2 | PHI | deg | 1D | 0.0 | 360.0 | Angle at the center of the bin |

Table 8: FITS Enumerated Axis binary table contents for the $\phi$ axis

| # | TTYPE | TUNIT | TFORM | TLMIN | TLMAX | Comment |
|---|---|---|---|---|---|---|
| 1 | ORDER_AXIS | | 1I | 1 | TBD | ORDER Bin |
| 2 | ORDER | | 1D | −30.0 | 30.0 | Dispersion order of the data |

Table 9: FITS Enumerated Axis binary table contents for the Order axis

| # | TTYPE | TUNIT | TFORM | TLMIN | TLMAX | Comment |
|---|---|---|---|---|---|---|
| 1 | DEFOCUS_AXIS | | 1I | 1 | TBD | DEFOCUS Bin |
| 2 | DEFOCUS | | 1D | −30.0 | 30.0 | Amount of Defocus um |

Table 10: FITS Enumerated Axis binary table contents for the DEFOCUS axis

## 4.2 Image Hypercube coordinate Definitions

These tables list the coordinate information for each axis for the primary HDU and the HDU containing the total count information. Table 12 defines the coordinate axes for an image which contains the total number of counts for the data in the primary HDU (table 11). The pixels of the image will contain the number of counts in the original image and each pixel will correspond to one PSF dataset in the primary HDU. The off-axis angle is specified by $\theta_{HR}$ (see Applicable Document 2 for the definition of the coordinate system AXAF-HSC-1.2) and the rotation about the aim point is $\phi_{HR}$. for the zero order image.

| n | CTYPEn | CDELTn | CUNITn | CRPIXn | CRVALn | CEXTNn | Comments |
|---|---|---|---|---|---|---|---|
| 1 | PSF_R | | deg | 1 | 0. | n/a | |
| 2 | WAVELENGTH_AXIS | 1 | Angstroms | 1 | 1 | WAVELENGTH | Enumerated axis |
| 3 | THETA_AXIS | 1 | deg | 1 | 1 | THETA | Enumerated axis |
| 4 | PHI_AXIS | 1 | deg | 1 | 1 | PHI | Enumerated axis |
| 5 | ORDER_AXIS | 1 | | 1 | 1 | ORDER | Enumerated axis |
| 6 | DEFOCUS_AXIS | | um | | | DEFOCUS | Focus Position |

Table 11: The principal HDU for the the PSF containing the 1-dimensional PSF data for the gratings.

| n | CTYPEn | CDELTn | CUNITn | CRPIXn | CRVALn | CEXTNn | Comments |
|---|---|---|---|---|---|---|---|
| 1 | WAVELENGTH_AXIS | 1 | Angstroms | 1 | 1 | WAVELENGTH | Enumerated axis |
| 2 | THETA_AXIS | 1 | deg | 1 | 1 | THETA | Enumerated axis |
| 3 | PHI_AXIS | 1 | deg | 1 | 1 | PHI | Enumerated axis |
| 4 | ORDER_AXIS | 1 | | 1 | 1 | ORDER | Enumerated axis |
| 5 | DEFOCUS_AXIS | | um | | | DEFOCUS | Focus Position |

Table 12: The SUMRCTS HDU for the the PSF containing the total counts in the 1-dimensional PSF data for the gratings.

Table 11 is the primary HDU and contains the one dimensional data for the grating PSF's. This data can be the Encircled Energy (REEF) or the Line Spread Function (LSF).

## 4.3 Column and Axis Descriptions

The axes of the SUMRCTS and primary image are listed below:

**PSF_R:** the radial coordinate measured in degrees

**WAVELENGTH:** the wavelength, measured in angstroms.

**THETA:** the off-axis angle measured in degrees,

**PHI:** the azimuthal angle, measured in degrees, and

**ORDER:** the diffraction order for the grating image

**DEFOCUS:** the defocus amount in $\mu$m

## 4.4 Additional Required Keywords

These additional Keywords need to be set in the primary HDU.

All these keywords must be set by the software that generates the PSF library and the values given below are examples only.

```
GRATING = 'HETG    '           /HETG, LETG, or NONE allowed
GRATTYPE= 'HEG     '           /HEG, MEG, LEG or NONE allowed
CDTP0001= 'DATA    '           /Virtual data set
CVSD0001= '1999-05-20T00:00:00 /Date and Time dataset is valid
CCLS0001= 'BCF     '           /Basic Calibration file
CCNM0001= '1D_PSF  '           /This is a 1-d file
CDES0001= 'Radial PSF dataset' /
CBD10001= 'Energy(0.07-20)keV' /Energy range for PSF
CBD20001= 'THETA(0-xx)arcmin'  /Distance from optical axis for PSF
CBD30001= 'PHI(0.0-xx.x)deg'   /Azimuthal angle for PSF
CBD40001= 'DEFOCUS(-100-100um)   /Focus Range
CCLS0000= 'CPF'
CDTP0000= 'DATA'
CCNM0000= 'LSF'
RAYMETH = 'MARX v2.2'          /Ray Generator
```

## 4.5 Coordinate Keywords

```
CUNIT1P = 'mm      '
CTYPE1P = 'PSF_R_PHYS'
CDELT1P =                    1
CRPIX1P =                    1
CRVAL1P =                    0
CUNIT1  = 'deg      '
CTYPE1  = 'PSF_R   '
CDELT1  =                    1
CRPIX1  =  1
CDELT1  =  0
CUNIT2  = 'mm      '
CTYPE2  = 'DEFOCUS_BIN'
CDELT2  =                    1
CRPIX2  =                    1
CRVAL2  =                    1
CEXTN2  = 'DEFOCUS   '
CNAME3  = 'DEFOCUS   '
CUNIT3  = 'Anstroms  '
CTYPE3  = 'WAVELENGTH_BIN'
CDELT3  =                    1
CRPIX3  =                    1
CRVAL3  =                    1
CEXTN3  = 'WAVELENGTH'
CNAME3  = 'WAVELENGTH'
CUNIT4  = 'deg  '
CTYPE4 = 'THETA_BIN'
CDELT4 =                   1
CRPIX4 =                   1
```

```
CRVAL4 =                    1
CEXTN4 = 'THETA   '
CNAME4 = 'THETA'
CUNIT5 = 'deg  '
CTYPE5 = 'PHI_BIN '
CDELT5 =                    1
CRPIX5 =                    1
CRVAL5 =                    1
CEXTN5 = 'PHI     '
CNAME5 = 'PHI     '
CDELT6  =                    1
CRPIX6  =                    1
CRVAL6  =                    1
CEXTN6  = 'ORDER   '
CNAME6  = 'ORDER   '
MTYPE1  = 'MSC_BIN   '
MFORM1  = 'THETA_BIN,PHI_BIN'
MTYPE2  = 'MSC'
MFORM2  = 'THETA,PHI'
```