AXAF Science Center

PSF Data Products:
Data Product Interface Document:

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04 Aug 98	1.1	all	Revised to reflect the changes in the inputs to the PSF tools and incorporate comments
06 Oct 98	1.0	all	Added MK to Author list

Unresolved Issues

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

1. 980806: The analytic fits will now need a separate FITS file since we are now using rayfiles.
2. 980806: How the analytic fits to the 1d and 2d PSF will be provided is now TBD since the conversion to rayfiles. Provide fits for the nominal focus, and grade selection. How to account for various aspect blurring - convolution?

Contents

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1 Introduction

This document describes the interface to be employed in generating the PSF products for the ASC PSF tools, according to the requirements stipulated in Applicable Document TBD.

1.1 Purpose

The purpose of this document is to define the Point Spread Function (generically referring to as the PSF) to be used in Level 2 processing, as described in Applicable Document 3. This consists of reading the task specific calibration data file and returning the user specified product (e.g. PSF image, PSF model, characteristic size, psf fraction).

1.2 Scope

This interface shall apply to all PSF-specific data products that are generated by ASC tools and distributed to the ASC Data Archive (see Applicable Document 3 & 4) during the course of the AXAF mission.

1.3 Applicable Documents

The Applicable Documents required for background and detail on PSF products are as follows:

1. AXAF Coordinate Systems
   `http://hea-www.harvard.edu/ jcm/asc/coords`
2. ASC AMO-2401 (DS01)
   ASC Data System Software Design (ASC.500.93.0006)
3. NOST 100-1.1, Definition of the Flexible Image Transport System (FITS)
   `http://www.cv.nrao.edu/fits/`
4. HEASARC FITS Standards:
   `http://legacy.gsfc.nasa.gov/docs/heasarc/ofwg/`
   `docs/summary/ogip_93_001_summary.html`
5. ASC FITS File Designers' Guide
   `http://hea-www.harvard.edu/ arots/asc/fits/ascfits.ps`
6. HRC Data Products Guide:
   Level 1 to ASC Archive Interface Control Document
   `http://hea-www.harvard.edu/asclocal/sdsd/ICD/l1icd.ps.gz`
7. ACIS Data Products Guide:
   Level 1 to ASC Archive Interface Control Document
   `http://hea-www.harvard.edu/asclocal/sdsd/ICD/acis_l1.ps.gz`

1.3.1 Data Content Summary

All PSF data sets generated by the PSF tools shall consist of data files conforming to the FITS format (Applicable Document 3) and further conforming to HEASARC standards (Applicable Document 4) and the ASC conventions (Applicable Document 5). These files contain header keyword entries and binary table (BINTABLE) extensions.

1.4 Recipients and Utilization

The primary recipients of TG Level 2 data products, via distribution from the archive, are AXAF observers, who will utilize these data products for scientific data analysis. The ASC may also make use of specific Level 2 data products for instrument calibration, instrument and/or spacecraft monitoring and trends analysis, and validation and verification of the Level 0, Level 1, Level 1.5, and Level 2 software and of the data products themselves.

1.5 Assumptions and Constraints

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), are not currently included within the interface defined by this document.

2 Point Spread Function Tools Output Data Files

The PSF tools are intended to provide the user and pipelines with information on the PSF. This information ranges in fidelity from a coarse size estimate as an initial guess for the detect algorithms to an accurate two dimensional image of the PSF which takes into account the details of the user's individual observation. While the PSF provided will be the best available it is up to the user to verify that the PSF is accurate enough for their purposes. For some cases (eg. deconvolution) a custom set of PSF's may need to be generated as described in section TBD.

2.1 Detailed Interface Specifications

The primary input for the PSF tools is SAOsac rayfiles as defined in TBD. These rayfiles will be be basis for an assortment of derived products (functional forms, enclosed energy tables) for use in Calc_PSF_Size and Calc_PSF_Frac.

2.2 PSF Tool Create_PSF_Model

The tool create_psf_model is intended to supply a model psf in the form of an image, either from raytrace data or from a functional form, or return the parameters of the functional form. This will allow a user to compare their source with a model of the PSF. In addition the ability to return a functional form can be used in conjunction with other tools (eg. ASCfit) for further analysis.

This section describes the output files generated by the tool ASC Create_PSF_Model. This tool will generate 2-dimensional psf's (images) and 1-dimensional psf's (profiles) for use with other software or for direct comparison with data.

2.2.1 *Create_PSF_Model* Labeling and Identification

The data files generated by the PSF tools shall be assigned default external names as shown in Table 1. The names obey the following convention (TBR): and may be changed by the user.

$$\texttt{GAS\_}theta_{HR}\_\phi_{HR}\_type\texttt{.fits}$$

where *GAS* is a mnemonic specifying the grating, array, and sub-array configuration. *G* can have values of `H` for HEG, `M` for MEG, `L` for LETG or `N` for none. The detector array, *A*, is specified by `A` for ACIS or `H` for HRC. The sub-array, *S*, may be `S` for spectroscopic array or `I` for imaging. The off-axis angle in arcmin is specified by θ_{HR} and the rotation about the aim point is ϕ_{HR} , where the coordinate system use is AXAF-HSC-1.2 (see Applicable Document 1) and *type* specifies the file type (see Table 1).

Title	File name
2d image data	`*_2dPSF.fits`
1D binary table	`*_1dPSF.fits`

Table 1: PSF Output Data Product Files

2.2.2 Substructure Definition and Format

The basic definitions for the PSF output formats is derived from OGIP Memo CAL/GEN/92-027 for the 2d data sets and CAL/GEN/92-020 for the 1d datasets. These formats have keywords added to bring them into compliance with the "ASC FITS Designers Guide" (Applicable Document 5).

2.2.3 Output files

The output from *Create_PSF_Model* shall be a one or two dimensional image created from SAOsac rayfiles and projected to the focal plane, with or without the gratings, and binned into an image using one of either ACIS or HRC detector models or with a user defined binning for the image. This image shall be in the primary HDU with the following image extension containing the error array.

Create_PSF_Model shall also be able to bin this two dimensional image into a one dimensional PSF dataset. The binning can be a projection onto any axis with the most common being a projection onto the x or y axis. With the gratings in place the most common projection will be along the dispersion or cross-dispersion direction. The other type of binning that will be supported is radial (azimuthal) binning. Both the binning and projection can be done from an arbitary center and user selected binsize.

2.2.4 Create_PSF_model 2-D HDU Components

The following table (Table 2.2.4) 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 (*)	IMAGE	IMAGE	IMG	IMAGE	Image of the PSF
2	IMAGE	PSF_ERROR	IMG	Error array for the generated PSF image	

The structure of the HDUs, as specified by the ASC FITS Guide (Document 5), is

- Image Primary HDU:
  - image mandatory
  - image coordinate
  - null configuration control
  - full timing
  - full observation
- Auxiliary Image HDU:
  - image mandatory
  - image coordinates
  - short configuration control
  - short timing
  - short observation

2.2.5 2D-PSF Primary Header Keyword Description

All PSF data products produced by Create_PSF_Model shall consist of files in FITS format, as defined in Applicable Document 3. Each FITS file is comprised of a primary component and zero or more extension components. Some PSF data files contain Binary Table extensions which will contain the parameters for the best fit functional form to the data. The final format for this extension is TBD. Table 2.2.5 shows the keywords for ACIS or HRC 2-Dimensional PSF file without the keywords outlined in section 2.2.4.

```
GRATTYP = 'HEG     '            /Grating data
GDEFOCUS=              0.00000 /Defocus of the gratings (mm)
BACKGRND=              0.00000 /       1
ENERG_LO= '5       '            /       3
ENERG_HI= '5       '            /       3
SUMRCNTS=                   1. /       1
HDUCLASS= 'OGIP    '            /OGIP Defined
HDUDOC  = 'CAL/GEN/92-020'      /Defining Document
HDUVERS = '1.0.0   '            /Version # of OGIP Definition
HDUCLAS1= 'IMAGE   '            /This is an image
HDUCLAS2= 'PSF     '            /PSF Image
HDUCLAS3= 'PREDICTED'           /PSF image is from MARX
HDUCLAS4= 'NET     '            /PSF image has no background
CDTP0001= 'TASK    '            /Virtual data set
CCLS0001= 'BCF     '            /Basic Calibration file
CCNM0001= '2D_PSF  '            /This is a 2-d file
CDES0001= 'MARX    '            /File Generator
CBD10001= 'Energy(5)keV'        /Energy range for PSF
CBD20001= 'THETA(0)arcmin'      /Distance from optical axis for PSF
CBD30001= 'PHI(0.0)deg'         /Azimuthal angle for PSF
END
```

Table 2.2.5 Format of 2-D FITS Header Keywords

2.2.6 2D-PSF Error Image Header Keyword Description

All PSF data products shall have an associated 2 PSF error image. This error image shall consist of a 2-dimensional image with the same dimensions as the input image. The error calculated shall be the statistical error (Gaussian or Poisson) and any additional error terms shall be added in quadrature with the statistical errors. Each error term shall add a ETERM keyword to identify the source of the error terms.

Table 2.2.6 shows the keywords which need to be added or changed in an ACIS or HRC 2-Dimensional PSF header for the error image header. The image size will be the same as the PSF image and will follow the PSF image.

```
XTENSION= 'BINTABLE'
OBJECT  = 'PSF_ERROR'           /MARX PSF image
TITLE   = 'PSF_ERROR'           /MARX PSF image
POISSERR =                   F /       1
```

```
SYS_ERR = 0.05                  /       1
ETERM01 = 'POISSON'             /       1
ETERM02 = '2nd error source'    /       1
```

Table 2.2.6 Format of 2-D Error image FITS Header Keywords

2.2.7 Create_PSF_model 1-D HDU Components

This section describes the one dimensional PSF data sets. These can be one dimensional azimuthal sums or projections of a two dimensional image to a one dimensional profile.

HDU	Type	EXTNAME	CONTENT	HDUCLASS	Description
1	NULL	N/A	N/A	N/A	
2 (*)	BINTABLE	RPSF	RADIAL PSF	OGIP	Dataset is a radial point response function

The structure of the HDUs, as specified by the ASC FITS Guide (Document 5), is

- Null Primary HDU:
  - image mandatory
  - null configuration control
  - short timing
  - short observation
- Principle Image HDU:
  - bintable mandatory
  - table coordinates
  - full configuration control
  - full timing
  - full observation

2.2.8 Create_PSF_Model 1-D Header Keyword Description

Below is described a 1-D PSF file which is a FITS header followed by a FITS binary table which is created by Create_PSF_Model when a 1-dimensional (profile) is requested. The binary tables are further described by an extension header that immediately follows the keyword header (since the primary data unit is empty). The format of a generic FITS binary table file is described fully in Applicable Documents 6. and 7. The error columns to be added to the 1-D PSF data set are described in OGIP calibration memo CAL/GEN/92-003 and consist of statistical and systematic error terms. The error terms from the 2-D PSF file shall be added in quadrature to determine the error for the 1-D PSF file.

```
HDUCLASS= 'OGIP    '            /
PHI     = 0.0                   /
THETA   = 0.0                   /
GRATTYPE= 'HEG     '            /
END
```

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	TDBIN	TNULL	Comments
RAD_LO	arcsec	1E	0	INDEF	INDEF	NONE	Required.
	angstrom	1634D	0.0	400	1.E-05	NaN	
	degrees	1634D	-2.0	2.0	1.E-05	NaN	
	mm	1634D	0.0	300	0.012	NaN	
	keV	1634D	0.0	14	1.E-03	NaN	
	pixel	1634D	0.0	65536	1	NaN	
RAD_HI	arcsec	1E	n/a	n/a	n/a	NONE	Required.
	angstrom	1634D	0.0	400	1.E-05	NaN	
	degrees	1634D	-2.0	2.0	1.E-05	NaN	
	mm	1634D	0.0	300	0.012	NaN	
	keV	1634D	0.0	14	1.E-03	NaN	
	pixel	1634D	0.0	65536	1	NaN	
ENERG_LO	KEV	1E	0	10	N/A	NONE	Required; Lower limit of energy range for PSF
ENERY_HI	KEV	1E	0	10	N/A	N/A	Required; Upper limit of energy range for PSF
REEF	COUNTS	1I	0	N/A	N/A	N/A	Required; profile
AREA_WGT		1E	N/A	N/A	N/A	NONE	Required;
STAT_MIN		1E	N/A	N/A	N/A	NONE	Required; Min statistical error
STAT_MAX		1E	N/A	N/A	N/A	NONE	Required; Max statistical error
SYS_MIN		1E	N/A	N/A	N/A	NONE	Required; Min systematic error
SYS_MAX		1E	N/A	N/A	N/A	NONE	Required; Max systematic error

Table 2: *Required 1D-PSF FITS data file binary table contents for extension "1d-PSF" (one entry per profile). "N/A" means "Not Applicable". The "TNULL" value of "NaN" stands for the IEEE "Not A Number" (which is not actually encoded into the header, but is implicit in the FITS convention).*

Table 2.2.8 Primary Header Keywords for 1-D PSF

Table 2 Keywords for the binary extention with the 1D PSF data

2.3 PSF Tool Calc_PSF_Size

The tools calc_psf_frac and calc_psf_size are designed to be called from other tools and by the user in an interactive mode. These tools will be able to output the results to the screen or to append the results to an input table of sources.

2.3.1 *Create_PSF_Size* Labeling and Identification

The tool *Create_PSF_Size* will return the characteristic size for a source in arcseconds for a given input fraction of the PSF in percent. This size can be returned as an ascii string to the screen for the case of an interactive user and will also be stored in any table (binary or ascii) which is used to input the source positions. For the case of an input table columns will be added to store the radius, E_low, E_hi, and spectrum type information. The format for these parameters are shown in table 3.

TTYPE	**TFORM**	**TUNIT**
PSF_SIZE	E	ARCSEC
E_LO	E	keV
E_HI	E	keV
SPECTRUM	8A	

Table 3: Columns for PSF Size to Add

The table column with TTYPE SPECTRUM will contain the name of the input spectrum used for the calculation. The allowed values are USER for a user input spectrum, FLAT for a uniform spectral distribution or an ASCfit model name. If no input table is given the the tool will output the parameters in table 3 to the screen.

2.4 PSF Tool Calc_PSF_Frac

2.4.1 *Calc_PSF_Frac* Labeling and Identification

Calc_PSF_Frac is a tool to generate the fraction the total psf which is enclosed in a given region. This region can be specified as a region mask as specified in (TBD) or as a radius about a position. The fraction of the PSF which lies within the specified region is returned as a fraction of the total area of the integrated PSF. This number can be written to the screen or in the case where the source or a list of sources is input via a table the results are appended to the input table. Table 4 lists the columns to be added to the input table.

TTYPE	**TFORM**	**TUNIT**
PSF_FRAC	E	
BINLO	E	see below
BINHI	E	see below
REGION	A	
SPECTRUM	A	

Table 4: Columns added by PSF Fraction to an Input Table

where the column SPECTRUM is described above. The column PSF_FRAC contains the fraction of the PSF enclosed in that region and is a number between 0 and 1. BINLO gives position of the lower edge bin and BINHI gives the position of the upper edge of the bin. The units for BINLO and BINHI can be any of the units described for ENERGY_LO and ENERGY_HI in Table 2

3 Size Estimates

The space that the PSF products require depends on several choices that the user makes. The 2-D PSF can be generated at HRC, ACIS, or at HRMA resolution, each of which has a different binning factor. In addition to these "natural" bin sizes the user can also request a binning to match the binning for an extracted image. The largest size needed for the PSF image should be about 1Mbyte for the HRMA (currently 1um) resolution. The 1-dimensional profiles are much smaller, but again the size will depend in the user's choice of the bin size. Using the HRMA resolution PSF as a guide the size of the 1-d PSF file will be $\sim$2 kbyte.