Chandra PSFs and PSF Library

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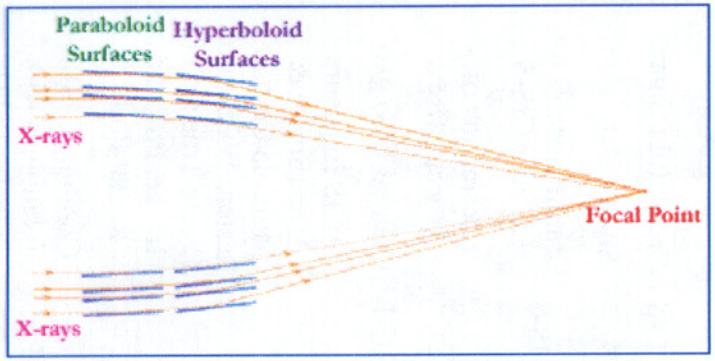
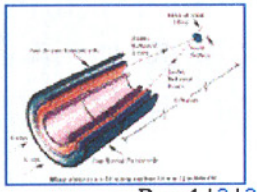
Telescope System

The Chandra telescope system consists of four pairs of mirrors and their support structure.



X-ray telescopes must be very different from optical telescopes. Because of their high energy, X-ray photons penetrate into a mirror in much the same way that bullets slam into a wall. Likewise, just as bullets ricochet when they hit a wall at a grazing angle, so too will X-rays ricochet off mirrors.

The mirrors have to be exquisitely shaped and aligned nearly parallel to incoming X-rays. Thus they look more like glass barrels than the familiar dish shape of optical telescopes.



2. Chandra PSFs (Simulations and Examples)

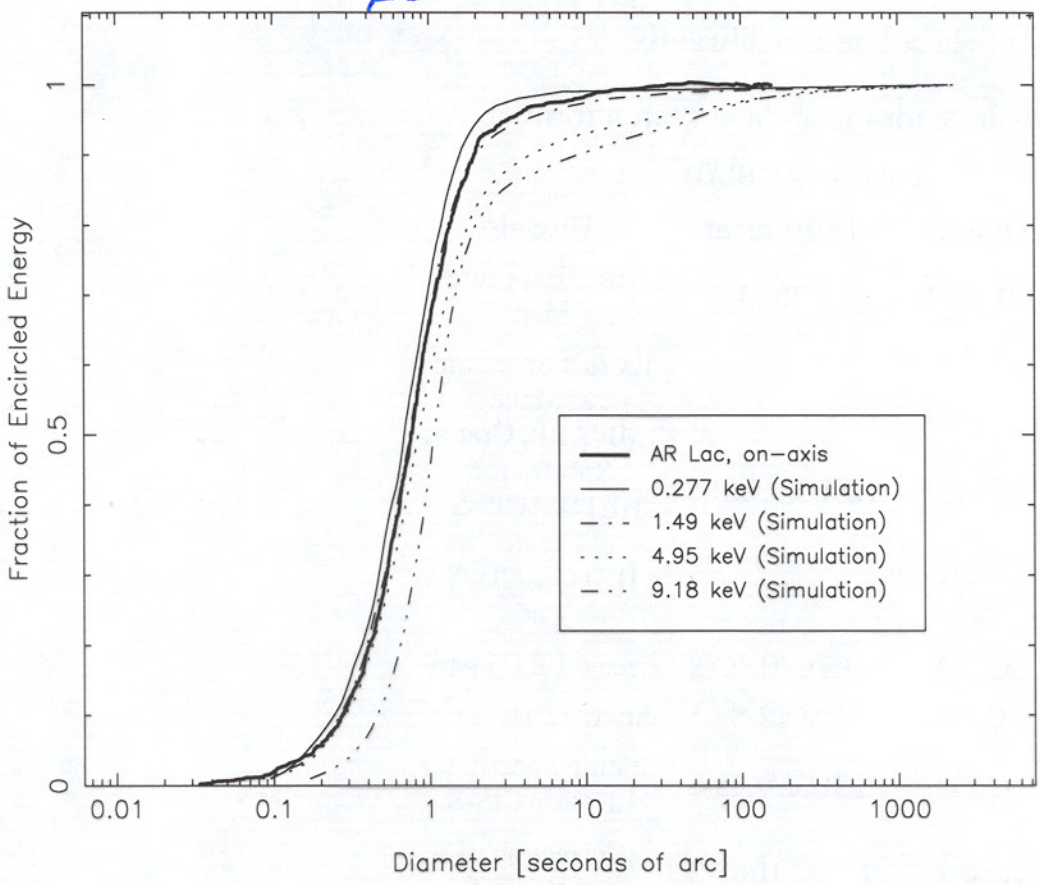
Simulated PSFs

The simulated Chandra PSFs used in the PSF library files are generated in two steps:

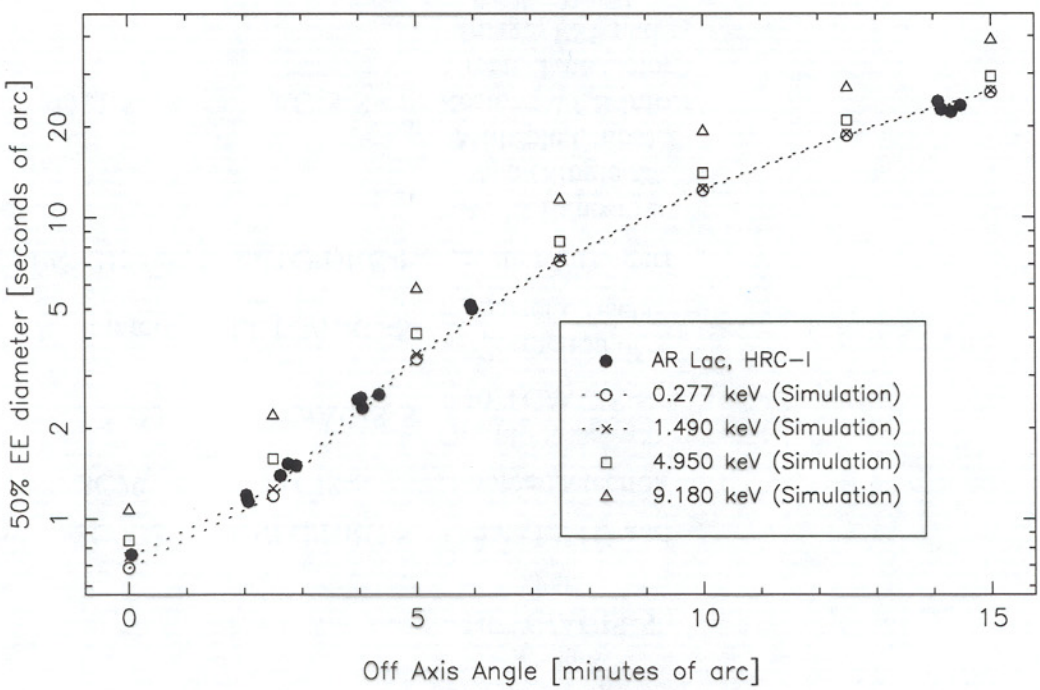
1. ray files are generated using SAOsac , a ray–trace code which models the interaction of photons (rays) passing through HRMA (Jerius et al 2000, Proc. SPIE 4012)

2. PSF model images are made by projecting these rays to the detector planes and then creating images with pixel smaller than the pixel sizes of the detectors (HRC: 0.13175"; ACIS: 0.492")

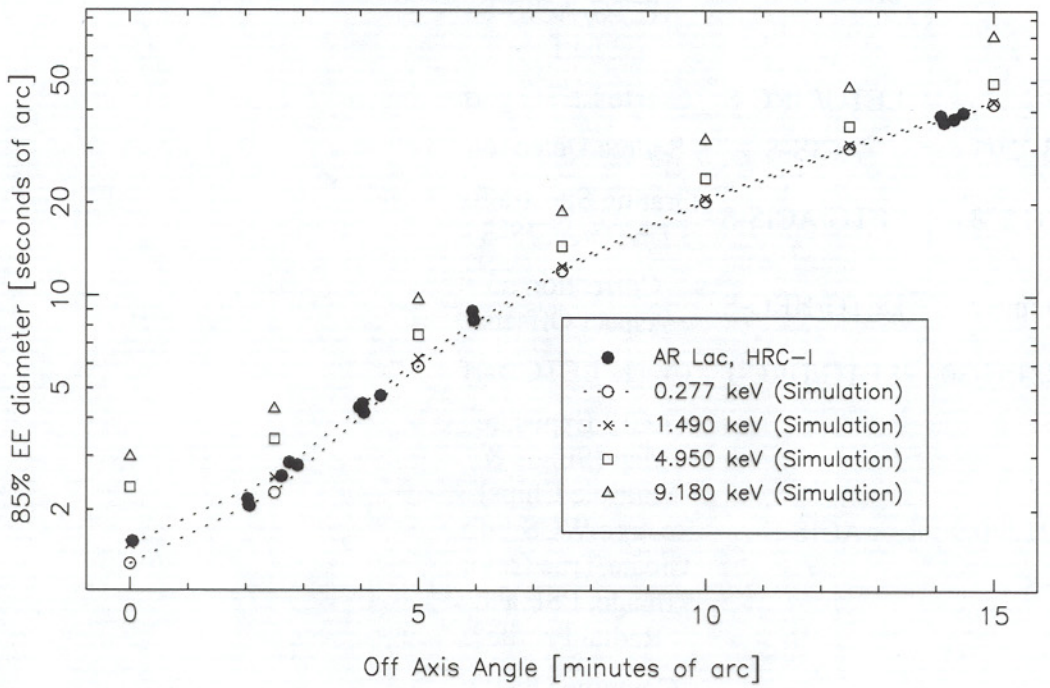
EE ON-AXIS


Fraction of Encircled Energy
0
0.5
1
0.01
0.1
1
10
100
1000
Diameter [seconds of arc]
AR Lac, on-axis
0.277 keV (Simulation)
1.49 keV (Simulation)
4.95 keV (Simulation)
9.18 keV (Simulation)

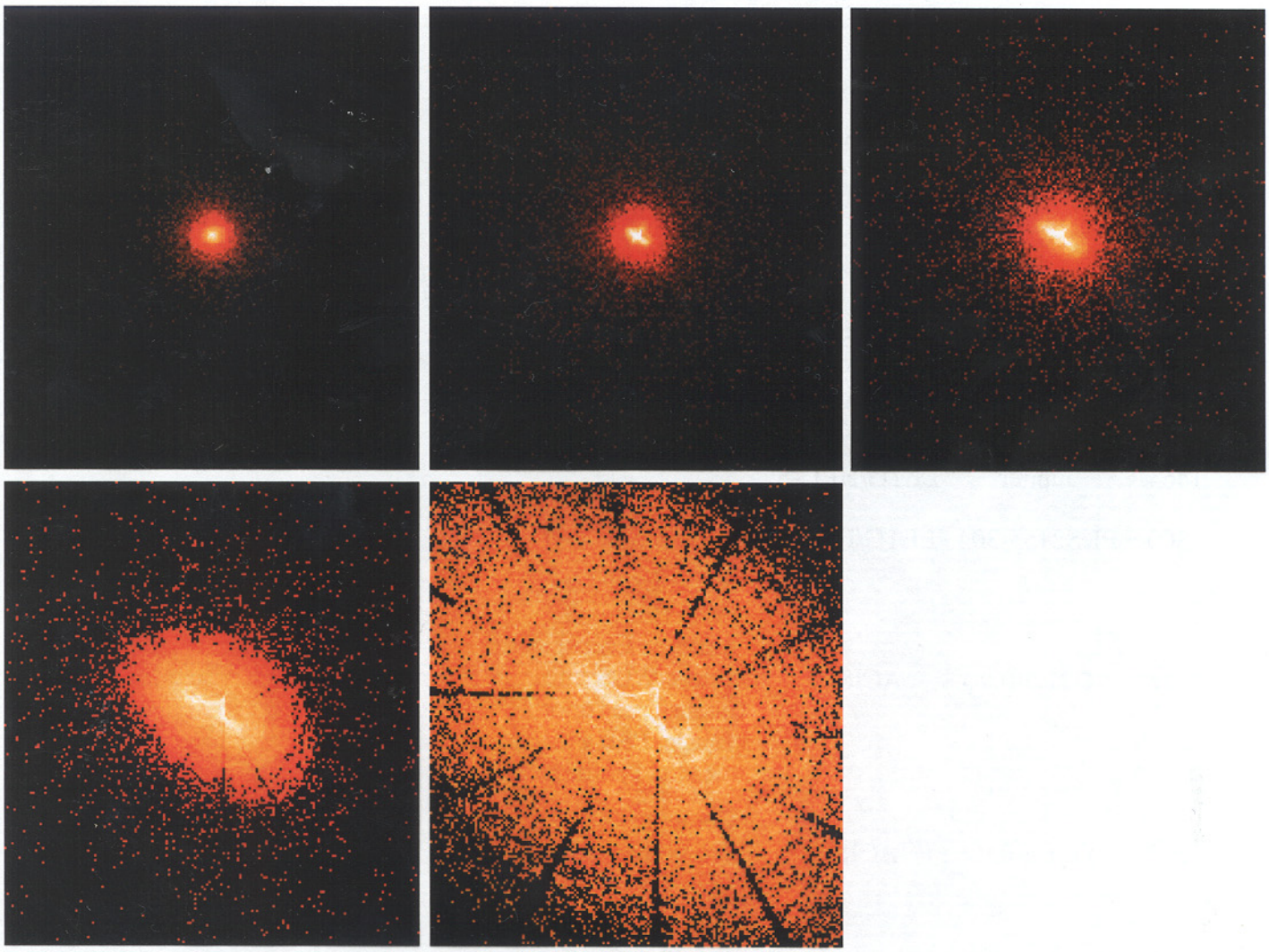
50% EE off-AXIS



85%. EE off-AXIS



HRMA PSFs @ 1.5 keV

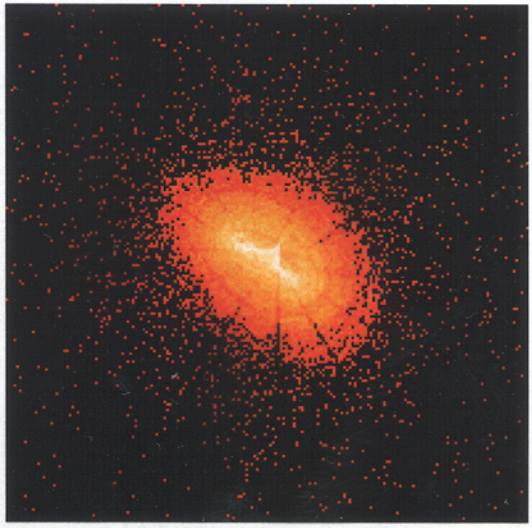


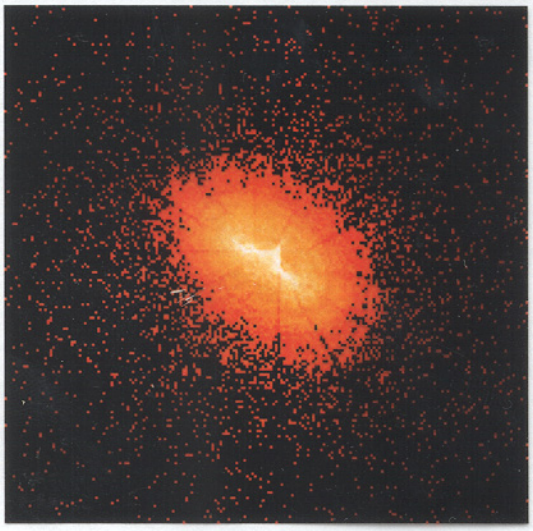
FOV 0.5'

HRMA PSFs @ 6′

0.277 keV

1.5 keV





4.5 keV

3. CIAO PSF Library

– general structure

–standard set of library files

3. CIAO PSF LIBRARY

3.1. General PSF Library Definition and Format

The PSF library general format is summarized in Table 1:

The HDUs in PSF data FITS files		
HDU	**Type**	**Description**
Primary array	1	hypercube
IMAGE extension	2	SUMRCTS image (optional)
BINARY table	3	Irregular coordinate definitions (as many as needed; optional)

Table 1: Single hypercube self-contained PS F

HDU type 1 – the PSF image: - These are n-dimensional images, hypercubes primary array) that extend along a minimum of five coordinates. The known coordinate axes are:

l - spatial x-direction of the PSF image (PSFX)

m - spatial y-direction of the PSF image (PSFY)

X - spatial x-direction offset coordinate (DETX)

Y - spatial y-direction offset coordinate (DETY)

E - energy (ENERG)

f - defocus (DEFOCUS)

Every image is required to have the following axes: (l, m, E, X, Y, f)

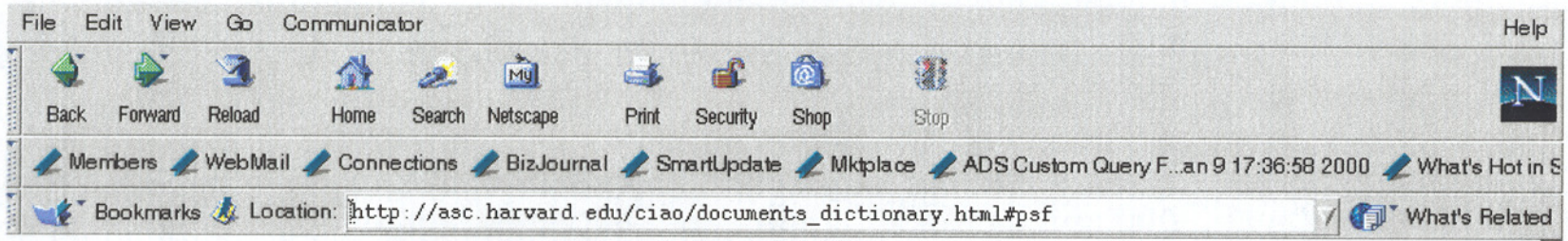
Each coordinate may be regularly sampled, in which case the sample points are defined by the usual CTYPEi, etc., keywords; or irregularly, in which case the sample points are defined in a table extension (in the same file).

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 are defined in the usual way (CTYPEi, etc.). The coordinate axes (most notably the spatial ones) have several aliases defined in the header. The headers of these images contain the required Caldb keywords. These images have SUMRCTS=1.0.

HDU type 2 – the irregularly sampled coordinate definition table s: - These are binary tables which allow an unambiguous translation of "bins" or "pixels" to physical coordinates (e.g., energy, defocus).

HDU type 3 – SUMRCTS image: - The SUMRCTS images contain the information on how many photons (weights) are there per individual PSF data in the PSF hypercubes. These images match the PSF hypercubes exactly, except that the l and m axes are missing. The image pixels indicate the number of counts used for each 2-D PSF image. The SUMRCTS images are kept in IMAGE extensions.

3.2. STANDARD PSF LIBRARY FILES



PSF: Point Spread Function

Describes the shape of the image produced by a delta function (point) source on the detector. Also known as 'Point Response Function' or PRF.
(Standard OGIP file format)

PSF Libraries

The Chandra PSFs vary strongly with source location in the telescope field of view, as well as somewhat with the energy, and so with the spectrum of the source. Standard sets of simulated Chandra PSFs covering the field of view of the ACIS-I, ACIS-S, HRC-I and HRC-S detectors are available via the standard PSF library files.
The CIAO tool **mkpsf** reads one of these libraries (at the users choice) and interpolates. Naturally this interpolation is more accurate for the finer grids.

There are 4 standard PSF libraries provided per instrument:
Medium res library (file No. 1) 1 arcmin step size between images. 6 micron pixel images.
Grid about the optical axis covering:
ACIS-I and HRC-I: a -10 to +10 arcmin square grid (21x21);
ACIS-S and HRC-S: a -10 to +10 arcmin in azimuth and -5 to +5 arcmin in elevation grid (21x11).
Low res library (file No. 2) 5 arcmin step size between images. 12 micron pixel images.
Grid about the optical axis covering:
ACIS-I: a -25 to +10 arcmin in elevation and -10 to +10 arcmin in azimuth (8x5) grid;
ACIS-S: a -25 to +25 arcmin in azimuth and -5 to +5 arcmin in elevation (11x3) grid;
HRC-I: a -25 to +25 arcmin in elevation and -25 to +25 arcmin in azimuth (11x11) grid;
HRC-S: a -30 to +30 arcmin in azimuth and -5 to +5 arcmin in elevation (13x3) grid
High res library (file No. 3) 1 arcmin step size between images. 2 micron pixel images.
Grid covering a -6 to +6 arcmin (11x11) in azimuth and elevation about the optical axis.
High res library (file No. 4) 1 arcmin step size between images. 1 micron pixel images.
Grid covering a -1 to +1 arcmin (3x3) about the optical axis.
[NB: ACIS pixel size is 24 microns; HRC pixel size is 6 microns.]

See also:
- PSF Manual
- Cal's HRMA PSF Page

A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V | W-Z

HRC-I Standard Library files

The center of the coordinate system is the HRC-I aimpoint at x=16384.5, y=16384.5 in DETECTOR coordinates (0,0 in azimuth and elevation).

File 1 (F1):

256x256 pixels images for currently only one defocus position (0), 5 energies, and 21x21 off-axis angles defined by the elevations:

elevation (-10, -9, -8, -7, -6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10) arcminutes

azimuth (-10, -9, -8, -7, -6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10) arcminutes

Pixel size: 6 μ m

File Size 580 Mb

File 2 (F2):

512x512 pixels images for one defocus position, 5 energies, and off-axis angles defined by the following elevations and azimuths:

elevation (-25, -20, -15, -10, -5, 0, 5, 10, 15, 20, 25) arcminutes

azimuth (-25, -20, -15, -10, -5, 0, 5, 10, 15, 20, 25) arcminutes

Pixel size: 12 μ m

File Size 620 Mb.

File 3 (F3):

512x512 pixels images for one defocus position, 5 energies, and 13x13 off-axis angles defined by the following SAOSAC elevations and azimuths in arcminutes:

elevation (-6,-5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6) arcminutes

azimuth (-6,-5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6) arcminutes

Pixel size: 2 μ m

File Size 890 Mb

File 4 (F4):

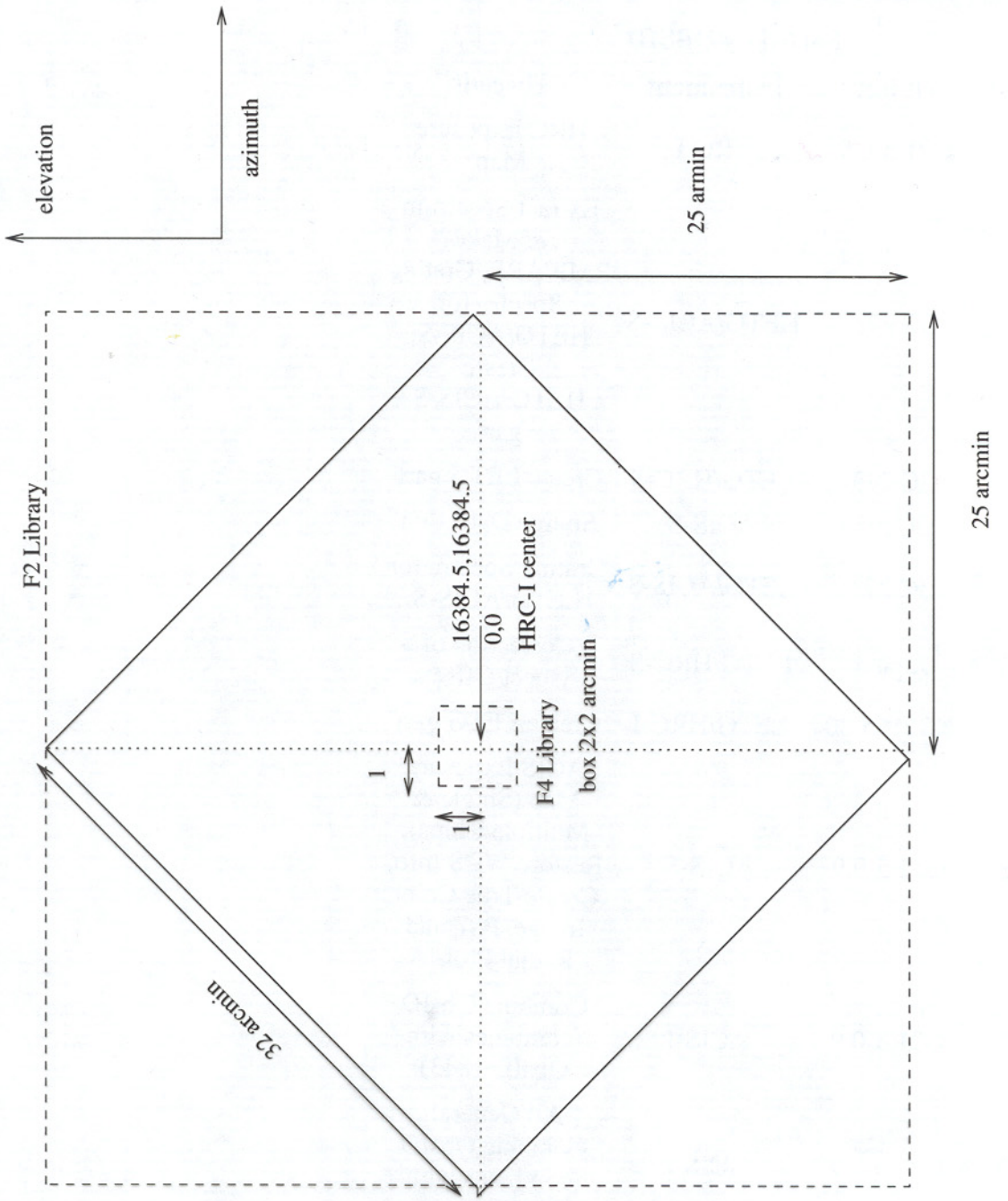
512x512 pixels images for one defocus positions, 5 energies, and 3x3 off-axis angles defined by the following elevations and azimuths:

elevation (-1, 0, 1) arcminutes

azimuth (-1, 0, 1) arcminutes

Pixel size: 1 μ m

File Size 46 Mb.



– A schematic diagram of HRC-I detector. This diagram is NOT TO SCALE!! The aimpoint is marked with a cross. The pixel size is 0.006429 mm, corresponding to 0.13175 arcsec.

4. Make PSFs with mkpsf

CIAO 2.1 Science Threads

Create a PSF (9 April 2001)

Return to Threads Page.

For illustration, this thread utilizes data from the ObsID 1838 dataset (ACIS-S, G21.5-09), which was downloaded from the Archive.

The aim of this thread is to create an image of the Point Spread Function (PSF) for a source, and normalize it to the source flux. The PSF changes with source position and photon energy, and is created by interpolation of a library of pre-launch, calibration files (the PSF hypercube library) by using the CIAO tool `mkpsf`. The latest information on the status of the PSF libraries can be found in the "Responses" section of the Data Caveats page (especially the mkpsf caveats) and the PSF HRMA calibration page. Please review this information before following the thread.

Contents

Parameter Files:

- plist dmextract
- plist dmstat
- plist mkpsf

Estimating Source Counts thread for further details.

Please note that the regions used for calculating the source and background signals are examples only: they should be changed to match the particulars of each dataset. For example, the background region above will definitely *not* be correct for large, extended sources.

C. Create a PSF Image File (mkpsf)

The CIAO tool `mkpsf` creates a PSF image. If the requested coordinates and energy do not match those in the PSF library, then the output image is constructed by linearly interpolating the library data. We shall use the **f1** ACIS-S library for the sky coordinates (4069.5,4250.5) and evaluated at an energy of 3.0 keV. The pixel size, and roll angle, of the output image are taken from the img_src_0.3-8keV.fits file.

```
unix% punlearn mkpsf
unix% pset mkpsf coord=SKY x=4069.5 y=4250.5 energy=3.0
unix% pset mkpsf psflibfile=$CALDB/data/chandra/acis/cpf/2dpsf/aciss1998-11-052
unix% pset mkpsf infile=img_src_0.3-8keV.fits
unix% pset mkpsf outfile=psf_3keV.fits
unix% pset mkpsf rotpts=9
unix% mkpsf
input coordinate system (SKY|DET) (SKY):
PSF binning in x direction (0.25:256.0) (INDEF):
PSF binning in y direction (0.25:256.0) (INDEF):
PSF size in x direction (2:2048) (INDEF):
PSF size in y direction (2:2048) (INDEF):
input file (img_src_0.3-8keV.fits):
energy in keV (3):
x (4069.5):
y (4250.5):
angle to rotate image in degrees (INDEF):
number of pixel points in x or y direction for rotation (1) (9):
PSF library file (/soft/ciao/CALDB/data/chandra/acis/cpf/2dpsf/aciss1998-11-052
output file (psf_3keV.fits):
CASE: Recursive interpolation...
Rebinning images from 256x256 to 64x64
File psf_3keV.fits was created
```

The output image (psf_3keV.fits) looks like this. You can check the mkpsf parameter file that was used with plist mkpsf.

D. Normalise PSF to total counts in source (dmstat, dmimgcalc)

We use `dmstat` to find the "signal" in the PSF image, and then `dmimgcalc` to normalize this image to the source counts (here 21835):

```
unix% dmstat psf_3keV.fits
AXAF_2DPSF
        min:    0.000000
        max:    0.339299
        mean:   0.000028
        total:  1.818789
        good:   65536
        nulls:  0
```

Caveat: Using mkpsf

3/8/01

The CIAO tool **mkpsf** and the standard PSF library files can be used to view the general distortions and structure of the HRMA PSFs, and the variations as a function of off-axis angle and energy. The user should be aware that the variation of the PSF can be significant even for small off-axis angles (<1').

The PSFs extracted using **mkpsf** and the standard PSF library files are by no means the ''exact'' PSFs needed for detailed analysis or for deconvolution. The current PSFs will help estimate the size of the PSF and provide information on how the PSF shape changes as a function of off-axis angles and energy. This would help avoid misidentification of PSF-related structures as structures intrinsic to the observed source.

The PSF library grids used by the CIAO tool **mkpsf** are very coarse (azimuth and elevation angular off-sets of 1' or 5', only 5 energies, and only one defocus position). Therefore, the user needs to interpolate in these grids to get a PSF for the off-axis angle and the energies (spectrum) of the observed source. If the current linear spatial/spectral interpolation incorporated in the **mkpsf** tool is not satisfactory to the user for their analysis, users can use their own interpolation scheme after extracting the PSF models in detector coordinates from the four grid locations closest to the location of the source, and at the five standard energies

The files created in this way should not be used for detailed scientific analysis.

For best results, we suggest library file No. 1 ("f1") if the off-axis angle of the source is within the library field of view. For larger off-axis angles please use library file "f2". As said before, use with caution (see PSF library caveat).

CAVEATS

The PSF library is not derived directly from calibration data, but rather through the SAOSAC ray-tracing routine, with inputs specifying the current Chandra HRMA model. The version of the model configuration is "orbit_XRCF+tilts_02". This model seems to replicate the low-energy core and wings of the on-axis PSF well. High energy (greater than 2keV) comparisons of the wings are not yet sufficiently mature enough to draw conclusions (see http://asc.harvard.edu/cal/Hrma/hrma/psf). Also, the detailed comparisons of the simulated off axis PSF to observations are not complete; we believe that in general the PSF matches, but specifics are not yet available.

The standard PSF libraries can be used to view the general distortions and structure of the HRMA PSFs, and the variations as a function of off-axis (angle and energy. The variation can be significant even for small off-axis angles. They are by no means the "exact" PSFs needed for detailed analysis or for deconvolution. The current PSFs will help estimate the size of the PSF and provide information on how the PSF shape changes as a function of off-axis angles and energy. This would help avoid misidentification of PSF-related structures as structures intrinsic to the observed source.

The PSF library grids are very coarse (azimuth and elevation angular off-sets of 1' or 5', only 5 energies, and only one defocus position). Therefore, the user needs to interpolate in these grids to get a PSF for the off-axis angle and the energies (spectrum) of the observed source. If the current linear spatial/spectral interpolation incorporated in the **mkpsf** tool is not satisfactory to the user for their analysis, users can use their own interpolation scheme after extracting the PSF models in detector coordinates from the four grid locations closest to the location of the source, and at the five standard energies.

At this time the mkpsf tool cannot access the weight information in the PSF library hypercubes. Our plan is to make this option available in the next CIAO release. The current standard library files do not contain the error information due to uncertainties in the parameters of the models used to produce the PSF images. We plan to address this and other issues in the future, and to produce updated PSF libraries based on the on-orbit calibration information.