# ICD for REEF circular Encircled Energy calibration file

## Parameter data cube HDU for PSF encircled energy

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# Contents

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# 1 Introduction

It is fairly common to have a data product which gives the value of some quantity or parameter versus a number of coordinates. A number of approaches are used to represent such data in FITS. Here were recommend use of multiple IMAGE HDUs together with tabular coordinates in binary table HDUs. Storing the data in IMAGE HDUs makes it easy for generic tools to visualize them.

Note: in this document, we do not distinguish between encircled energy and encircled counts fractions; this needs to be fixed in a future rev.

# 2 PSF encircled energy file

The PSF encircled energy data consists of parameters as a function of detector position, energy, and encircled energy fraction: f(ECF,THETA,PHI,E). Each such parameter corresponds to a 4-D IMAGE HDU. In the circular ECF file, there is a triple of such parameters: the best estimate radius and the 1-sigma-low and 1-sigma-high values of the radius. In the elliptical ECF file, there are further triples corresponding to each of the ellipse fit parameters and their errors. In each case, it is recommended that the image grid be the same for all parameters in the file, so that they can share the same coordinate system.

The structure of the file is: (/data/jcm/sds/dp/ecf.new)

```
dmlist ecf.new blocks
--------------------------------------------------------------------------------
Dataset: ecf.new
--------------------------------------------------------------------------------

     Block Name                              Type         Dimensions
--------------------------------------------------------------------------------
Block    1: RADIUS                             Image      Real4(100x14x8x40)
Block    2: RADIUS_SMIN                        Image      Real4(100x14x8x40)
Block    3: RADIUS_SMAX                        Image      Real4(100x14x8x40)
Block    4: WCS-TAB1                           Table         1 cols x 1        rows
Block    5: WCS-TAB2                           Table         1 cols x 1        rows
Block    6: WCS-TAB3                           Table         1 cols x 1        rows
Block    7: WCS-TAB4                           Table         3 cols x 1        rows
```

For an elliptical ECF file, extra image HDUs for different parameters would be added as needed.

## 2.1 IMAGE HDU header

The following keywords will be used for the CXC PSF file IMAGE HDU headers. First, we list the CXC keywords describing the observing configuration and then the CALDB indexing keywords.

```
HDUCLAS1            RESPONSE                      dataset relates to instrument response
HDUCLAS2            REEF2
HDUCLAS3            PREDICTED
HDUCLAS4            NET
ORIGIN              CXC Calibration
CREATOR             write-ecf-fits 1.14
DATE                2004-02-24T23:16:31
MODEL               orbit_XRCF+tilts_04           raytrace configuration
MISSION             AXAF                          should you accept it
TELESCOP            Chandra                       satellite
INSTRUME            TEL
DETNAM              HRC-I
GRATING             NONE
SHELL               1111                          Shell 1346 bitmap
FILTER              NONE

CCNM0001            REEF2
CDES0001            HRMA Encircled Energy
CBD10001            ECF(0.010000-1.000000)
CBD20001            THETA(0.000000-20.000000)arcmin
CBD30001            PHI(0.000000-360.000000)deg
CBD40001            ENERG_LO(0.125000-9.875000)keV
CBD50001            ENERG_HI(0.375000-10.125000)keV
CBD60001            SHELL(1111)
CCLS0001            BCF
CDTP0001            DATA
CVSD0001            1996-12-20T02:57:00

BUNIT   = 'arcsec'           /  Units of Radius
```

The actual example file has a more extensive header:

```
SIMPLE      = T                    / file does conform to FITS standard
BITPIX      = -32                  / number of bits per data pixel
NAXIS       = 4                    / number of data axes
NAXIS1      = 100                  / length of data axis
NAXIS2      = 14                   / length of data axis
NAXIS3      = 8                    / length of data axis
NAXIS4      = 40                   / length of data axis
EXTEND      = T                    / FITS dataset may contain extensions
COMMENT     =   FITS (Flexible Image Transport System) format is defined in 'Astronomy /
COMMENT     =   and Astrophysics', volume 376, page 359; bibcode: 2001A&A...376..359H /
HDUNAME     = RADIUS               / ASCDM block name
LONGSTRN    = OGIP 1.0             / The HEASARC Long String Convention may be used.
COMMENT     =   This FITS file may contain long string keyword values that are /
COMMENT     =   continued over multiple keywords.  The HEASARC convention uses the & /
```

```
COMMENT      =   character at the end of each substring which is then continued /
COMMENT      =   on the next keyword which has the name CONTINUE. /
HDUCLAS1     = RESPONSE             / dataset relates to instrument response
HDUCLAS2     = REEF2                /
HDUCLAS3     = PREDICTED            /
HDUCLAS4     = NET                  /
BUNIT   = 'arcsec'           /  Units of Radius
CCNM0001     = REEF                 /
CDES0001     = HRMA Encircled Energy /
ORIGIN       = CXC Calibration      /
CREATOR      = write-ecf-fits 1.14  /
DATE         = 2004-02-24T23:16:31  /
MODEL        = orbit_XRCF+tilts_04  / raytrace configuration
MISSION      = AXAF                 / should you accept it
TELESCOP     = Chandra              / satellite
INSTRUME     = TEL                  /
DETNAM       = HRC-I                /
GRATING      = NONE                 /
CBD10001     = ECF(0.010000-1.000000) /
CBD20001     = THETA(0.000000-20.000000)arcmin /
CBD30001     = PHI(0.000000-360.000000)deg /
CBD40001     = ENERG_LO(0.125000-9.875000)keV /
CBD50001     = ENERG_HI(0.375000-10.125000)keV /
CBD60001     = SHELL(1111)          /
CCLS0001     = BCF                  /
CDTP0001     = DATA                 /
CVSD0001     = 1996-12-20T02:57:00  /
SHELL        = 1111                 / Shell 1346 bitmap
FILTER       = NONE                 /
HISTORY      = write-ecf-fits       /
HISTORY      =   --config orbit_XRCF+tilts_04 /
HISTORY      =   --denergy 0.5      /
HISTORY      =   --detector HRC-I   /
HISTORY      =   --extract_order energy,theta,phi /
HISTORY      =   --extract_re       /
HISTORY      = ($RE{num}{real})[_/]($RE{num}{real})[_/]($RE{num}{real}).rdb /
HISTORY      =   --flip_phi 1       /
HISTORY      =   --frac fraction    /
HISTORY      =   --output hrmaD1996-12-20hrci_ecf_N0002.fits /
HISTORY      =   --rpar radius,arcseconds,radius_median,radius_p15.87,radius_p84.13 /
HISTORY      =   --vdate 1996-12-20T02:57:00 /
CTYPE1B      = ECF--TAB             / Encircled fraction contour
CTYPE2B      = THET-TAB             / [arcmin] Off Axis Angle
CNAME2B      = THETA                /
CUNIT2B      = arcmin               /
CTYPE3B      = PHI--TAB             / [deg] Azimuth
```

```
CUNIT3B      = deg                  /
CTYPE4B      = ENER-TAB             / [keV] Energy
CNAME4B      = ENERGY               /
CUNIT4B      = keV                  /
PS1_0B       = WCS-TAB              / Table for lookup coord
PV1_0B       = 1                    / Table for lookup coord
PS1_1B       = ECF                  / Column name
PS2_0B       = WCS-TAB              / Table for lookup coord
PV2_0B       = 2                    / Table for lookup coord
PS2_1B       = THETA                / Column name
PS3_0B       = WCS-TAB              / Table for PHI coord
PV3_0B       = 3                    / Table for lookup coord
PS3_1B       = PHI                  / Column name
PS4_0B       = WCS-TAB              / Table for lookup coord
PV4_0B       = 4                    / Table for lookup coord
PS4_1B       = ENERGY               / Column name
CTYPE1P      = ECF_BIN              /
CRVAL1P      = 0                    /
CRPIX1P      = 0                    /
CDELT1P      =       1.00000000     /
WCSTY1P      = PHYSICAL             /
CUNIT1P      = bin                  /
LTV1         = 0                    /
LTM1_1       =       1.00000000     /
CTYPE1       = ECF1                 /
CRVAL1       =       0.01000000     /
CRPIX1       =       1.00000000     /
CDELT1       =       0.01000000     /
CUNIT1       =                      /
CTYPE2P      = THETA_BIN            /
CRVAL2P      = 0                    /
CRPIX2P      = 0                    /
CDELT2P      =       1.00000000     /
WCSTY2P      = PHYSICAL             /
CUNIT2P      = bin                  /
LTV2         = 0                    /
LTM2_2       =       1.00000000     /
CTYPE3P      = PHI_BIN              /
CRVAL3P      = 0                    /
CRPIX3P      = 0                    /
CDELT3P      =       1.00000000     /
WCSTY3P      = PHYSICAL             /
CUNIT3P      = bin                  /
LTV3         = 0                    /
LTM3_3       =       1.00000000     /
CTYPE3       = PHI1                 /
```

```
CRVAL3       = 0                    /
CRPIX3       =       1.00000000     /
CDELT3       =      45.00000000     /
CUNIT3       = deg                  /
CTYPE4P      = ENERGY_BIN           /
CRVAL4P      = 0                    /
CRPIX4P      = 0                    /
CDELT4P      =       1.00000000     /
WCSTY4P      = PHYSICAL             /
CUNIT4P      = bin                  /
LTV4         = 0                    /
LTM4_4       =       1.00000000     /
CTYPE4       = ENERGY1              /
CRVAL4       =       0.25000000     /
CRPIX4       =       1.00000000     /
CDELT4       =       0.25000000     /
CUNIT4       = deg                  /
```

## 2.2 BINARY TABLE header

For each axis of the images we include a binary table with HDUNAMES WCS-TAB1,2,3,4.

These HDUs contain single-row binary tables with vectors corresponding to the coordinate values. (I wish that WCS paper 3 had allowed column-oriented coordinate vectors instead of single-row-arrays, but we'd better go with the standard).

```
XTENSION     = BINTABLE             / binary table extension
BITPIX       = 8                    / 8-bit bytes
NAXIS        = 2                    / 2-dimensional binary table
NAXIS1       = 400                  / width of table in bytes
NAXIS2       = 1                    / number of rows in table
PCOUNT       = 0                    / size of special data area
GCOUNT       = 1                    / one data group (required keyword)
TFIELDS      = 1                    / number of fields in each row
EXTNAME      = WCS-TAB              / name of this binary table extension
EXTVER       = 1                    /
HDUNAME      = WCS-TAB1             / ASCDM block name
COMMENT      = Coordinate lookup for axis /
TTYPE1       = ECF                  / Coordinate
TFORM1       = 100E                 / format of field
TUNIT1       =                      /
```

## 2.3 Coordinate systems

In the example file, I provide three different paths to the coordinate systems:

1. Standard FITS WCS for the ECF, PHI, ENERGY axes. These are useful for DS9 to be able to image the RADIUS data images and put coord values on them. THETA is not included since it's not regularly spaced.

2. FITS "Paper 3" WCS-TAB keywords which allow modern, compliant FITS software (if any) to recognize the coordinate array HDUs as being the coordinates on the relevant axes. These keywords tie the PHI axis to the values in the lookup table HDU called WCS-TAB3. I recommend that CXC software should either use these keywords, or hard-code the lookups to the WCS-TAB HDUs for the ECF, THETA, PHI, ENERGY lookups. The ENERG_LO and ENERG_HI vectors are bin steps on ENERGY and have been included as separate arrays in the ENERGY bintable. It is to be hoped that a generic mechanism will eventually be provided to do this.

The file ecf.new2 contains a 3D version of the ECF data, for ECF = 90 percent only. This file is easier to look at in DS9; each frame is a theta,phi map at a fixed energy, and using the cube play option you can cycle through the energies. We might consider using such small (50x smaller) derived files for applications where only one value of the ECF is going to be used.