Creating an Image of the PSF

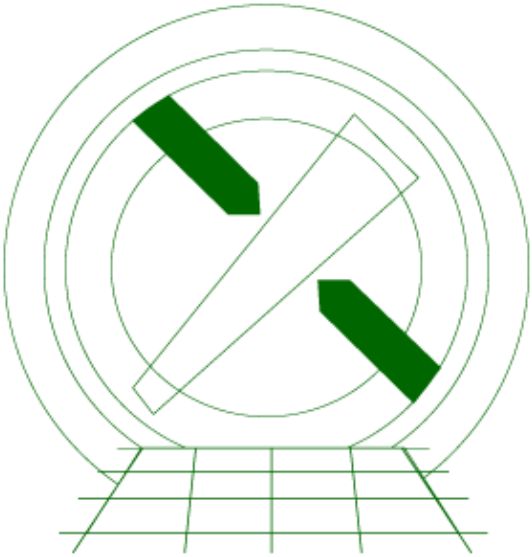

ChaRT Threads

Table of Contents

Creating an Image of the PSF

ChaRT Threads

Overview

Last Update: 17 Feb 2010 - reviewed for CIAO 4.2: minor updates to screen output

Synopsis:

The output of MARX is a pseudo event file containing a list of rays that have been projected onto the detector (recall that MARX includes the instrumental response when doing this). This thread shows how to bin the output file into an image that (optionally) matches that of your data. This image can then be used in your scientific analysis.

Get Started

This example uses `marx_HRMA_theta5.949_phi197.7_en1.7_d2.fits`, which was created in the Using MARX to Create an Event File thread. Also:

Sample ObsID used: 942 (ACIS-S, NGC 4244)

File types needed: evt2

Examine the Data

The following sections describe how to create an image of the PSF that is either centered on the PSF or matches an existing image of the dataset.

The projected rayfile (`marx_HRMA_theta5.949_phi197.7_en1.7_d2.fits`) can be examined with `dmlist`:

```
unix% dmlist marx_HRMA_theta5.949_phi197.7_en1.7_d2.fits blocks

--------------------------------------------------------------------------------
Dataset: marx_HRMA_theta5.949_phi197.7_en1.7_d2.fits
--------------------------------------------------------------------------------

     Block Name                          Type         Dimensions
--------------------------------------------------------------------------------
Block    1: NULL                           Null
```

```
Block    2: EVENTS                          Table        22 cols x 116315   rows
Block    3: GTI4                            Table         2 cols x 1        rows
Block    4: GTI5                            Table         2 cols x 1        rows
Block    5: GTI6                            Table         2 cols x 1        rows
Block    6: GTI7                            Table         2 cols x 1        rows
Block    7: GTI8                            Table         2 cols x 1        rows
Block    8: GTI9                            Table         2 cols x 1        rows
Block    9: MARX_PAR                        Table         1 cols x 480      rows

unix% dmlist marx_HRMA_theta5.949_phi197.7_en1.7_d2.fits cols

-------------------------------------------------------------------------------
Columns for Table Block EVENTS
-------------------------------------------------------------------------------

ColNo  Name                 Unit        Type             Range
   1   TIME                 s            Real8          362912400.0:362912600.6024336219 time since obs
   2   CCD_ID                            Int2           0:9                   CCD id number
   3   NODE_ID                           Int2           -                     0-4
   4   EXPNO                             Int4           0:2147483647          Exposure number
   5   chip(CHIPX,CHIPY)    pixel        Int2           2:1023                CHIP X
   6   tdet(TDETX,TDETY)    pixel        Int4           2:8191                Detector X
   7   det(DETX,DETY)       pixel        Real8          0.50:     8192.50     Focal Plane X
   8   sky(X,Y)             pixel        Real8          0.50:     8192.50     sky X pixel
   9   PHA                  adu          Int4           0:36855               Total PHA for event
  10   ENERGY               eV           Real4          0:  1000000.0         Nominal energy of event
  11   PI                   Chan         Int2           -                     pulse invariant energy of
  12   FLTGRADE                          Int2           0:255                 Event Grade Code
  13   GRADE                             Int2           -                     ACIS grade code
  14   STATUS[2]                         Bit(2)                               status flags
  15   SHELL                             Int2           -                     Mirror Shell (0=1,1=3,2=4,
  16   ZCOS                              Real4          -Inf:+Inf             Z direction cosine
  17   YCOS                              Real4          -Inf:+Inf             Y direction cosine
  18   XCOS                              Real4          -Inf:+Inf             X direction cosine
  19   ZPOS                 mm           Real4          -Inf:+Inf             Z position in MARX coords
  20   YPOS                 mm           Real4          -Inf:+Inf             Y position in MARX coord s
  21   XPOS                 mm           Real4          -Inf:+Inf             X position in MARX coord s
  22   MARX_ENERGY          keV          Real4          -Inf:+Inf             Energy of ray

-------------------------------------------------------------------------------
World Coord Transforms for Columns in Table Block EVENTS
-------------------------------------------------------------------------------

ColNo    Name
8:    EQPOS(RA ) = (+184.3430) +TAN[(-0.000136667)* (sky(X)-(+4096.50))]
           (DEC)   (+37.7809 )      (+0.000136667)  (   (Y) (+4096.50))
```

Note that the table contains coordinates for the events in a number of coordinate systems. We shall assume that we want an image of the PSF in `SKY` coordinates.

Centering the PSF

Get the coordinates

The center of the PSF can be found by using the `dmcoords` tool to convert the input `THETA` and `PHI` values used to create the PSF into `SKY` coordinates. Note that "centering" may be a bit of a misnomer; far off-axis, it is likely that the "center" of the PSF is not coincident with either the centroid and/or the sky pixel matching the off-axis angle.

The necessary values are both recorded in the filename

(marx_HRMA_**theta5.949_phi197.7**_en1.7_d2.fits) and in the header of the original ChaRT output (HRMA_theta5.949_phi197.7_en1.7_d2.fits):

```
unix% dmlist HRMA_theta5.949_phi197.7_en1.7_d2.fits header | egrep 'SRC_(THET|PHI)'
0011 SRC_THET                     5.9490 [arcmin]        Real8        input THETA
0012 SRC_PHI                    197.740 [degrees]       Real8        input PHI
```

dmcoords can now be used to convert between this position (in the msc coordinate system) and the sky coordinate system. This conversion depends on the aspect solution, which varies with time; we use the nominal aspect solution (as given by the RA_NOM, DEC_NOM, and DEC_NOM keywords in the header of the event file:

```
unix% punlearn dmcoords
unix% dmcoords acisf00942N003_evt2.fits asol=pcadf075214790N003_asol1.fits
dmcoords>: MSC 5.9490 197.740
(RA,Dec):     12:16:57.136    +37:43:35.90
(RA,Dec):      184.23807       37.72664 deg
THETA,PHI          5.949'        197.74 deg
(Logical):        4704.01       3699.93
SKY(X,Y):         4704.01       3699.93
DETX,DETY         3405.51       3875.45
CHIP ACIS-S2       573.44        753.80
TDET              3448.44       2455.80
```

This step could also be done with dmcoords in non-interactive mode:

```
unix% dmcoords acisf00942N003_evt2.fits asol=pcadf075214790N003_asol1.fits opt=msc theta=5.9490 p
unix% pget dmcoords x y
4704.010656034712
3699.93423167626
```

Calculate the binning factor

We choose to create a 512 x 512 pixel image around the central position (with a binning factor of 1) in order to encompass most of the PSF signal. To calculate a 512 x 512 region centered at (4704.01, 3699.93):

```
512/2 = 256

X direction: 4704.01-256 = 4448.01
             4704.01+256 = 4960.01

Y direction: 3699.93-256 = 3443.93
             3699.93+256 = 3955.93
```

Rounding to 0.5 pixel, the binning factor is [bin x=4448.5:4960.5:1,y=3443.5:3955.5:1].

Create the image

Now we can use dmcopy with the binning syntax to create an image:

```
unix% dmcopy \
      "marx_HRMA_theta5.949_phi197.7_en1.7_d2.fits[bin x=4448.5:4960.5:1,y=3443.5:3955.5:1]" \
      psf_512.fits
```

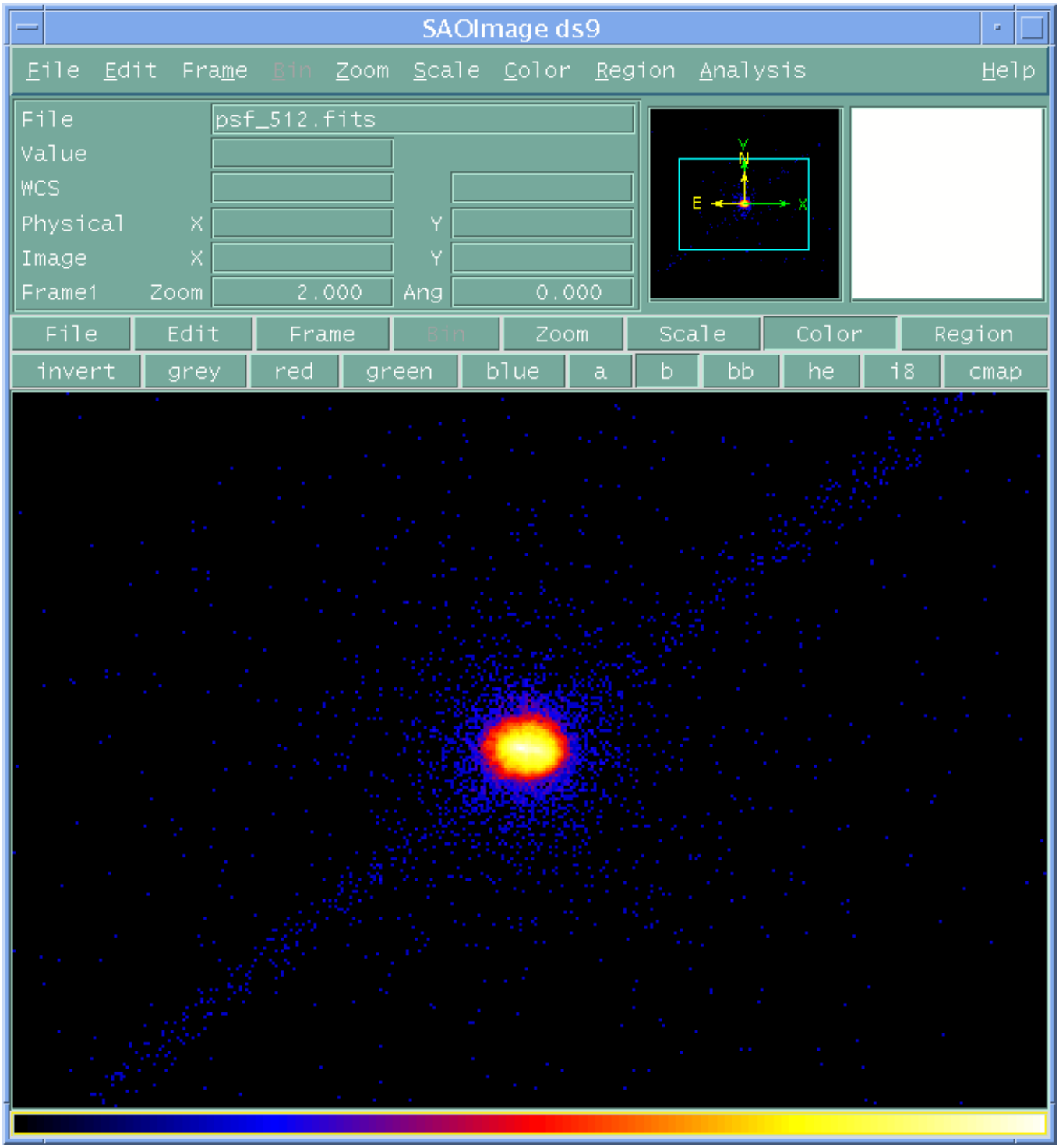

Figure 1: Image of the PSF

The PSF image is 512 x 512 pixels.

Binning the Rayfile to Match an Image

An alternative approach is to bin the PSF image to match an existing image of your data. The image of the data in this example was made by creating an event file of chip S2 (`ccd_id=6`) and simultaneously binning it into an image:

```
unix% more ds9.reg
# Region file format: CIAO version 1.0
rotbox(4552.2734,3517.8837,1071.6108,1064.0118,38.490129)

unix% dmcopy \
      "acisf00942N003_evt2.fits[ccd_id=6,sky=region(ds9.reg)][bin sky=2]" \
      942_image.fits
```

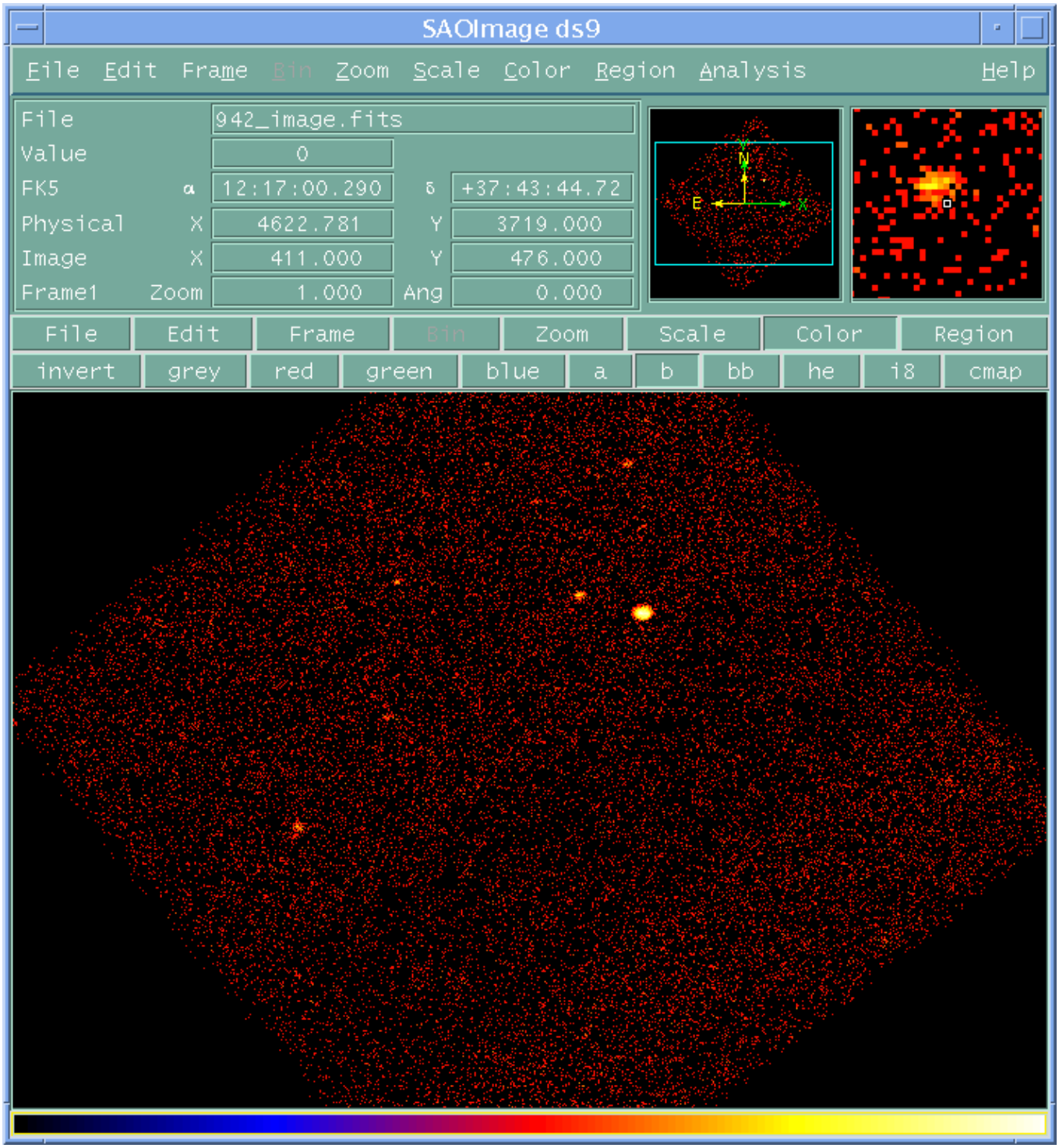

Figure 2: Image of the event data

The event file for ObsID 942 is filtered on ccd_id=6 and sky, then binned by a factor of 2 to create an image.

The `get_sky_limits` script (part of the CIAO Scripts distribution) can be used to find out the necessary DM binning specification to match the PSF to this image:

```
unix% get_sky_limits 942_image.fits verbose=1
Checking binning of image: 942_image.fits
  Image has 751 x 750 pixels
```

```
  Lower left (0.5,0.5) corner is x,y= 3801.8, 2768.0
  Upper right (751.5,750.5) corner is x,y= 5303.8, 4268.0
  DM filter is:
    x=3801.8:5303.8:#751,y=2768.0:4268.0:#750
  mkexpmap xygrid value is:
    3801.8:5303.8:#751,2768.0:4268.0:#750
```

Finally, use `dmcopy` to create the image:

```
unix% dmcopy \
      "marx_HRMA_theta5.949_phi197.7_en1.7_d2.fits[bin x=3801.8:5303.8:#751,y=2768.0:4268.0:#750
      psf_match.fits
```

Displaying the two images side-by-side:

```
unix% ds9 psf_match.fits 942_image.fits &
```

Figure 2: Image of the event data

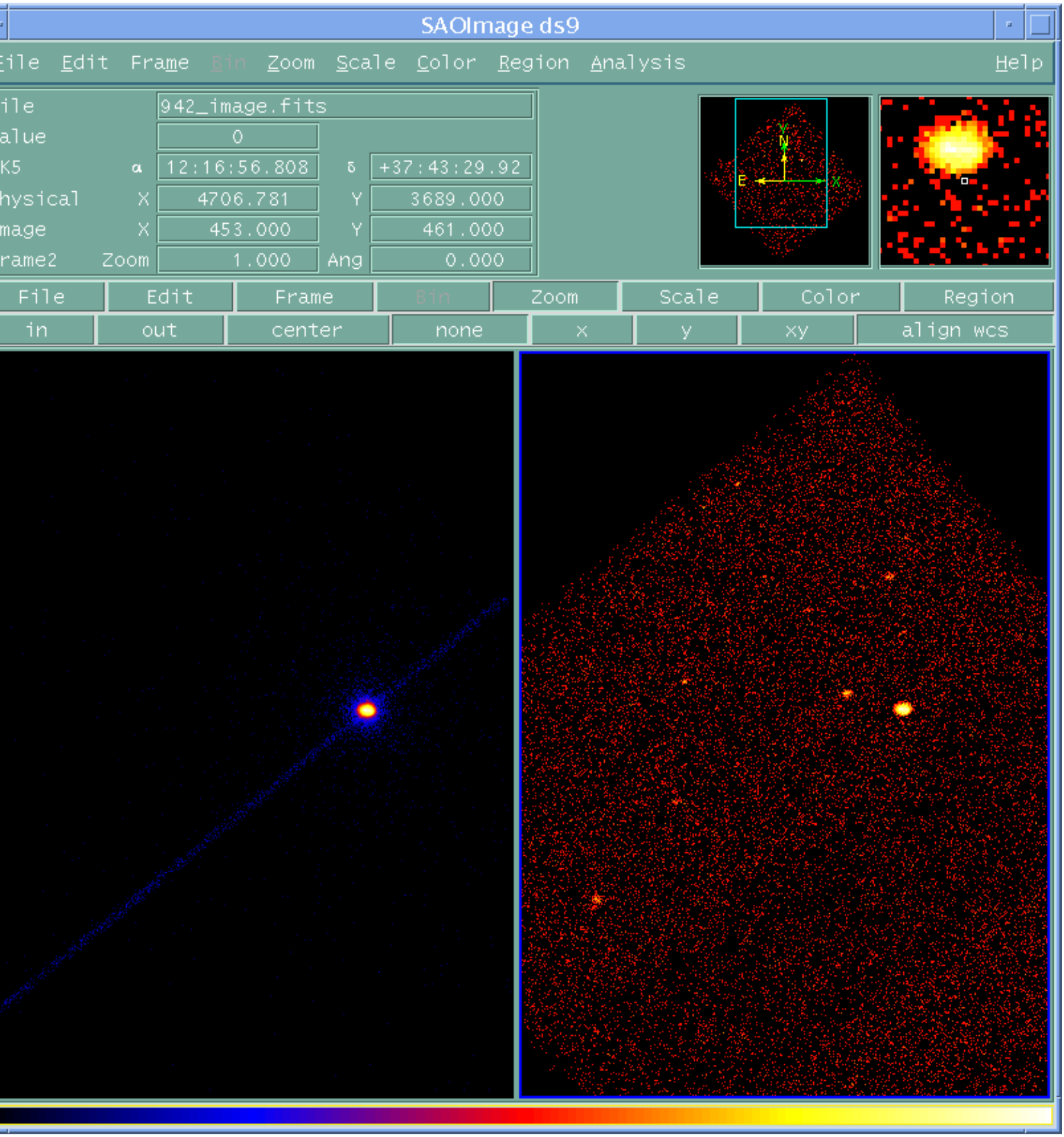

Figure 3: Image of the PSF matched to the data

The PSF image is on the left and the event data is on the right. It is easy to see that the PSF lines up with the chosen source (see the Preparing to Run ChaRT thread).

Create a Sub-pixelated PSF Image

Viewing in ds9

Since the projected event file contains X and Y values without any pixel quantization, a 2-D histogram image can be made at any desired sub-pixel scale. To visualize this with ds9, load the event file:

```
unix% ds9 marx_HRMA_theta5.949_phi197.7_en1.7_d2.fits &
```

Using the Bin and Zoom menus, zoom in and center on the object. Select "Bin -> Binning Parameters" from the menu bar. By changing the "Bin Factor" in the pop-up window, you can adjust the scale size of a bin.

Figure 4 shows the sub-pixelated PSF image resulting from a 0.1 pixel bin factor. The smooth distribution of events verifies that the simulation was done correctly.

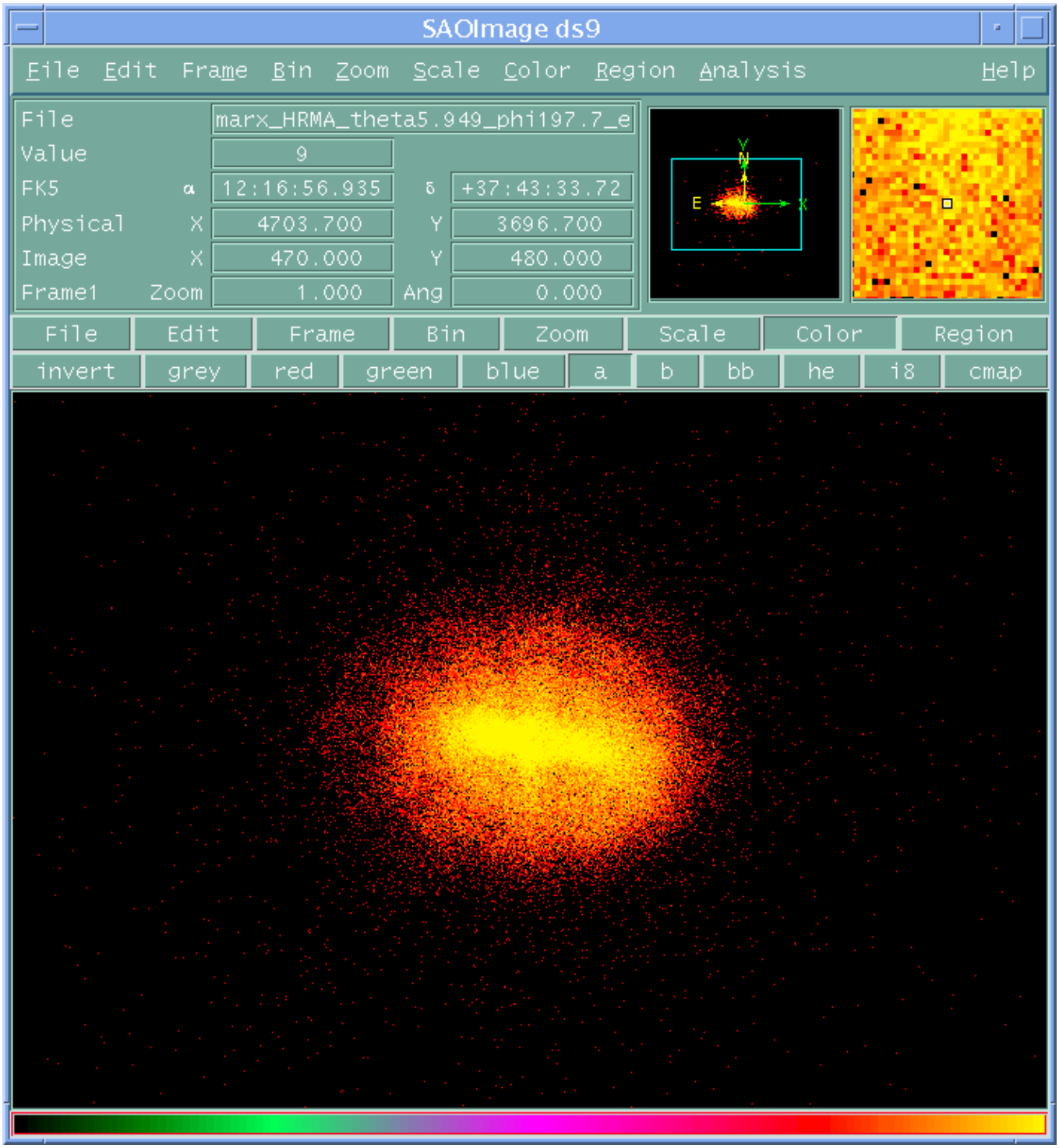

Figure 4: Sub-pixelated PSF image from good event file

This sub-pixelated PSF image was made with a 0.1 pixel bin factor. The smooth distribution of events verifies that the simulation was done correctly.

If the image has boxy features, as shown in Figure 5, something was done wrong.

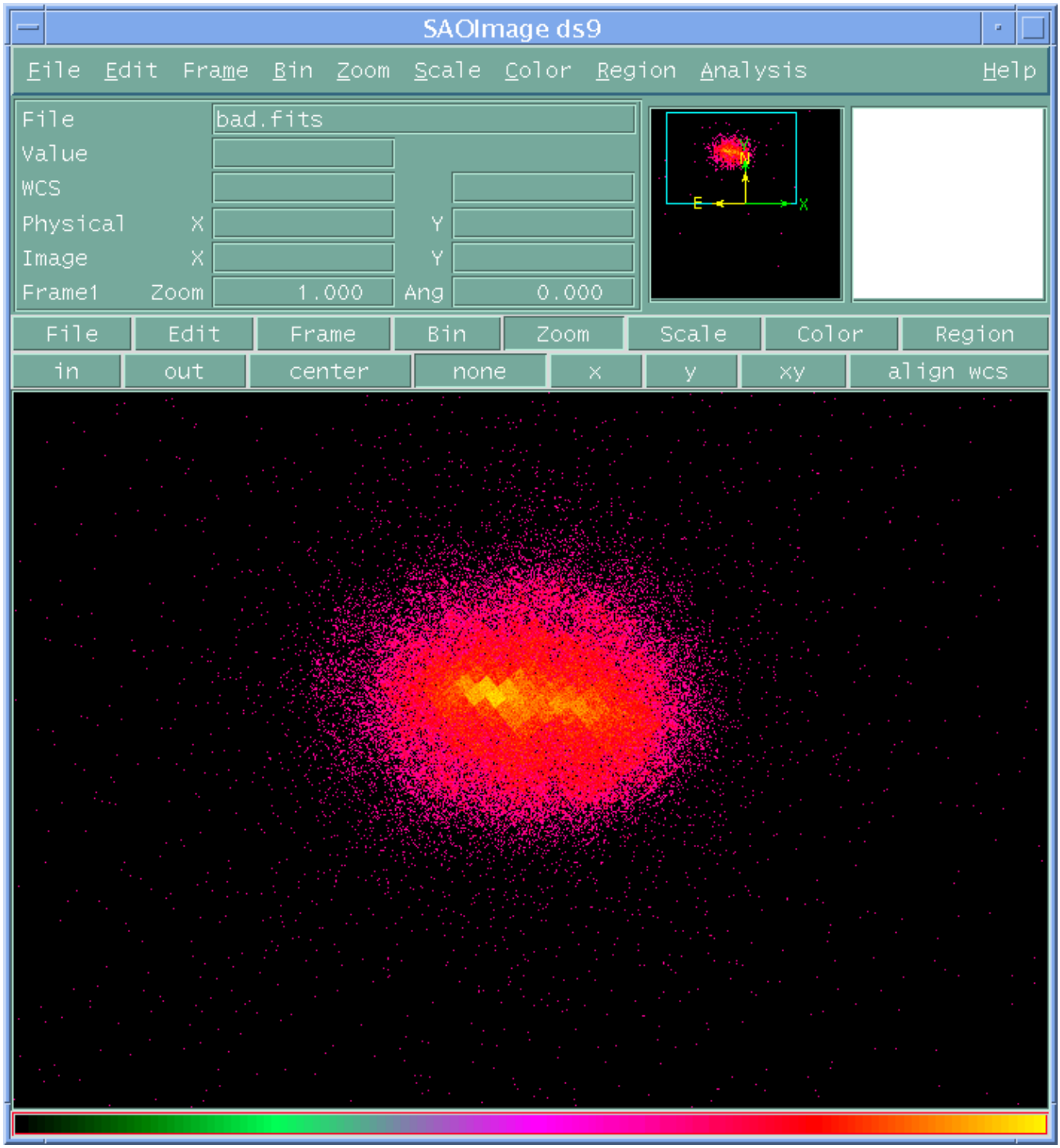

Figure 5: Sub-pixelated PSF image from bad event file

This image was created from a similar MARX run as used in the Using MARX to Create an Event File thread, but with `DitherModel` set to `NONE`; the event file therefore *does not* contain sub-pixel resolution.

Binning with dmcopy

To create the sub-pixelated image with `dmcopy`, use a similar filter to the one given in the Centering the PSF section. Since the binning factor has been decreased from 1.0 to 0.1, the limits have been changed to +/- 25.6 pixels to create the 512 square pixel image:

```
unix% dmcopy \
      "marx_HRMA_theta5.949_phi197.7_en1.7_d2.fits[bin x=4678.41:4729.61:0.1,y=3674.33:3725.53:0.1]" \
      psf_subpix.fits
```

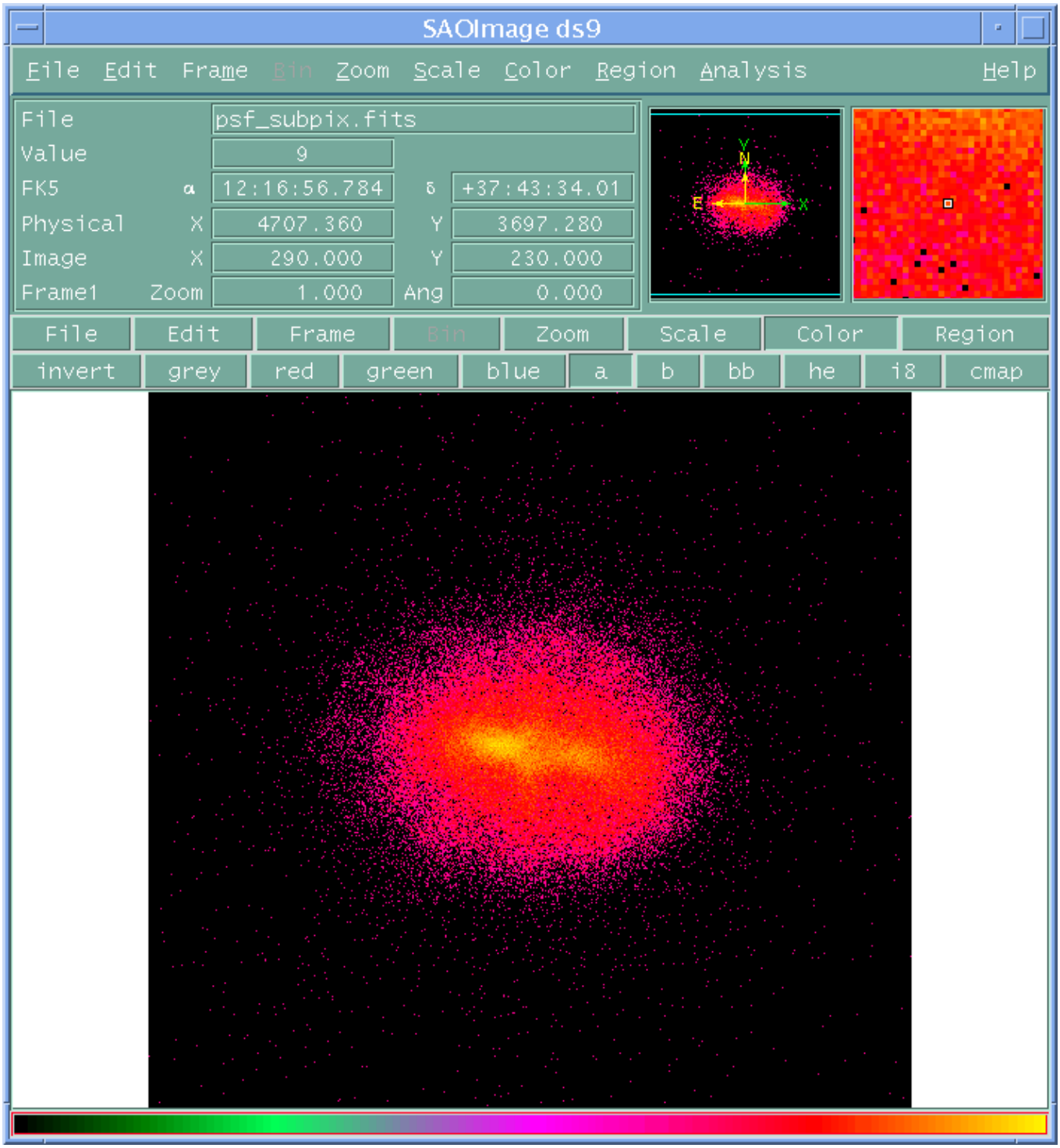

Figure 6: Sub-pixelated PSF image created with dmcopy

A 512 square pixel image of the PSF created at a binning of 0.1.

Caveats

Encircled-energy fractions

The images created above are unlikely to contain all the flux of the PSF. The output of MARX contains 114776 rays (as shown in the Examine the Data section). The first image we create from the rayfile contains only 113861 rays, as shown by `dmstat`:

```
unix% dmstat psf_512.fits centroid=no sigma=no
EVENTS_IMAGE
    min:        0             @:        ( 4449 3444 )
    max:        2097          @:        ( 4702 3701 )
   mean:        0.44020843506
    sum:        115398
   good:        262144
   null:        0
```

In comparison, running the same command on `psf_match.fits` reveals a total of 114732 rays in that image:

```
unix% dmstat psf_match.fits centroid=no sigma=no
EVENTS_IMAGE
    min:        0             @:        ( 3802.8 2769 )
    max:        7034          @:        ( 4700.8 3701 )
   mean:        0.2064198846
    sum:        116266
   good:        563250
   null:        0
```

Since we chose a large region around the PSF center, virtually all the rays were included. For smaller regions the loss will be larger. This factor will need to be included in calculations of the encircled-energy fraction for an aperture.

Summary

These images of the PSF can now be used in a CIAO analysis session.

History

27 Jun 2003	original version, updated for CIAO 3.0: layout
16 Feb 2005	reviewed for CIAO 3.3: no changes

18 Aug 2008	updated for CIAO 4.0: version N003 event file, minor changes to screen output; converted images to inline
17 Feb 2010	reviewed for CIAO 4.2: minor updates to screen output

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URL: http://cxc.harvard.edu/chart/threads/psf_image/ Last modified: 17 Feb 2010