CHANDRA
X-ray Center 60 Garden St., Cambridge Massachusetts 02138 USA

MEMORANDUM

Date: April 18, 2007
From: Nancy Adams-Wolk
To: SOT ACIS Operations
Subject: Using *Xspec*, *Obsvis* and *MARX* for high count rate simulations
File: `MARX_doc.tex`
Version: `0.1`

Abstract

This document describes the setup and execution of *MARX* simulations for high count rate observations to determine potential damage to ACIS. In addition, the *obsvis* and *xspec* tools are discussed as they are needed in the preparation of the *MARX* simulations.

1 Introduction

Occasionally, there are observations of bright sources which could pose a threat to ACIS. In these cases, we want to model the spectrum of the source and simulate the observation to determine if they pose any danger of damaging the detector.

There are three tools to utilize in simulating data: *xspec* to create the spectral model, *obsvis* to visualize the observation and *MARX* to simulate the observation through the HRMA and onto ACIS. This document will explain the setup for these tools and run through an example with ObsId 7501, an off-axis observation of Cygnus X-1.

2 Create the spectrum

The ACIS detector is sensitive to the different energies of the source and we don't want to assume a monochromatic source. The first step in any simulation is to determine the spectral model. It is often advantageous to contact the PI/Observer for the observation to ask for the model. Another route would be to do a literature search via ADS and find papers that describe the spectrum.

In almost any case, once you have the model and parameters, you'll want to run *xspec* to create the model file. It is advised to use *xspec 11.3*. There have been reports of issues with *xspec 12.0* and Paul Plucinsky can help with the commands for *xspec 11.3*.

2.1 Start *xspec*

To set up the *xspec* software (in tcsh)

- setenv LD_LIBRARY_PATH /opt/SUNWspro/lib
- setenv HEADAS /soft/lheasoft/headas/sparc-sun-solaris2.8
- source $HEADAS/headas-init.csh
- xspec11

This will set the terminal into the *xspec* environment.

To run the model, you need to know the model components. For this document, I am using Cyg X-1 as the example bright source.

2.2 Build the model

First enter the model into *xspec* and the prompts will ask for the individual parameters. This example is a phabs with a high energy cutoff and a broken power law with a gaussian for the Fe line.

```
XSPEC>model phabs*highecut( bknpower + gaussian )
  Model:  phabs<1>*highecut<2>( bknpower<3> + gaussian<4> )
Input parameter value, delta, min, bot, top, and max values for ...
                   1     0.001         0         0     1E+05     1E+06
1:phabs:nH>
...
```

2.3 Scale the normalization

For many of the bright source observations it is best to enter a *fractional normalization to scale down the flux*. This will eliminate lengthy calculation times and possible write errors with *MARX*. Be sure to account for all normalizations in the model. Start with changing the normalizations by 0.01. To see the model parameters type "show all".

```
XSPEC>show all
 14:32:46 29-Mar-2007
 Auto-saving is done after every command.
 Fit statistic in use is Chi-Squared
 Minimization technique is Lev-Marq
  Convergence criterion =  0.01
 Querying enabled
 Prefit-renorming enabled
 Solar abundance table is angr
 Cross-sections are bcmc
 Cosmology in use : H0 =  70.000  Lambda0 =   0.730

  Model:  phabs<1>*highecut<2>( bknpower<3> + gaussian<4> )
  ---------------------------------------------------------------------------
  ---------------------------------------------------------------------------
  Model:  phabs<1>*highecut<2>( bknpower<3> + gaussian<4> )
  Model Fit Model Component  Parameter  Unit     Value
  par   par comp
    1    1    1   phabs      nH         10^22      1.40000     +/-   0.00000
    2    2    2   highecut   cutoffE  keV        27.4000     +/-   0.00000
    3    3    2   highecut   foldE    keV        237.000     +/-   0.00000
    4    4    3   bknpower   PhoIndx1            1.72800     +/-   0.00000
    5    5    3   bknpower   BreakE   keV        9.22000     +/-   0.00000
    6    6    3   bknpower   PhoIndx2            1.53600     +/-   0.00000
    7    7    3   bknpower   norm                1.03000     +/-   0.00000
    8    8    4   gaussian   LineE    keV        6.35000     +/-   0.00000
    9    9    4   gaussian   Sigma    keV       0.370000     +/-   0.00000
   10   10    4   gaussian   norm               3.100000E-03 +/-   0.00000
  ---------------------------------------------------------------------------
  ---------------------------------------------------------------------------
```

I have not yet lowered the normalizations here. I would do that with the "newpar" command. Use the parameter numbers to specify which item to change. To change the bknpower norm, I need parameter 7 and for the gaussian norm, I need parameter 10.

```
XSPEC>newpar 7
                1.03      0.01         0         0     1E+24     1E+24
```

```
7:bknpower:norm>0.013
  ---------------------------------------------------------------------------
  ---------------------------------------------------------------------------
  Model:  phabs<1>*highecut<2>( bknpower<3> + gaussian<4> )
  Model Fit Model Component  Parameter  Unit     Value
  par   par comp
    1    1    1   phabs      nH       10^22      1.40000     +/-   0.00000
    2    2    2   highecut   cutoffE  keV        27.4000     +/-   0.00000
    3    3    2   highecut   foldE    keV        237.000     +/-   0.00000
    4    4    3   bknpower   PhoIndx1            1.72800     +/-   0.00000
    5    5    3   bknpower   BreakE   keV        9.22000     +/-   0.00000
    6    6    3   bknpower   PhoIndx2            1.53600     +/-   0.00000
    7    7    3   bknpower   norm               1.300000E-02 +/-   0.00000
    8    8    4   gaussian   LineE    keV        6.35000     +/-   0.00000
    9    9    4   gaussian   Sigma    keV       0.370000     +/-   0.00000
   10   10    4   gaussian   norm               3.100000E-03 +/-   0.00000
  ---------------------------------------------------------------------------
  ---------------------------------------------------------------------------
XSPEC>newpar 10
              0.0031      0.01         0         0     1E+24     1E+24
10:gaussian:norm>0.000031
  ---------------------------------------------------------------------------
  ---------------------------------------------------------------------------
  Model:  phabs<1>*highecut<2>( bknpower<3> + gaussian<4> )
  Model Fit Model Component  Parameter  Unit     Value
  par   par comp
    1    1    1   phabs      nH       10^22      1.40000     +/-   0.00000
    2    2    2   highecut   cutoffE  keV        27.4000     +/-   0.00000
    3    3    2   highecut   foldE    keV        237.000     +/-   0.00000
    4    4    3   bknpower   PhoIndx1            1.72800     +/-   0.00000
    5    5    3   bknpower   BreakE   keV        9.22000     +/-   0.00000
    6    6    3   bknpower   PhoIndx2            1.53600     +/-   0.00000
    7    7    3   bknpower   norm               1.300000E-02 +/-   0.00000
    8    8    4   gaussian   LineE    keV        6.35000     +/-   0.00000
    9    9    4   gaussian   Sigma    keV       0.370000     +/-   0.00000
   10   10    4   gaussian   norm               3.100000E-05 +/-   0.00000
  ---------------------------------------------------------------------------
  ---------------------------------------------------------------------------
   10 variable fit parameters
```

2.4 Create fake data to check the number of expected photons.

Next, a fake dataset should be created using the “fakeit” command. This will take the model, the instrument RMF and ARF files and create a dataset for a given exposure time. This gives the ability to check the photons expected from the observation.

```
XSPEC>fakeit none
For fake data, file #   1 needs response file: acisi_aimpt_cy08.rmf
              ... and ancillary response file: acisi_aimpt_cy08.arf
Use randomization in creating fake data? (y) y
Input optional fake file prefix (max 4 chars):
 Fake data filename (acisi_aimpt_cy08.fak) [/ to use default]:
 Exposure time, correction norm  (1, 1): 10000
Note that RESPFILE keyword in ARF is grid(acisi_aimpt_cy08.rmf[MATRIX][cols ENERG_LO,ENERG_HI])
```

```
 Net count rate (cts/s) for file   1   2.683    +/-  1.6380E-02
   using response (RMF) file...       acisi_aimpt_cy08.rmf
   using auxiliary (ARF) file...      acisi_aimpt_cy08.arf
 Chi-Squared =      762.1366     using  1024 PHA bins.
 Reduced chi-squared =     0.7516140     for   1014 degrees of freedom
 Null hypothesis probability =  1.00
```

With the scaled model, with these ACIS responses, the simulation should produce approximately 26,830 photons striking the telescope in 10ks. For the simulation purposes, reducing the exposure time to 5ks would produce about 13,000 photons, enough to get an accurate determination of damage, but not so many that the calculation will take too long.

To find the RMF and ARF files for the specific observation cycle, go to: /proj/web-cxc/htdocs/caldb2/prop_plan/imaging/CY<XX> where XX is the two digit year.

2.5 Save the model

The model that was entered and scaled needs to be saved in the *xspec* format.

```
XSPEC>cpd /xw
XSPEC>plot model
XSPEC>iplo
PLT>Wdata cygx1_acisi_lowstate.dat
```

3 Visualizing the Observation

If there are no Y or Z offsets, this section is not relevant for simulations, but it is useful to see where the source falls on the CCD array.

CIAO includes a tool called *obsvis.* This will take the coordinates and the basic instrument setup to create a Sloan Digital Sky Survey (DSS) image with the ACIS field of view, the default aimpoint and the actual aimpoint in a DS9 window.

3.1 Running *obsvis*

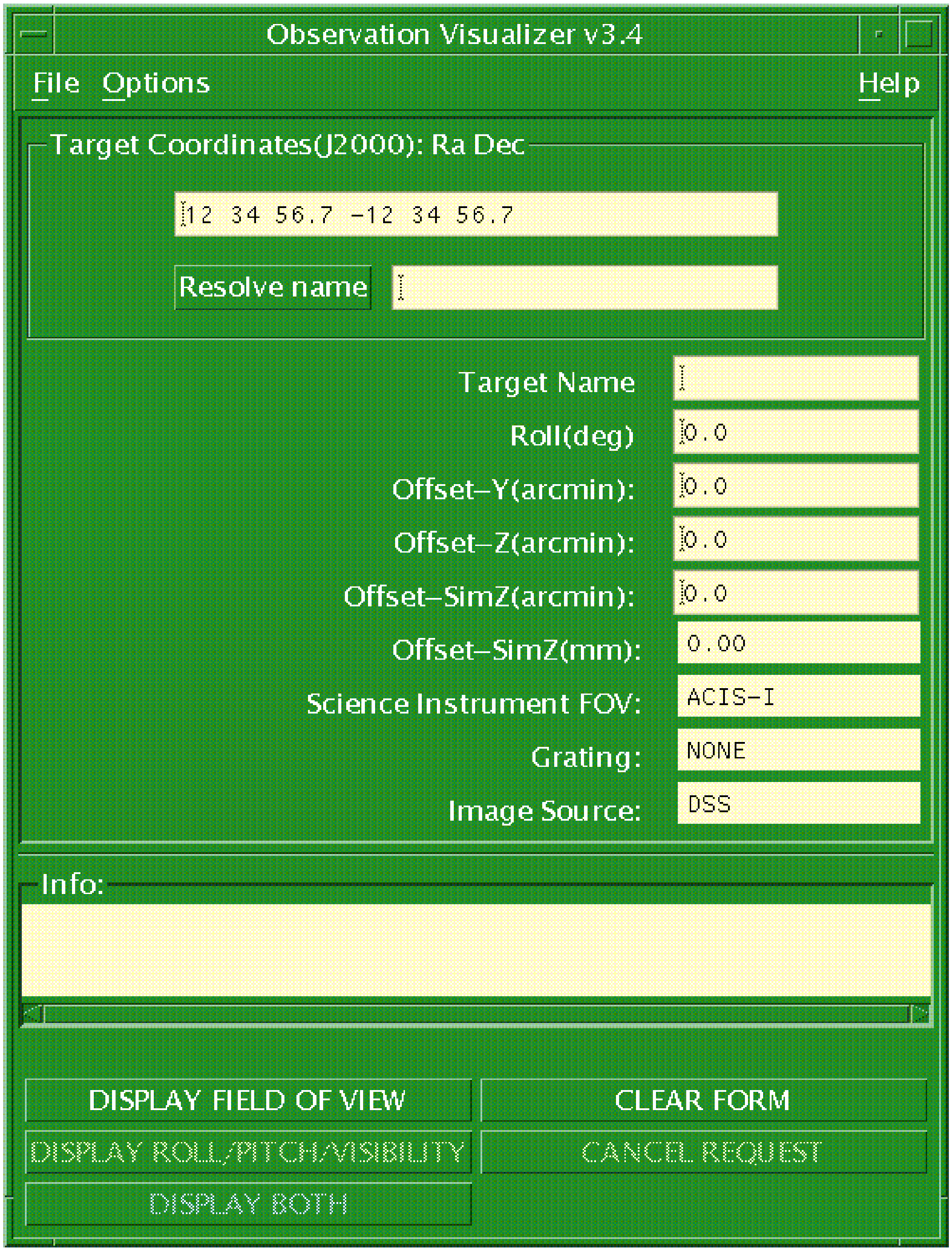
To run *obsvis*,

- source /soft/ciao/bin/ciao.csh -k
- set prompt="CIAO> "
- obsvis &

A start up window as shown in Figure 1 will appear. In your favorite browser, bring up the USINT webpage for this observation, in this example, http://cxc.harvard.edu/cgi-gen/target_param.cgi?7501. First, set the correct focal plane instrument by selecting "Options...Parameters" to bring up the window with the CCDs to overlay in the Field of View. This is important to do first as the Y and Z offsets are changed when you change the instrument setup. Click "Apply" and then "Close" when done.

At this point, use the parameters specified in the USINT webpage for RA, DEC the Y-Offset, the Z-Offset, the roll and the SIM-Z offset. If entering the RA and Dec as decimal degrees, place a comma between the RA and Dec. Then click "DISPLAY FIELD OF VIEW". This will bring up a ds9 window with the overlays as seen in Figure 2. *It is important to note that the roll in the USINT pages is the predicted roll for mid-week of the planned week. Once the preliminary schedule is out, the planned roll is available here. Use the most accurate roll as possible. A small change in roll is important for off-axis observations.*

This is how the observation looks to the telescope. However, this setup is NOT what we need for *MARX.* We need the observation's aimpoint (the red box with inscribed circle) to be on the bright



Target Coordinates(J2000): Ra Dec: 12 34 56.7 -12 34 56.7

Target Name:

Roll(deg): 0.0

Offset–Y(arcmin): 0.0

Offset–Z(arcmin): 0.0

Offset–SimZ(arcmin): 0.0

Offset–SimZ(mm): 0.00

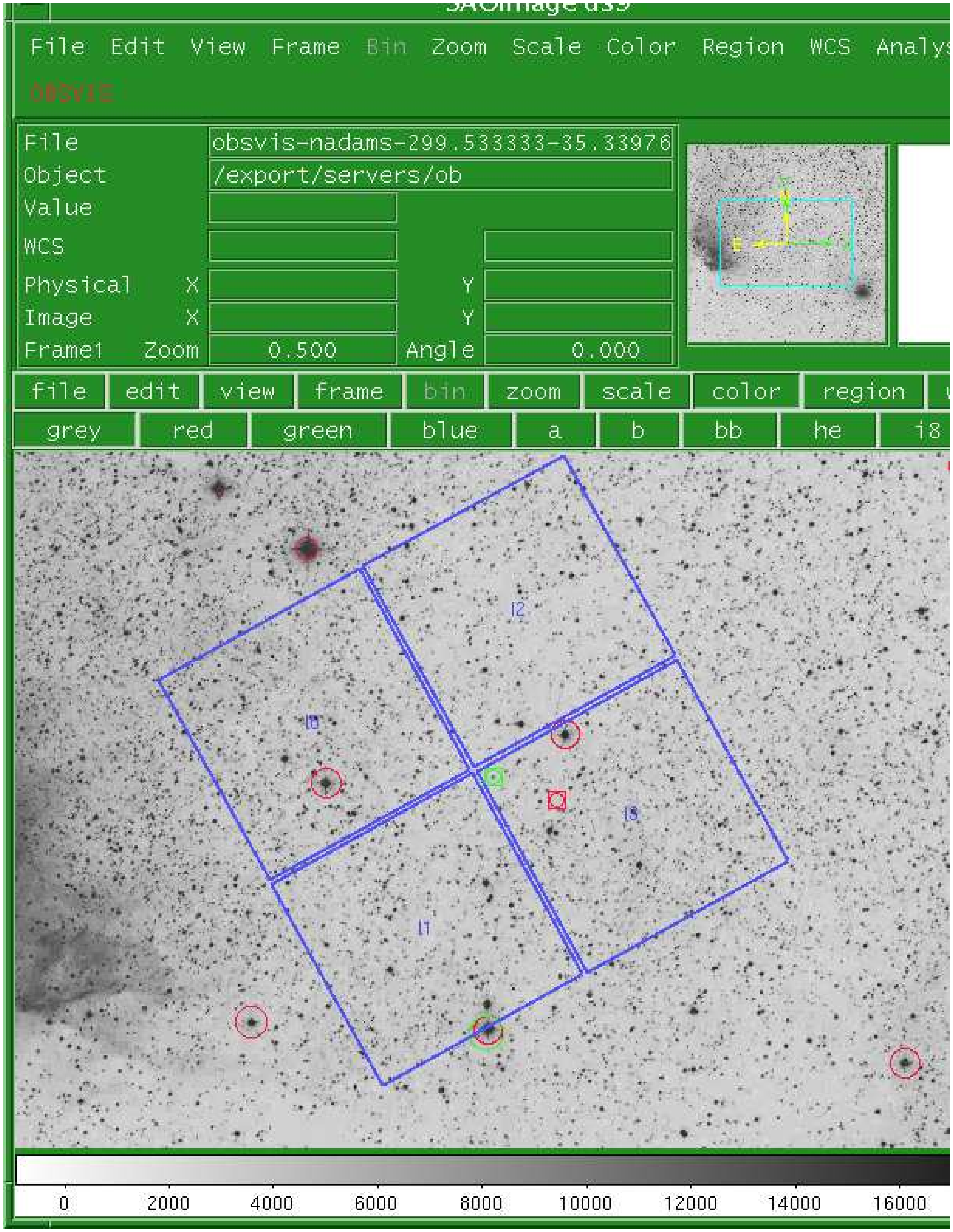
Science Instrument FOV: ACIS-I

Grating: NONE

Image Source: DSS

Info:

Figure 1: The *obsvis* start GUI.



File obsvis-nadams-299.533333-35.33976
Object /export/servers/ob
Value
WCS
Physical X Y
Image X Y
Frame1 Zoom 0.500 Angle 0.000

SAOImage ds9
File Edit View Frame Bin Zoom Scale Color Region WCS Analys
OBSVIS
file edit view frame bin zoom scale color region
grey red green blue a b bb he i8
I2
I0
I3
I1
0
2000
4000
6000
8000
10000
12000
14000
16000

Figure 2: ObsId 7501-Over the DSS image as planned. The offsets and nominal pointing place Cyg X-1 at the edge of the I1 CCD. The green box-circle is the detector aimpoint and the red box-circle is the aimpoint with the offsets applied.

source in question (in this case Cyg X-1). To do this, the RA, Dec and the pointing offsets can be changed to place the aimpoint of the observation at the same location as the bright source. For this example, the RA and Dec were moved to Cyg X-1's location (to place the aimpoint there) and then offsets were added to move the aimpoint to the edge of the I1 CCD.

A screen shot of the new *obsvis* window is shown in Figure 3 and the resulting overlay is shown in Figure 4.

4 Using *MARX* for the simulation

The next step is to use the spectrum and the positional information to run *MARX* and simulate the photons incident on the detector. For the purposes of ACIS instrument safety, we want to run *MARX* version 3.01. The goal of these simulations is to determine the number of photons that impact the detector, not the photons that are detected. For this reason, the quantum efficiency of the detectors should be set to 1.0. However, *MARX*4.0 bundles the QE and optical blocking filter transmissions together. The filter transmissions need to be kept in place for these simulations.

In *MARX* 3.01, the filter transmissions and QE have been separated and there are QE files for I3/S3 that have been created with a uniform QE. These files are stored in the $MARX_DATA_DIR (defined below).

In the case that we can no longer use the older version of *MARX*, it is possible to create new files to work with *MARX* 4.0 and higher. These would need to be FITS files that contain only the filter functions and NOT the QE. These files would be placed in the data directory for *MARX* and used in place of the current QE files.

4.1 *MARX* setup

To set up *MARX*, use the installation on /data/acis0:

- set path = ($path /data/acis0/MARX/marx_3.0/bin/)
- setenv MARX_DATA_DIR /data/acis0/MARX/marx_3.0/marx/data/
- cp $MARX_DATA_DIR/marx.par ¡working directory¿

4.2 Entering the parameters

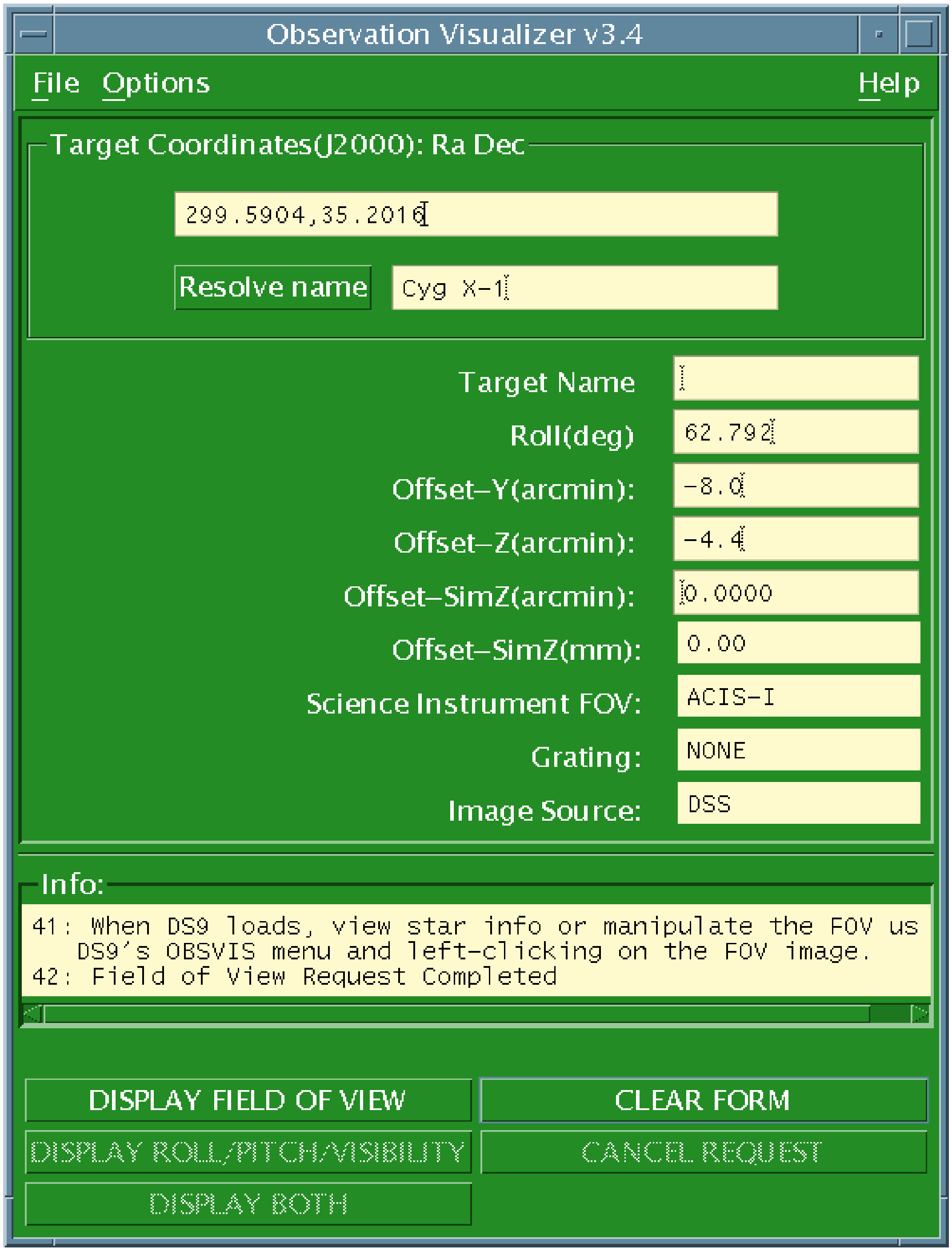
MARX runs with an IRAF style parameter file.

The parameters of interest are:

- SpectrumFile: The input source model in marx format.
- ExposureTime: The simulation exposure time in seconds.
- SourceOffsetY: The Y Offset in arcmin.
- SourceOffsetZ: The Z Offset in arcmin.
- Pointing_RA: The decimal degree Right Ascension of the source to model.
- Pointing_Dec: The decimal degree Declination of the source to model.
- DitherRoll: The planned roll of the observation in degrees.
- OutputDir: The name of the output directory
- DitherModel: Either INTERNAL or NONE, this sets if the simulation dithers.
- GratingType: NONE, HETG or LETG, should be set to reflect the setup.

Any or all of these parameters can be set by using the "pset" command or by using these on the command line.

Example:
To set the ExposureTime with pset:



Target Coordinates(J2000): Ra Dec

299.5904,35.2016

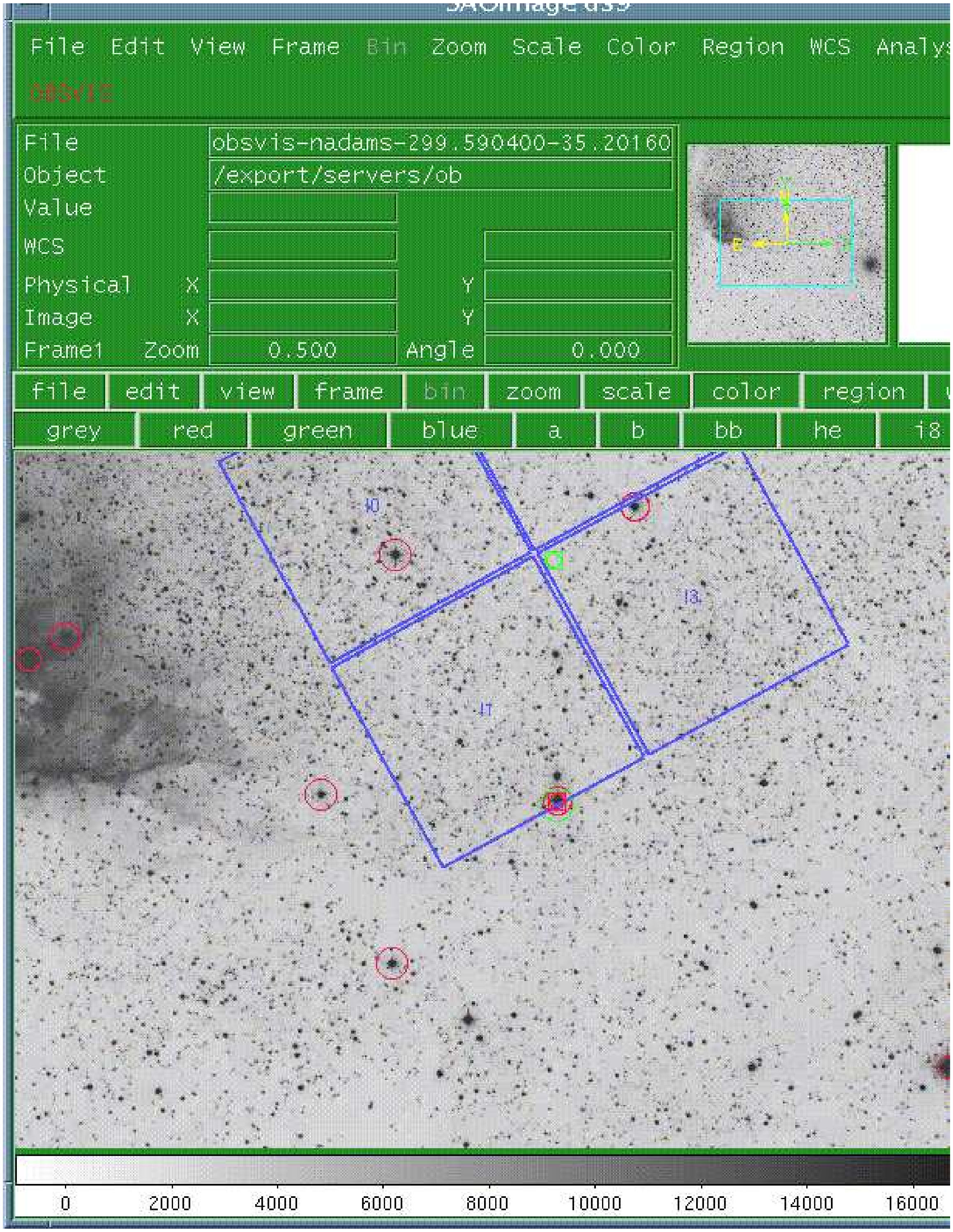
Resolve name: Cyg X-1

Target Name	
Roll(deg)	62.792
Offset–Y(arcmin):	-8.0
Offset–Z(arcmin):	-4.4
Offset–SimZ(arcmin):	0.0000
Offset–SimZ(mm):	0.00
Science Instrument FOV:	ACIS-I
Grating:	NONE
Image Source:	DSS

Info:

```
41: When DS9 loads, view star info or manipulate the FOV us
    DS9's OBSVIS menu and left-clicking on the FOV image.
42: Field of View Request Completed
```

Figure 3: The *Obsvis* GUI with the pointing changed for the *MARX* simulation. The large offsets are needed to place the aimpoint (red circle-box) on Cyg X-1's position in the planned observation.



File obsvis-nadams-299.590400-35.20160
Object /export/servers/ob
Value
WCS
Physical X Y
Image X Y
Frame1 Zoom 0.500 Angle 0.000

Figure 4: ObsId 7501-Over the DSS image as needed for the *MARX* simulation. Note that the red circle-box is now placed on Cyg X-1 and near the position for the planned observation.

```
pset marx ExposureTime=10000
```

To set the ExpsoureTime on the command line:

```
marx ExposureTime=10000
```

4.3 Converting the input spectrum

The input spectrum from *xspec* must be converted to a format that *MARX* expects. There is a marx tool to do this. It is a wrapper around a nawk command, so you must redirect the output to a file.

```
xspec2marx xspec_model.dat > marx_model.dat
```

This filename will be used in the *MARX* parameter “SpectrumFile”.

4.4 Running *MARX*

There are several different simulations to be run to cover failure scenarios:

- The observation as planned.
- The observation as planned with DitherType=NONE to simulate the case if dither fails.
- The observation with the source at the aimpoint (if not as planned).
- The observation with the source at the aimpoint AND DitherType=NONE to simulate the case if dither fails.
- If the source has a varying spectrum and/or a high/low count state, repeat all of the above with a second spectrum.

To run *MARX*, set up the parameters in section 4.2 with either “pset” or on the command line. For the on-axis simulations, use the coordinates of the source. For the as planned simulations, use the setup that you calculated in the second part of section 3.REMEMBER to NOT use the planned telescope setup if the source is not at the aimpoint. *It is important for MARX to think that the aimpoint is at the bright source to be simulated, not vice versa.* In other words, *MARX* will simulate the observation with the source spectrum placed at the red circle-box in Figures 2 and 4. This is why you spent the time resetting the *obsvis* setup to place the aimpoint at the bright source.

If you are simulating a long observation, it may be beneficial to cut the exposure time. Dither requires about 1 ks to complete a full trace of the pattern, so at least 1ks should be used. The final numbers should be scaled up to reflect the expected exposure time.

4.5 *MARX* output

MARX places a series of binary files in the directory that you specified in the OutputDir parameter. To actually read these, use the “marx2fits” converter.

```
marx2fits <directory with binary files>  marx.fits
```

The result is a FITS file that can be read into DS9 and processed with CIAO tools. If an error occurs indicating that disk space is an issue, the resultant FITS file may be over 2GB. This is a FITS limit inside the *cfitsio* libraries. Rerun the simulation with either a scaled model or exposure time.

5 Calculating the peak pixel

To determine to damage to ACIS, the pixel with the highest number of counts in the simulation (the peak pixel) needs to be found. This pixel is usually in the a corner of the dither pattern. One way to find the peak pixel is to use CIAO tools to copy the the CCD with the source to a FITS file and then converting it to a chip coordinate image. This chip coordinate image can be visualized(Figure 5) and then “dmstat” can be run on this image to locate the peak pixel.

```
dmcopy marx.fits"[ccd_id=3]" marx_i3.fits‘;
dmcopy marx_i3.fits"[bin chipx,chipy]" marx_i3_chipimg.fits option="type=i4"
dmstat marx_i3_chipimg.fits > marx_summary.txt‘;
```

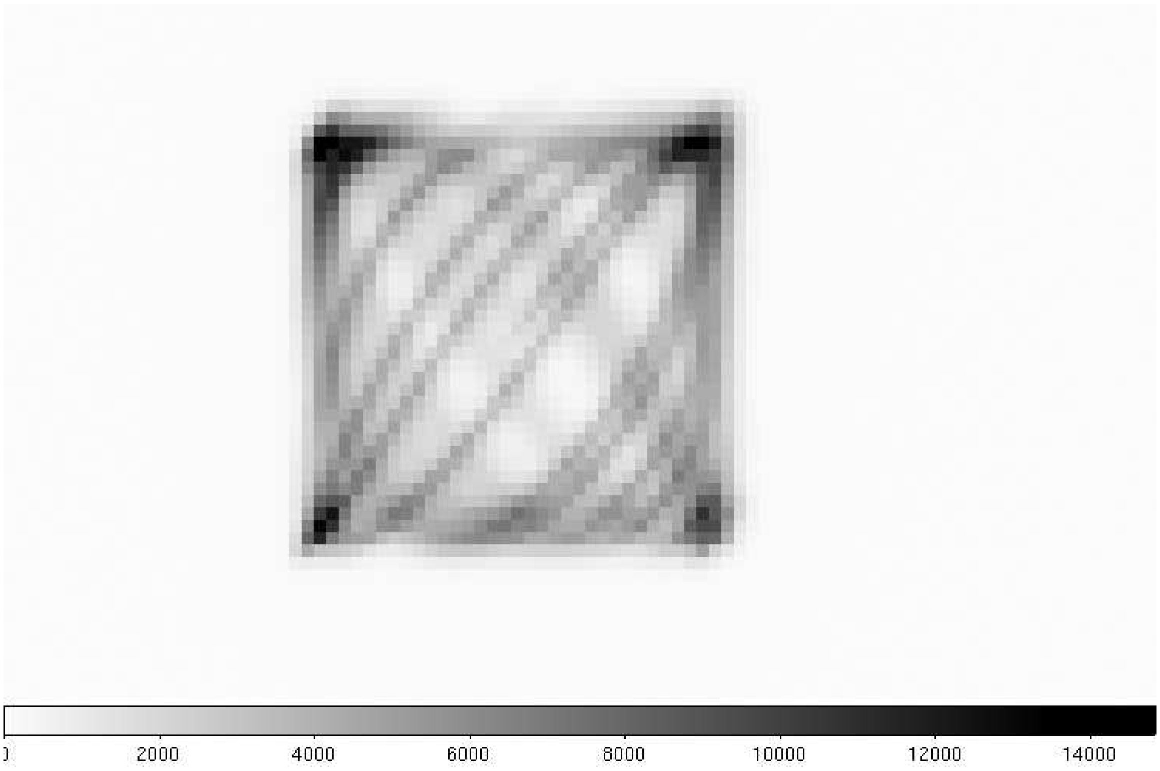


Figure 5: Chip Image of *MARX* simulation. This is the chip coordinate system image of the *MARX* simulation. The peak pixel will be in one of the corners of the dither pattern.

The first step copies just the I3 CCD. The second step creates a CHIP X/Y image. The final step runs a statistics tool that will report the maximum count and the position of that pixel. Figure 5 displays the marx_i3_chipimg.fits file. In the case of no dither, the peak pixel will be the same in the “marx_i3.fits” file as the “marx_i3_chipimg.fits” file. The concern is not the position of the peak pixel, but the value of the counts.

The counts must be properly scaled if the exposure time and/or the model were scaled to create the simulation. This will give the expected counts in the peak pixel.

5.1 Comparison to Mission Dose

To determine if this observation can cause damage to the detector, the expected counts in the peak pixel need to be compared against the mission dose. The values in Table 1 are used to calculate the kilorads that the observation would take and then this value is converted to a percent of the mission dose.

6 Reporting the simulation

After a simulation is completed, a short memo should be written to explain what source model was used, what scalings (if any) where used and the values of the peak pixels and percentages of mission

CCD	MD(krad)	cts/pix : rad/pix
FI	25	135:1
BI	625	100:1

Table 1: Mission Dose limits

dose for each simulation. This memo can be used to discuss any possible damage that could be done to the detector and shared between the ACIS SOT team and the MIT team.