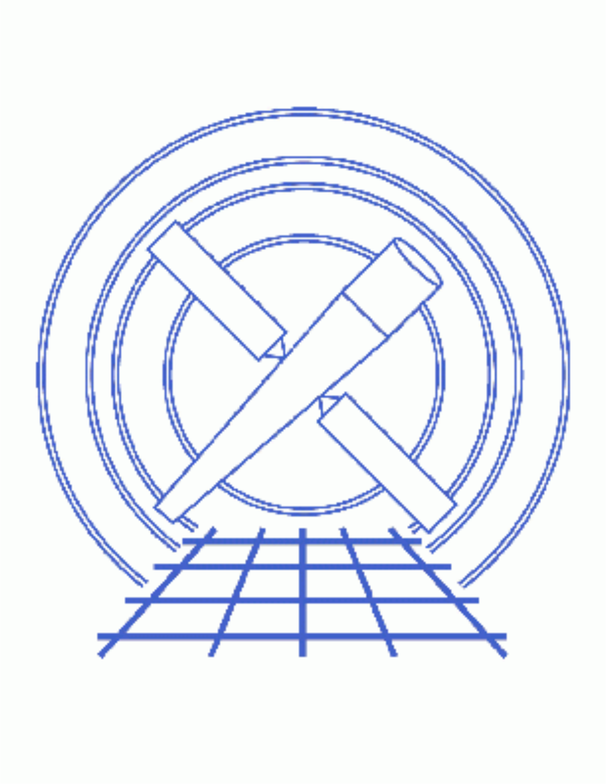
X−Ray Imaging of the Jet in J2310−43



POG Threads

Table of Contents

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Proposal Threads for

1. Thread Overview

Please note that although RPS forms and roll/visibility results have been updated for Cycle 9, this thread uses Cycle 7 versions of tools and calculated values based on Cycle 7 effective area curves. The steps you need to take to complete the thread are the same for this cycle, however you may see slight differences in numerical results. If you have any questions about the results you get by following this thread, please contact the HelpDesk.

J2310−43 is an extreme example of an optically dull AGN. Optically dull AGN are bright in the X−ray and radio, but look like normal elliptical galaxies when viewed optically (no bright nucleus, no emission lines). In this thread we work through a proposal to image the X−ray source in J2310. The radio image shows a bright nuclear source and a jet with 3 knots. We use the Chandra data simulator, MARX, to create a simulated image of J2310−43 using the radio map as input. Our observational goal is to determine an exposure time which enables us to resolve the faint jet from the bright nuclear source. We first assume that the X−ray fluxes in the point source and jet knots are in the same ratio as in the radio. We then create another simulated image, scaling down the flux in the jet knots to be 1% of the total, and show that it is still possible to resolve the bright nuclear source and jet knots. Finally, we consider ways to mitigate pileup.

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2. Preliminary Considerations

- You need to have MARX installed. See the MARX download page for more information.
- You will need to have an application to view FITS event files and an X−Ray spectral fitting program to create input files for MARX. If you are a CIAO user, you already have SAOImageDS9 and Sherpa installed.
- Check for previous observations of J2310−43 using WebChaser. This target was approved for 30 ks in Cycle 3. Additional observations need to be justified.
- Check for other bright sources in the field of view using the Observation Visualizer, which is described in the obsvis ahelp. The ObsVis tool is available in the Proposal toolkit, which is packaged with CIAO. The J2000 coordinates for J2310−43 are: RA=23 10 41.8, Dec=−43 47 34.3

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3. Estimate Total Count Rate, Flux, and Choose Detector

Use COLDEN to estimate the galactic line−of−sight nH to J2310−43. Here we use the coordinates RA=23 10 41.8, Dec=−43 47 34.3 (J2000). The resulting nH returned by COLDEN is 1.57E20.

J2310−43 has a ROSAT PSPC count rate of 0.331 counts/sec. The ROSAT spectrum is characterized by a power law with photon index 2.43. To get the predicted ACIS−S count−rate, run PIMMS (see Groups and Clusters thread" for details of how to run PIMMS) PIMMS gives an estimated ACIS−S count rate of 0.553 counts/sec, with 52% pileup and an ACIS−I count rate of 0.257 counts/sec with 28% pileup. The 0.2−10keV flux is 3.12E−12 ergs/cm^2/s.

The pileup values are large enough to cause concern. In the section on Instrument Configuration we describe how to mitigate pileup for this observation. We choose to use the ACIS−S detector. Even though the pileup is slightly larger for ACIS−S the data will be easier to analyze because the S3 chip has lower CTI.

4. Determine Approximate Exposure Time

The count rate for J2301−43 is 0.553 cts/s. If approximately 1−10% of the flux is in a jet, we will need ~40ks to get 200−2000 counts in the jet. In the next section we use MARX to simulate 2 images to determine whether this exposure time is sufficient to resolve the nuclear source and jet.

5. MARX Simulations

Preparing a Spectrum File for MARX

MARX includes an internal FLAT spectrum model which produces a uniform flux at all energies. More complicated spectral models require the use of the FILE option in which the user provides a spectrum file. This is an ASCII file with two columns; the first in the energy in keV, the second the flux in units of photons/s/cm^2/keV. The overall normalization of the spectrum (in photons/s/cm^2) can either be set by the SourceFlux parameter, or if SourceFlux is set to"−1" the intrinsic normalization of the file will be used. Here we show how to create a spectrum file within Sherpa, and estimate the source flux in photons/s/cm^2. If you want to use XSPEC to create the spectrum file, please refer to the MARX manual for details.

First run CIAO, then Sherpa. The following commands

- define a spectral model of a simple powerlaw convolved with absorption (using XSPEC "wabs" and "powerlaw" functions)
- set the powerlaw photon index to be 2.43 and the nH 0.016 (values appropriate for J2310−43
- create an energy grid for the model −− in this case from 0.1keV to 14 keV in steps of 0.01 keV
- write the source model to an ASCII file named jet.dat

```
sherpa> source = xswabs*xspowlaw
xswabs.nH parameter value [0.1] 0.016
xspowlaw.PhoIndx parameter value [1] 2.43
xspowlaw.norm parameter value [1]
sherpa> dataspace(0.1:14:0.01) histogram
sherpa> fakeit
sherpa> write model jet.dat ascii
Write X−Axis: Bin  Y−Axis: Flux (Counts)
```

We can use the file jet.dat as input to MARX. Note that X and Y Axis units are given incorrectly as Bin and Counts. They are in fact keV and photons/s/cm^2/keV. The normalization of the spectral file is not scaled to the flux of J2310−43, but set to 1. As explained above, we will use the SourceFlux parameter to scale the overall flux.

From section 3, we found that the 0.2−10 keV flux for J2310−43 is 3.14E−12 ergs/cm^2/s. We can use Sherpa to convert this to photons/s/cm^2 (units for the SourceFlux parameter in MARX). First use the show command to view the current model parameters:

```
sherpa> show

Optimization Method: Levenberg-Marquardt
Statistic:           Chi-Squared Gehrels

-----------------
Input data files:
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Data 1: fake.
Total Size: 1390 bins (or pixels)
Dimensions: 1
Total counts (or values): 6

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Defined analysis model stacks:
------------------------------

source 1 = (xswabs * xspowlaw)

-------------------------------------------
Defined source/background model components:
-------------------------------------------

xswabs[xswabs]  (XSPEC model name: absw)  (integrate: off)
    Param   Type      Value        Min        Max                 Units
    -----   ----      -----        ---        ---                 -----
 1     nH thawed    1.6e-02      1e-07         10           10^22/cm^2

xspowlaw[xspowlaw]  (XSPEC model name: pwlw)  (integrate: on)
    Param   Type      Value        Min        Max                 Units
    -----   ----      -----        ---        ---                 -----
 1PhoIndx thawed       2.43         -3         10
 2   norm thawed          1          0      1e+24photons/keV/cm**2/s at 1 keV
```

Now the eflux command to get the flux of the model in ergs/cm^2/s with the normalization set to 1:

```
sherpa> eflux
Flux for source dataset 1: 5.31921e-09 counts
```

Rescale to the flux of J2310−43 (set normalization to 3.146e−12/5.31921e−9=0.0005915) and use the flux command to get the flux in photons/s/cm^2.

```
sherpa> xspowlaw.norm=0.0005915
sherpa> fakeit
sherpa> eflux
Flux for source dataset 1: 3.14631e-12 counts
sherpa> flux
Flux for source dataset 1: 0.00304953 counts
```

Once again, the units are given incorrectly on the command line. The flux in the model is 3.146e−12 ergs/s/cm^2 or 0.00305 photons/s/cm^2.

In the following simulations we make the simplifying assumption that the nuclear source and jet have the same spectral energy distribution.

MARX Simulations with Radio Image as Input

Our observational goal is to map the X−ray emission in J2310−43. We have no a priori way of determining the X−ray structure, but the radio map (J2310_radio.fits) shows a jet. For our first simulation we therefore assume that the X−ray structure follows the radio structure and use the radio image as an input to MARX.

First copy the default MARX parameter file to a file called radio.par. The default marx.par file resides in the directory MARX was installed in ($MARX_DIR).

```
unix% cp $MARX_DIR/marx.par radio.par
```

Now set up the simulation

```
unix% pset radio.par OutputDir=radio
unix% pset radio.par ExposureTime=40000
unix% pset radio.par DetectorType=ACIS−S
unix% pset radio.par SpectrumType=FILE
unix% pset radio.par SpectrumFile=jet.dat
unix% pset radio.par DitherModel=INTERNAL
unix% pset radio.par SourceFlux=0.00305
unix% pset radio.par GratingType=NONE
unix% pset radio.par  SourceType=IMAGE
unix% pset radio.par S−ImageFile=J2310_radio.fits
unix% pset radio.par SourceRA=347.674167
unix% pset radio.par SourceDEC=−43.792861
unix% pset radio.par RA_Nom=347.674167
unix% pset radio.par Dec_Nom=−43.792861
```

Full details of all these parameters are given in the MARX manual. The crucial parameters for this simulation are:

- The output directory is called radio
- the Exposure time is 40ks
- The detector is ACIS−S
- The source spectrum is read from a file
- The name of the spectrum file is jet.dat. Please note that in this simulation the parameter SourceFlux gives the overall flux normalization. The file jet.dat is used for the shape of the input spectrum.
- Use MARX default dither parameters
- The source flux is set to 0.00305 photons/sec/cm^2 (derived from the count rate)
- No grating is used. Note that the parameter file has HETG as the default, so this must be changed for an imaging simulation
- The spatial distribution of the source is read from a FITS file
- The name of the file is J2310_radio.fits
- Source RA and DEC
- Pointing position (in this case the same as the source)
- To use the contamination model in MARX, you need to provide a TSTART when you run marx. TSTART=264038464.18 will produce a MARX simulation with an amount of contaminant absorption projected for the date 2006−05−15T00:00:00, equivalent to the date used to create the ACIS Cycle 07 Responses available on the Chandra proposal planning web page.

Now run the simulation:

```
unix% marx @@radio.par TSTART=264038464.18
MARX version 4.2.0, Copyright (C) 2002−2005 Massachusetts Institute of Technology

        $MARX_DIR/marx/data/hrma/EKCHDOS06.rdb
Reading binary HRMA optical constants:
        $MARX_DIR/marx/data/hrma/iridium.dat
        $MARX_DIR/marx/data/hrma/corr_1.dat
        $MARX_DIR/marx/data/hrma/corr_3.dat
        $MARX_DIR/marx/data/hrma/corr_4.dat
        $MARX_DIR/marx/data/hrma/corr_6.dat
Reading scattering tables

(output truncated)
```

MARX does not output a FITS file. To create a FITS event file called radio.fits from the native MARX files in directory radio:

```

unix% marx2fits radio radio.fits
Examining radio/time.dat
Examining radio/detector.dat
Examining radio/energy.dat
Examining radio/b_energy.dat
Examining radio/xpos.dat
Examining radio/ypos.dat
Examining radio/zpos.dat
Examining radio/xcos.dat
Examining radio/ycos.dat
Examining radio/zcos.dat
Examining radio/xpixel.dat
Examining radio/ypixel.dat
Examining radio/pha.dat
Examining radio/mirror.dat
Examining radio/sky_ra.dat
Examining radio/sky_dec.dat
```

The resulting simulated FITS event file can be found here. It can be viewed using DS9 or other FITS image viewer. From this image we see that the bright point source and jet area clearly resolved. However, we can't be sure that the ratio of flux in the jet to flux in the nuclear point source is the same for the X−ray as it is for the radio. Therefore in the next set of simulations we assess the feasibility of a jet with reduced flux compared to the nuclear source.

MARX Simulations with Point Source Inputs

In this set of simulations we assume that the flux in the jet is only 1% of the nuclear source. We construct an image consisting of a nuclear point source and three point sources representing the knots in the jet. The overall flux in the jet is 0.0000305 photons/sec/cm^2. From the radio image, we see that the approximate peak fluxes in the knots scale as 14:9:9 for knot1:knot2:knot3. Here knot1 is the brightest knot closest to the nuclear source, knot3 the furthest. Assuming that the total flux scales as the peak flux we find knot1 has a flux of 1.31e−5 photons/sec/cm^2, knot2 and knot3 have a flux of 8.84e−6 photons/sec/cm^2. We use the radio image to measure the coordinates of the jet knots. Here is a summary of our composite source:

- Nuclear source, assumed to be point, 99% of total flux=0.003020 photons/sec/cm^2 RA=347.674 DEC=−43.7927
- Knot1, knot closest to nuclear source, flux=1.31e−5 photons/sec/cm^2, RA=347.6743 DEC=−43.7933
- Knot2, middle of jet, flux= 8.84e−6 photons/sec/cm^2, RA=347.6746 DEC=−43.79387
- Knot3, knot furthest from source, flux=8.84e−6 photons/sec/cm^2, RA=347.67489 DEC=−43.79452

To create this composite source we need to run MARX 4 times, once to create the nuclear source and 3 times for each of the knots. We then run the program marxcat to combine the 4 separate images.

The following set of commands copies over the default MARX parameter file to a file point.par, sets the critical parameters for the point source and runs the simulation. Note that unlike the "radio" simulation, we do not input a file for the source spatial distribution. We use the MARX internal POINT source model.

```
unix% cp $MARX_DIR/marx.par point.par
unix% pset point.par  OutputDir=point
unix% pset point.par   ExposureTime=40000
unix% pset point.par  DetectorType=ACIS−S
unix% pset point.par  SpectrumType=FILE
unix% pset point.par  SpectrumFile=jet.dat
unix% pset point.par   DitherModel=INTERNAL
unix% pset point.par  SourceFlux=0.0030789
unix% pset point.par  GratingType=NONE
unix% pset point.par  SourceType=POINT
unix% pset point.par  SourceRA=347.674
unix% pset point.par  SourceDEC=−43.7927
unix% pset point.par  RA_Nom=347.674
unix% pset point.par  Dec_Nom=−43.7927
unix% marx @@point.par TSTART=264038464.18
```

The following set of commands runs the simulation for knot1. Note that here the SourceRA and SourceDEC parameters have changed from the nuclear source simulation to reflect the location of the knot. The pointing direction is the same (RA_Nom and Dec_Nom unchanged).

```
unix% cp $MARX_DIR/marx.par knot1.par
unix% pset knot1.par OutputDir=knot1
unix% pset knot1.par ExposureTime=40000
unix% pset knot1.par DetectorType=ACIS−S
unix% pset knot1.par SpectrumType=FILE
unix% pset knot1.par SpectrumFile=jet.dat
unix% pset knot1.par DitherModel=INTERNAL
unix% pset knot1.par SourceFlux=1.31e−5
unix% pset knot1.par GratingType=NONE
unix% pset knot1.par SourceType=POINT
unix% pset knot1.par SourceRA=347.6743
unix% pset knot1.par SourceDEC=−43.7933
unix% pset knot1.par RA_Nom=347.674
unix% pset knot1.par Dec_Nom=−43.7927
unix% marx @@knot1.par TSTART=264038464.18
```

The parameter files for knot2 and knot3 are very similar to that for knot1. All the parameter files can be found here: knot1, knot2, knot3.

The composite image can now be created using the following commands:

```
unix% marxcat point knot1 knot2 knot3 jet
unix% marx2fits jet jet.fits
```

This combines the simulations in the directories point, knot1, knot2, knot3 into a directory jet. The command marx2fits then creates a FITS events file jet.fits from the native MARX files in the jet directory.

Inspection of this simulated image shows that the nuclear source and knots are still well resolved. Note that in order to view the knots, you will most likely need to use a log scale. You may notice other features in the image, such as streaks or bands. These are residual features of the input radio image and are not X−Ray events.

To obtain a more quantitative measure of the significance of the detection of the knots the user might want to run a source detection program such as celldetect. In addition, the jet might have some extended emission, and there might be extended emission from hot gas in the cluster. It might be useful to add an additional model component to simulate extended emission and show that it is still possible to detect the jet.

It is important to note that we have not included instrumental background in our simulations. To demonstrate why, we start by stating that in this thread, we have chosen to use a 1/8 subarray on the S3 chip (these choices are dicussed in the next section). Estimates of the background as a function of energy band are provided in the ACIS total background section of the POG. A table gives the total background rate for the S3 BI chip to be 0.74 counts/sec/chip, for the 0.3−10keV energy range, multiplied by the exposure time (40000 s), we find there will be 29600 cts over the entire S3 chip. We divide this by 8, to get that there will be 3700 cts over the 1/8 subarray. We scale this by a ratio of the jet are to subarray area to find the number of counts of background covering the area of the jet.

The subarray will contain 1024 pixels in each of 128 rows; converting this area to arcseconds results in an area of 30033.36 arcsec^2 (there are .492 arcsec/pixel). Since the jet only covers an area of about 10 arcsec by 3 arcsec, or 30 arcsec^2, we want to scale the background counts to this area. Consequently, we multiply the 3700 counts in the entire subarray by the ratio 30 [arcsec^2]/30033.36 [arcsec^2] to find there are 3.70 background counts over the same area as the jet. The jet contains in excess of 200 counts. If the background is greater than about 10% of the jet flux, the background counts should be included. In this case, the background is only about 2% of the jet flux, and therefore does not need to be included in our simulations.

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6. Instrument Configuration

The instrument configuration is driven by the need to reduce pileup and image the jet with the highest possible spatial resolution. To minimize pileup we use a 1/8 subarray −− restrict the region of the CCD from which data will be taken. This has the consequence of reducing the frame time (exposure time) from 3.2s to 0.4s and hence the probability that one or more photons will be detected in the same frame. It also has the consequence of lowering the efficiency with which data is taken, because 3.2s is required to read out the 6 chips of the ACIS−S array (hence there will be a time, approximately 3.2−0.4=2.8s, when no data are taken). The readout time depends on the number of chips turned on. The more chips turned on, the longer the readout time. In order to increase the efficiency we choose to turn off all chips but S3. This reduces our readout time to 0.48 s. The resulting RPS target form is shown here.

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5. Thread Summary

Our observational goal is to obtain an X−ray image of the active galaxy J2310−43. The radio map of this source shows a jet, and our simulations are driven by the need to determine an exposure time that will allow us to resolve a faint X−ray jet near a bright nuclear core. Our first simulation assumes that the X−ray emission follows the radio emission, and we use the radio image as input to the Chandra data simulator, MARX. Our next simulation assumes that the flux in the X−ray jet is only 1% that of the bright nuclear core. Here we construct a composite image of the core and jet by combining several MARX simulations. We find that 40ks will allow us to detect the jet even in the case where the flux in the jet is 1% that of the core.

J2310−43 is a bright source and is likely to be heavily piled. We mitigate pileup by choosing a 1/8 subarray to reduce the CCD frametime. This decreases the observing efficiency because 3.2 s is still required to readout all 6 ACIS−S chips. We therefore choose to turn on only S3.

History

24 Feb 2004	Initial Version
01 Feb 2005	Updated for Cycle 7
15 Dec 2005	Updated for Cycle 8
15 Dec 2006	Updated for Cycle 9

URL: http://cxc.harvard.edu/pog/threads/jet/ Last modified: 15 December 2006