Using FTOOLS and Fv for Data Analysis: Chandra

This tutorial is designed to build upon your current knowledge of FTOOLS and to also provide an introduction to the imaging program *Fv*. It is **strongly recommended** that you complete the main tutorial, *FTOOLS for Windows 95/98/NT*, before beginning this tutorial, as this tutorial will be difficult to understand without the background that *FTOOLS for Windows 95/98/NT* provides. For troubleshooting, check out the Troubleshooting Guide located both at the end of this tutorial and on the FTOOLS webpage. It contains useful tips, known problem areas, and solutions to common questions. In addition, the words highlighted in blue throughout this tutorial can be found, along with many other terms, in the glossary compiled by the Chandra X-ray Observatory Center. Just go to **http://chandra.harvard.edu/resources/glossaryA.html.**

The tutorial is separated into three main sections. In the Part I, we will be using FTOOLS and *Fv* to examine Quasar 3c273. In Part II, we will analyze the jet associated with this source. Finally, in Part III, we will use what we have learned to study the x-ray source Cassiopeia A.

Quasar is short for Quasi-stellar radio source. Quasars emit massive amounts of radio energy; they are the most distant and energetic objects that can be observed with our current instrumentation. However, while some quasars are brighter than many galaxies put together, others are smaller than our own Milky Way galaxy. 3c273 is of particular significance because it was one of the first quasars to be identified. It's name comes from its identification in the 3rd Cambridge catalog as the 273rd radio source identified. It lies approximately 3 billion light-years away, and at 5 trillion times the brightness of the sun, 3c273 is the brightest quasar known. (Check out **http://chandra.harvard.edu/xray_sources/3c273/3c273_2.html** for more information on the unique importance of 3c273 to astronomers. You'll find optical and x-ray images, too!)

Part I: Compiling Light Curves and Spectra

- Double click on the FTOOLS icon to setup the FTOOLS environment. Once the BASH window is ready and you have been given a prompt, create a folder for your 3c273 data by typing **mkdir 3c273**. (Make sure that you are in the general FTOOLS directory before you do this.)

- Open Netscape and go to **http://asc.harvard.edu**.

- At the top of the page, you'll see various buttons: click on the one that says **Archive**.

- A page will open that says "Welcome to the Chandra Data Archive". You'll see a list of links: click on **Search and Retrieve**.

- The next page will be "Search and Retrieval from the Chandra Data Archive". If you scroll down the page a bit, you will see **Provisional Web Interface for Browsing and Retrieval** in blue. Click on this link.

- You have now entered the Chandra Data Archive. Scroll down to "View Information About *Public Observations Available for Retrieval from the Archive…"*. Below this heading there will be four buttons. Click on **Sort by RA & Dec**.

- Upon scrolling down the next page, you'll see a long table of observations. Find the observation whose ObsId is **1711**, whose Object Name is **3C 273**, and whose RA (**r**ight **a**scension) is **12:29:07**. Click on **1711**.

- You'll then be returned to the Chandra Data Archive page that you were at earlier. This time, however, if you scroll down, you'll see that **1711** has been entered into the **Enter ObsId** box. Scroll down a little bit more and make sure that the **fully processed science products** box is checked, inside the Product Categories box. Click on **Browse Archive and Retrieve Data Products**.

- You will receive a list of four files. Upon scrolling down further, you'll see the instructions "Select files to retrieve from archive". In the white box below, click on the first file, hold down the shift key, and then click on the fourth file. This will allow you to select all four files. With all four files selected, click on **RETRIEVE from Archive**.

- The next page will give you the name of your tar file. After copying this filename down for future reference, find the sentence that says "Or you may download it directly **<u>here</u>**". Click on **<u>here</u>**.

- A window will appear which asks you whether you'd like to save the file to disk or open it. Select **Save to disk** and then click **OK**.

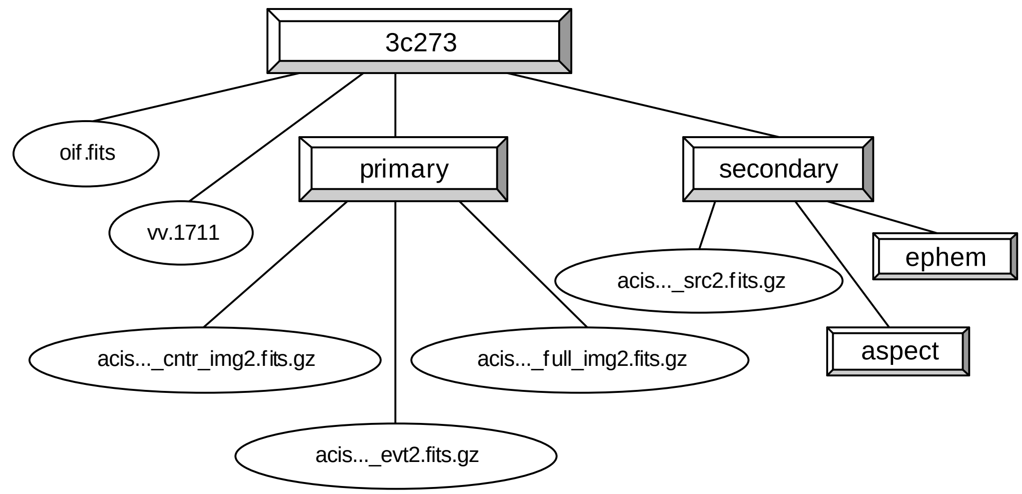
- Next, a window entitled "Save As…" will open. In the **File name:** field, the name of your tar file will already be entered. In the **Save in:** field, make sure that you are saving the tar file into your 3c273 folder. Once this is done, click **Save**.

- Minimize Netscape and then return to your BASH window.

- At the prompt, use the commands you know to enter the 3c273 directory. Once you are in this directory, type **ls** to view its contents. You will see the file you downloaded. (It should look something like *retrieve_1711_26079.tar*, but the last five numbers may be different.)

- Type **tar xvf <filename.tar>**, replacing **<filename.tar>** with the name of the file you downloaded. This will untar the data and save it into the directory 3c273.

Figure 1



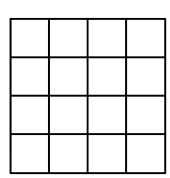
- When the untarring is complete, a directory structure similar to the one above will have been created. (Directories are shown in boxes, and filenames are in ovals.) The last step is to gunzip the files. We are only concerned with *acisf01711N001_evt2.fits.gz* for now, so get into the 'primary' directory by typing **cd primary**. Then type **gunzip acisf01711N001_evt2.fits.gz** to gunzip the file.

- Once you are given a prompt again, type **ls**. You should see three files, one of which is **acisf01711N001_evt2.fits**. This file is now ready for analysis.

- At the BASH prompt, type **f2dhisto acisf01711N001_evt2.fits**. You will be asked for a variety of information:

  - *Name of output FITS file []:* **firstout** (make sure that this filename does not already exist.
  - *X BINSIZE [INDEF]:* **4**
  - *Y BINSIZE [INDEF]:* **4**
  - *Name of x column to generate histogram [X]:* **X**
  - *Name of y column to generate histogram [Y]:* **Y**
  - *Enter the X-RANGE(Eg: 10.0,20.0)[INDEF,INDEF]:* **3000.0,6000.0**
  - *Enter the Y-RANGE(Eg: 10.0,20.0)[INDEF,INDEF]:* **3000.0,6000.0**

  ('Binsize' refers to the shrinking of the data into something like a summary of its original form. In an image, every place that a photon ends up represents one spot in the sky. By 'binning' the data in 4's, you are averaging 4 adjacent sky positions (or a total of 16 points) at a time, as in the following diagram. The X-RANGE and Y-RANGE represent the area in which almost all of the parts of the usable image are located.)



- FTOOLS will state a summary of what you entered and then return the BASH prompt. At this point, find the ***Fv*** icon on your desktop (shown below) and double-click on it.

- Multiple windows will open. Find the one labeled 'fv: File Dialog'. You'll see a list of files and directories under 'Contents': you want to find the output file you just created, **firstout**. Double-click on **3c273/**, then on **primary/**. You should then see four filenames, one of which is **firstout**. Click on **firstout**, and then click on the 'Open' button.

- Another window will pop up, labeled 'fv: Summary of firstout in C:/ftools/3c273/primary'. Click on the 'Image' button under the 'View' heading. (***Note:*** *You may get an error message saying that Fv is unable to find a file. If this happens, exit Fv (close ALL of its windows) and then reopen Fv by double-clicking on the icon.)*

- A window will open that contains a grid on which your image is displayed. Move the window so that it is as close to the top of your screen as possible. Then, using the zoom button, zoom in twice. You'll see the blue box around the picture in the upper right hand corner get smaller. Click on the blue box and drag it so that it is centered on the image. (The image should look something like a small blob right now.) Once the image is in the center of the blue box, zoom in two more times.

- Using the scroll-bar on the right side of the grid, scroll so that you can see the entire image. Place the cursor (without clicking) on the center of the circular part of the image. Look at the box in the upper left hand corner, labeled 'Image Pixel'. It should contain numbers close to (278, 236). Copy down these numbers on a piece of paper and then close all of the Fv windows.

- Back in your BASH terminal, type **f2dhisto <filename>**, and again replace **<filename>** with **acisf01711N001_evt2.fits**.

- You will be prompted for the same information as before, except this time your answers will be slightly different:

  - *Name of output FITS file[firstout]:* **output2** (Again, make sure that this file name doesn't already exist.)
  - *X BINSIZE [4]:* **1**
  - *Y BINSIZE [4]:* **1**
  - *Name of x column to generate histogram [X]:* **X**
  - *Name of y column to generate histogram [Y]:* **Y**

- X-RANGE and Y-RANGE: For this information, you need to do some calculations. For the X-RANGE, you must first correct for the binsize of 4 from earlier. To do this, multiple the X value from your ‘Image Pixel’ coordinates (~278) by 4. Add this number to your initial starting value for X, 3000. This should give you a number similar to 4112. Your X-RANGE needs to encompass about 100 on either side of this number. Thus, enter **4000.0,4200.0** for the X-RANGE.

  For the Y-RANGE, follow the same process. Multiply the Y value from your ‘Image Pixel’ coordinates (~236) by 4 and then add this to your initial starting value for Y, 3000. This should give you a number close to 3944. Therefore, enter **3850.0,4050.0** for your Y-RANGE.

- FTOOLS will summarize the information it will be entering into **f2dhisto**, and then return the BASH prompt. Now, find the Fv icon on your desktop and double-click on it to begin Fv.

- In the ‘File Dialog’ window, find **output2**, select it and click the ‘Open’ button. (*Hint*: Follow the path 3c273/primary/output2.)

- Another window will pop up, labeled ‘fv: Summary of output2 in C:/ftools/3c273/primary’. Like before, click on the ‘Image’ button under the ‘View’ heading.

- A window will open which contains your image of 3c273 on a grid. Move the window as close to the top of your screen as possible and use the scroll bar on the right hand side to scroll so that you can view the entire image. Use the ‘Zoom In’ button to zoom in twice. Move the blue box in the upper right hand corner so that it is centered on the circular part of the source. (The other part of the image is a jet. We will be analyzing that part later.)

- In the upper left hand corner of the window, there are four menu headings. Click on ‘Edit’ and then select ‘Region Files’. A window labeled ‘Edit Region’ will open. Select ‘Pixels’ underneath the scroll bar.

- Next, go back to the window containing your image. Right click on the center of the main source and, holding the mouse button down, pull the cursor away from the center. This will drag a circle around the source. Make the circle big enough to encompass the entire main source, and then release the mouse button. Clicking and holding the left mouse button anywhere inside the circle allows you to then move the circle if you wish.

- Return to the ‘Edit Region’ box. Copy onto a piece of paper the numbers that you see there. (They will look something like **Circle(109.05, 91.8499, 13.3185)**.) You will be using these in the next step. Once you have recorded these values, you can close all of the Fv windows and return to your BASH terminal.

- At the prompt, type **fselect**. You will be asked for the following information:
  - *Name of FITS file and [ext#][]*: **acisf01711N001_evt2.fits**
  - *Name of output FITS file[]*: **region1.fits**

- Selection Expression[]: This is where you will use the numbers you copied down from the 'Edit Region' box. First, add the starting X value that you entered into the last **f2dhisto** method (4000), to the first number in the **Circle** expression from the 'Edit Region' box (~109.05). Next, add the starting Y value that you entered into **f2dhisto** (3850) to the second number in the **Circle** expression (~91.8499). Record these two values on a piece of paper.

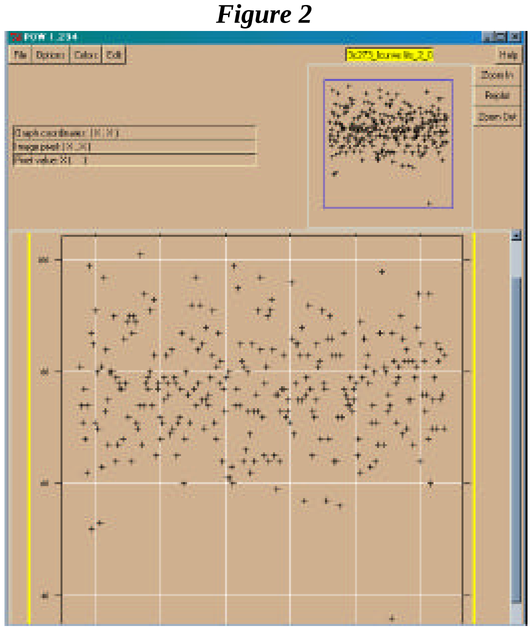
- Enter these values for the *Selection Expression[]* **EXACTLY** as follows: (The only difference might be the actual values, which may differ by a small amount.) **"circle(4109.05,3941.8499,13.3185,x,y)"**

- At the next prompt, type **fhisto region1.fits 3c273_lcurve.fits time 100** (This represents the input file, the output file, the keyword and the binsize in seconds, respectively.) FTOOLS will repeat the information you just entered, and then return a prompt. Go back to your desktop, and open Fv.

- Find the file you just created, **3c273_lcurve.fits** (using the path 3c273/primary/3c273_lcurve.fits), select it and click on the 'Open' button.

- In the 'Summary….' window that appears, click on 'Plot' under the 'View' heading. Another window will pop up, labeled 'Select Plot Columns'. On the left hand side, click on 'X'. Then click on the X button under the 'Axis' heading. Go back to the left hand column, click on Y and then click on the Y button under the 'Axis' heading. Finally, click 'Go'. A window will appear containing your plot, a light curve for 3c273! (See Figure 2)

Figure 2



♦ Next, we will obtain the plot of a spectrum. Start by closing all of the Fv windows. Then, in your BASH window, type:
fhisto region1.fits 3c273_spectrum.fits energy 10 lowval=100 highval=10000
(This represents your input file, output file, keyword, number of channels binned and the energy range in electron volts (eV) , respectively.)

♦ Again, FTOOLS will repeat your inputs and return a prompt. Go to your desktop and open Fv. Find the output file you just created, **3c273_spectrum.fits**, select it and click the 'Open' button. (3c273/primary/3c273_spectrum.fits)

♦ In the 'Summary….' window that appears, click on 'Plot' under the 'View' heading. A window labeled 'Select Plot Columns' will pop up. Like before, click on X in the left hand column and then on the X button under the 'Axis' heading. Click on Y in the left hand column and then on the Y button under the 'Axis' heading. Finally, click on 'Go'.

♦ A window will appear, containing an image. This is a plot of a spectrum of 3c273! (It should look similar to Figure 3.)

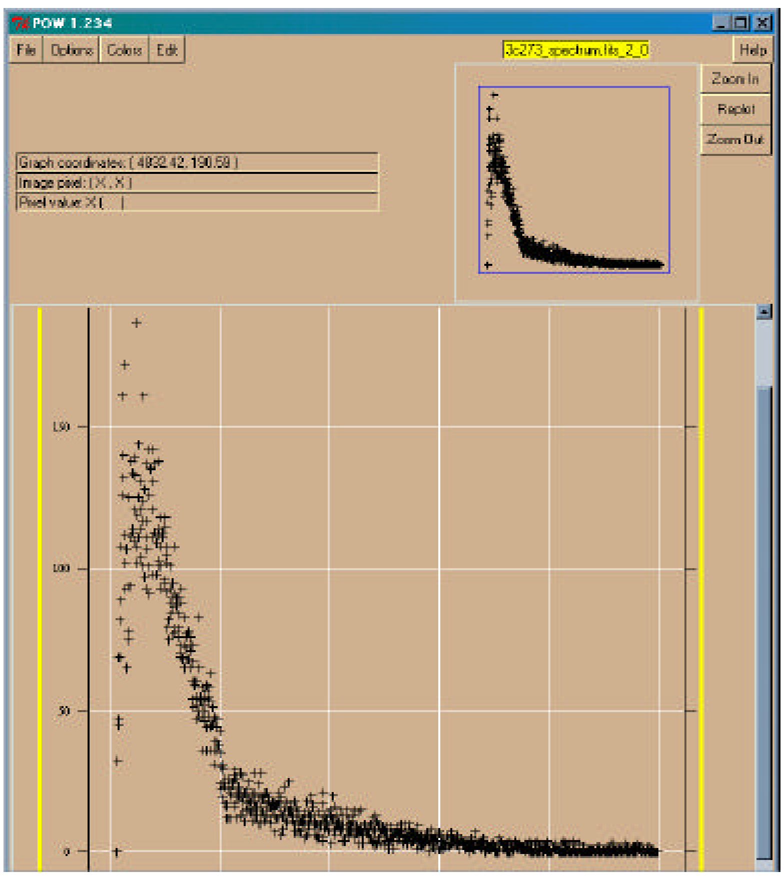


Figure 3

Part II: The Jet

- In this part of the tutorial, we will be examining the jet of 3c273 in the same way that you analyzed the main source. Close any Fv windows you may still have open from Part I. Reopen Fv.

- We will begin with the unbinned data file, **output2**. In the 'File Dialog' window, find **output2**, select it and click the 'Open' button. (*Hint*: Follow the path 3c273/primary/output2.)

- Another window will pop up, labeled 'fv: Summary of output2 in C:/ftools/3c273/primary'. Like before, click on the 'Image' button under the 'View' heading.

- A window will open which contains your image of 3c273 on a grid. Move the window as close to the top of your screen as possible and use the scroll bar on the right hand side to scroll so that you can view the entire image. Use the 'Zoom In' button to zoom in three times. Move the blue box in the upper right hand corner so that it is centered on the jet.

- In the upper left hand corner of the window, there are four menu headings. Click on 'Edit' and then select 'Region Files'. A window labeled 'Edit Region' will open. Select 'Pixels' underneath the scroll bar.

- Next, go back to the window containing your image. Right click on the approximate center of the jet and, holding the mouse button down, pull the cursor away from the center. This will drag a circle around the jet. Make the circle big enough to encompass the entire jet, and then release the mouse button. Adjust the circle if necessary.

- Return to the 'Edit Region' box. Copy onto a piece of paper the numbers that you see there. (They will be similar to **Circle(131.924, 66.8295, 12.5408)**.) You will be using these in the next step. Once you have recorded these values, you can close all of the Fv windows and return to your BASH terminal.

- Make sure that you are in the **3c273/primary/** directory. At the prompt, type **fselect**. You will be asked for the following information:

  - *Name of FITS file and [ext#][]*: **acisf01711N001_evt2.fits**
  - *Name of output FITS file[]*: **jetreg.fits**

- <u>Selection Expression[]</u>: This is where you will use the numbers you copied down from the 'Edit Region' box. First, add the starting X value that you entered into the **f2dhisto** method earlier (4000), to the first number in the **Circle** expression from the 'Edit Region' box (~131.924). Next, add the starting Y value that you entered into

f2dhisto (3850) to the second number in the **Circle** expression (~66.8295). Record these two values on a piece of paper.

- Enter these values for the *Selection Expression[]* **EXACTLY** as follows: (The only difference might be the actual values, which may differ by a small amount.) **"circle(4131.924,3916.8295,12.5408,x,y)"**

- At the next prompt, type **fhisto jetreg.fits 3c273_jet_lcurve.fits time 100** (This represents the input file, the output file, the keyword and the binsize in seconds, respectively.) FTOOLS will repeat the information you just entered, and then return a prompt. Go back to your desktop, and open Fv.

- Find the file you just created, **3c273_jet_lcurve.fits** (using the path 3c273/primary/3c273_jet_lcurve.fits), select it and click on the 'Open' button.

- In the 'Summary….' window that appears, click on 'Plot' under the 'View' heading.

- Another window will pop up, labeled 'Select Plot Columns'. On the left hand side, click on 'X'. Then click on the X button under the 'Axis' heading. Go back to the left hand column, click on Y and then click on the Y button under the 'Axis' heading. Finally, click 'Go'. A window will appear containing your plot, a light curve for the jet of 3c273! (See Figure 4)

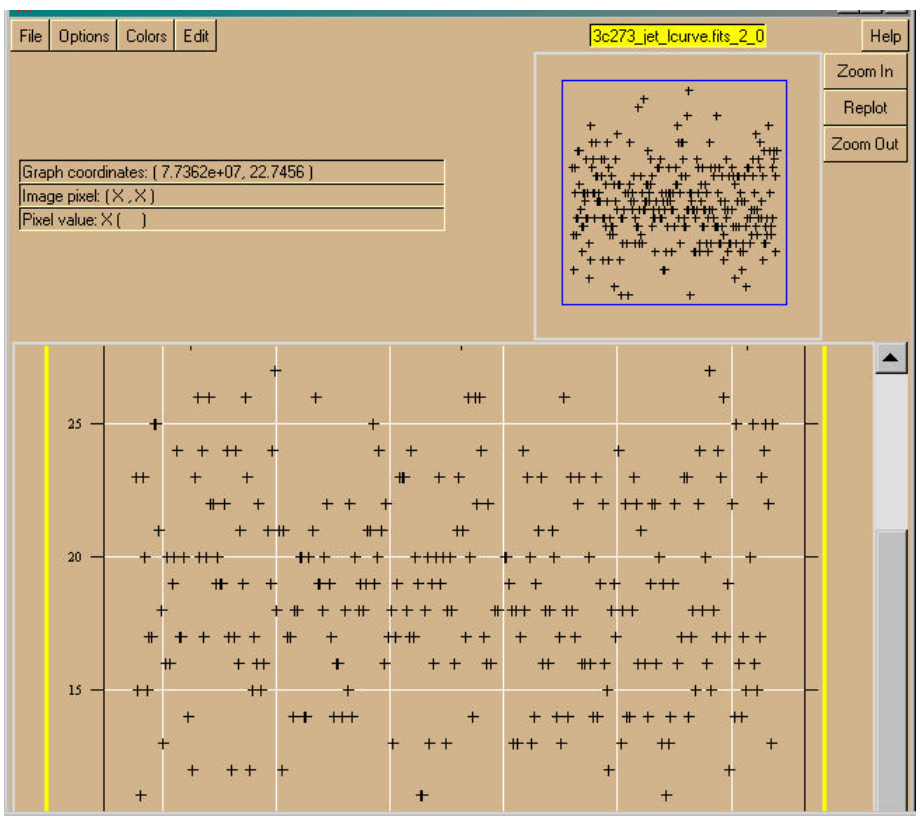


Figure 4

♦ Next, we will obtain a plot of the spectrum. Start by closing all of the Fv windows. Then, in your BASH window, type:
fhisto jetreg.fits 3c273_jet_spectrum.fits energy 10 lowval=100 highval=10000

♦ Again, FTOOLS will repeat your inputs and return a prompt. Go to your desktop and open Fv. Find the output file you just created, **3c273_jet_spectrum.fits**, select it and click the 'Open' button. (3c273/primary/3c273_jet_spectrum.fits)

♦ In the 'Summary….' window that appears, click on 'Plot' under the 'View' heading. A window labeled 'Select Plot Columns' will pop up. Like before, click on X in the left hand column and then on the X button under the 'Axis' heading. Click on Y in the left hand column and then on the Y button under the 'Axis' heading. Finally, click on 'Go'.

♦ A window will appear, containing an image. This is a plot of a spectrum of the jet! (See Figure 5.) You can use the scroll bar to try to view more of the image. Also, clicking on 'Edit' and then 'Choose Graph Size' will allow you to set the dimensions of the graph.

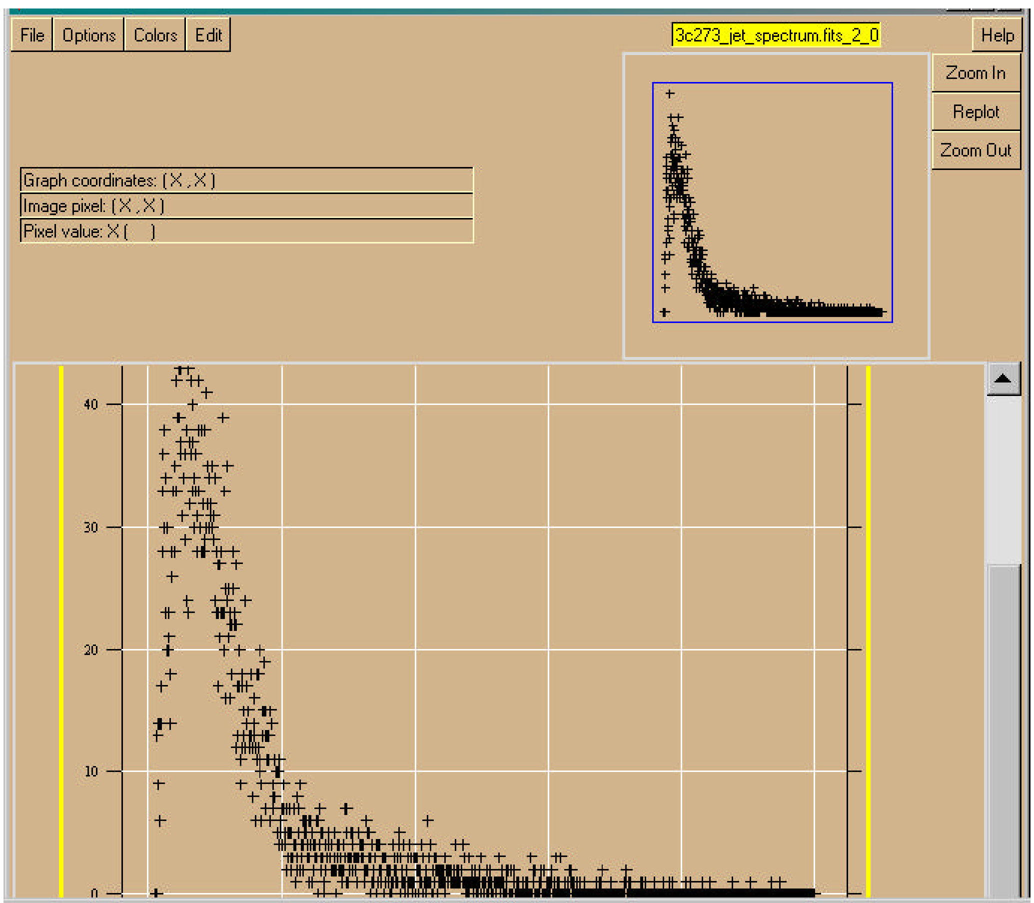
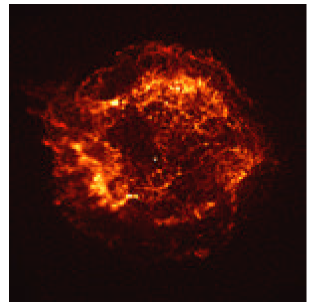


Figure 5

Part III: Cassiopeia A



Cassiopeia A (Cas A) is a 320-year-old supernova remnant. A massive star exploded, ejecting a shell of matter that created a bubble of gas 10 light years in diameter with a temperature of about 50 million degrees. As this hot gas expands, (and it will continue to do so for thousands of years), it produces x-rays. Astronomers can use this data to find x-ray spectra and then use these spectra to determine the chemical makeup of Cas A. The image to the right was made with the Advanced CCD Imaging Spectrometer (ACIS) over the span of 5,000 seconds. The outer shock wave can be compared to a sonic boom. (Check out **http://chandra.harvard.edu/press/casfact.html** for more about supernovae and Cas A.)

- Begin by closing all of the Fv windows you have open from the previous sections. In your BASH window, type **cd /ftools** to get back to your main directory. Create a folder for your Cas A data by typing **mkdir cas_a**.

- Open Netscape and go to **http://asc.harvard.edu**.

- At the top of the page, you'll see various buttons: click on the one that says **Archive**.

- A page will open that says "Welcome to the Chandra Data Archive". You'll see a list of links: click on **Search and Retrieve**.

- The next page will be "Search and Retrieval from the Chandra Data Archive". If you scroll down the page a bit, you will see **Provisional Web Interface for Browsing and Retrieval** in blue. Click on this link.

- You have now entered the Chandra Data Archive. Scroll down to "View Information About *Public Observations Available for Retrieval from the Archive…*". Below this heading there will be four buttons. Click on **Sort by RA & Dec**.

- Upon scrolling down the next page, you'll see a long table of observations. Find the observation whose ObsId is **1512**, whose Object Name is **CAS A, CHIP S2** and whose RA (**r**ight **a**scension) is **23:22:46**. Click on **1512**.

- You'll then be returned to the Chandra Data Archive page that you were at earlier. This time, however, if you scroll down, you'll see that **1512** has been entered into the **Enter ObsId** box. Scroll down a little bit more and make sure that the **fully processed science products** box is checked, inside the Product Categories box. Click on **Browse Archive and Retrieve Data Products**.

- You will receive a list of four files. Upon scrolling down further, you'll see the instructions "**Select files to retrieve from archive**". In the white box below, click on the first file, hold down the shift key, and then click on the fourth file. This will allow you to select all four files. With all four files selected, click on **RETRIEVE from Archive**.

- The next page will give you the name of your tar file. After copying this filename down for future reference, find the sentence that says "Or you may download it directly **here**". Click on **here**.

- A window will appear which asks you whether you'd like to save the file to disk or open it. Select **Save to disk** and then click **OK**.

- Next, a window entitled "Save As…" will open. In the **File name:** field, the name of your tar file will already be entered. In the **Save in:** field, make sure that you are saving the tar file into your **cas_a** folder. Once this is done, click **Save**.

- Minimize Netscape and return to your BASH window.

- At the prompt, use the commands you know to make your way to the cas_a directory. Once you are in this directory, type **ls** to view its contents. You will see the file you downloaded. (It should look something like *retrieve_1512_7166.tar*, but the last four numbers may be different.)

- Type **tar xvf <filename.tar>**, replacing **<filename.tar>** with the name of the file you downloaded. This will untar the data and save it into the directory cas_a.

- When the untarring is complete, a directory structure similar to the one set up for 3c273 will be created. The last step is to gunzip the files. We are only concerned with *acisf01512N001_evt2.fits.gz* for now, so enter the **primary**/ directory by typing **cd primary**. Then type **gunzip acisf01512N001_evt2.fits.gz** to gunzip the file.

- Once you are given a prompt again, type **ls**. You should see three files, one of which is **acisf01711N001_evt2.fits**. This file is now ready for analysis.

- At the BASH prompt, type **f2dhisto acisf01512N001_evt2.fits**. You will be asked for a variety of information:

  - *Name of output FITS file []:* **casfirstout** (make sure that this filename does not already exist.
  - *X BINSIZE [INDEF]:* **4**
  - *Y BINSIZE [INDEF]:* **4**
  - *Name of x column to generate histogram [X]:* **X**
  - *Name of y column to generate histogram [Y]:* **Y**
  - *Enter the X-RANGE(Eg: 10.0,20.0)[INDEF,INDEF]:* **3000.0,6000.0**
  - *Enter the Y-RANGE(Eg: 10.0,20.0)[INDEF,INDEF]:* **3000.0,6000.0**

- FTOOLS will state a summary of what you entered and then return the BASH prompt. At this point, find the ***Fv*** icon on your desktop and double-click on it.

- Multiple windows will open. Find the one labeled ‘fv: File Dialog’. You’ll see a list of files and directories under ‘Contents’: you want to find the output file you just created, **casfirstout**. Double-click on **cas_a/**, then on **primary/**. You should then see four filenames, one of which is **casfirstout**. Click on **casfirstout**, and then click on the ‘Open’ button.

- Another window will pop up, labeled ‘fv: Summary of casfirstout in C:/ftools/cas_a/primary’. Click on the ‘Image’ button under the ‘View’ heading. (***Note:*** *You may get an error message saying that Fv is unable to find a file. If this happens, exit Fv (close ALL of its windows) and then reopen Fv by double-clicking on the icon.)*

- A window will open that contains a grid on which your image is displayed. Move the window so that it is as close to the top of your screen as possible. Then, using the ‘Zoom In’ button, zoom in twice. Then, click and drag the blue box in the upper right hand corner so that it is centered on Cas A. Release the mouse button.

- Using the scroll-bar on the right side of the large grid, scroll so that you can see as much of the image as possible. Place the cursor (without clicking) on the center of the image. Look at the box in the upper left hand corner, labeled ‘Image Pixel’. It should contain numbers close to (116, 167). Copy down these numbers on a piece of paper and then close all of the Fv windows.

- Back in your BASH terminal, type **f2dhisto acisf01512N001_evt2.fits**.

- You will be prompted for the same information as before, except this time your answers will be slightly different:

  - *Name of output FITS file[firstout]:* **casoutput2** (Again, make sure that this file name doesn’t already exist.)
  - *X BINSIZE [4]:* **1**
  - *Y BINSIZE [4]:* **1**
  - *Name of x column to generate histogram [X]:* **X**
  - *Name of y column to generate histogram [Y]:* **Y**

- <u>X-RANGE and Y-RANGE</u>: For this information, you need to do some calculations. For the X-RANGE, you must first correct for the binsize of 4 from earlier. To do this, multiple the X value from your ‘Image Pixel’ coordinates (~116) by 4. Add this number to your initial starting value for X, 3000. This should give you a number similar to 3464. Your X-RANGE needs to encompass about 100 on either side of this number. Thus, enter **3360.0,3560.0** for the X-RANGE.

For the Y-RANGE, follow the same process. Multiply the Y value from your ‘Image Pixel’ coordinates (~167) by 4 and then add this to your initial starting value for Y, 3000. This should give you a number close to 3668. Therefore, enter **3560.0,3760.0** for your Y-RANGE.

- FTOOLS will summarize the information it will be entering into **f2dhisto**, and then return the BASH prompt. Now, find the Fv icon on your desktop and double-click on it to begin Fv.

- In the ‘File Dialog’ window, find **casoutput2**, select it and click the ‘Open’ button. (*Hint*: Follow the path cas_a/primary/casoutput2.)

- Another window will pop up, labeled ‘fv: Summary of casoutput2 in C:/ftools/cas_a/primary’. Like before, click on the ‘Image’ button under the ‘View’ heading.

- A window will open which contains your image of Cas A on a grid. However, the image is too big! To fit the entire image on the grid, you need to go back and try a different X-RANGE and Y-RANGE. Close all Fv windows and return to your BASH window. Again, type **f2dhisto acisf01512N001_evt2.fits** at the prompt. This time, enter **casout** for the output filename, **1** for each binsize, **X** and **Y** for the column names; finally, try **3100.0,3800.0** for the X-RANGE and **3250.0,3950.0** for the Y-RANGE.

- Once a prompt is returned, find the Fv icon on your desktop and double-click on it to open Fv.

- In the ‘File Dialog’ window, find **casout**, select it and click the ‘Open’ button.

- Another window will pop up, labeled ‘fv: Summary of casout in C:/ftools/cas_a/primary’. Like before, click on the ‘Image’ button under the ‘View’ heading.

- This time when the grid opens, you should see that the image just about fits on the grid. This is sufficient, but you can go back and make the grid slightly larger if you wish.

- In the upper left hand corner of the window, there are four menu headings. Click on ‘Edit’ and then select ‘Region Files’. A window labeled ‘Edit Region’ will open. Select ‘Pixels’ underneath the scroll bar.

- Next, go back to the window containing your image. Right click on the center of the image and, holding the mouse button down, pull the cursor away from the center. This will drag a circle around Cas A. Make the circle big enough to encompass the entire supernova, and then release the mouse button. Clicking and holding the left mouse button anywhere inside the circle allows you to then move the circle if you wish.

- Return to the 'Edit Region' box. Copy onto a piece of paper the numbers that you see there. (They will look something like **Circle(370.1, 419.1, 309.176)**.) You will be using these in the next step. Once you have recorded these values, you can close all of the Fv windows and return to your BASH terminal.

- At the prompt, type **fselect**. You will be asked for the following information:

  - *Name of FITS file and [ext#][]*: **acisf01512N001_evt2.fits**
  - *Name of output FITS file[]*: **cas_a_reg.fits**

- Selection Expression[]: This is where you will use the numbers you copied down from the 'Edit Region' box. First, add the starting X value that you entered into the last **f2dhisto** method (3100), to the first number in the **Circle** expression from the 'Edit Region' box (~370.1). Next, add the starting Y value that you entered into **f2dhisto** (3250) to the second number in the **Circle** expression (~419.1). Record these two values on a piece of paper.

- Enter these values for the *Selection Expression[]* **EXACTLY** as follows: (The only difference might be the actual values, which may differ by a small amount.) **"circle(3470.1,3669.1,309.176,x,y)"**

- When a prompt is returned (*Note: processing the last step may take awhile)*, type **fhisto cas_a_reg.fits cas_a_lcurve.fits expno 1** (The first two parts are the input file and output file, respectively. The third piece of information, the keyword **expno**, is the exposure number for the observation. Finally, the last part, **1**, is the binsize. Specifically, **1** indicates that every exposure interval is plotted separately.) FTOOLS will repeat the information you just entered, and then return a prompt. Go back to your desktop, and open Fv.

- Find the file you just created, **cas_a_lcurve.fits** (using the path cas_a/primary/cas_a_lcurve.fits), select it and click on the 'Open' button.

- In the 'Summary….' window that appears, click on 'Plot' under the 'View' heading. Another window will pop up, labeled 'Select Plot Columns'. On the left hand side, click on 'X'. Then click on the X button under the 'Axis' heading. Go back to the left hand column, click on Y and then click on the Y button under 'Axis'. Finally, click 'Go'. A window will appear containing a plot of a light curve for Cas A! (It should look similar to Figure 6.)

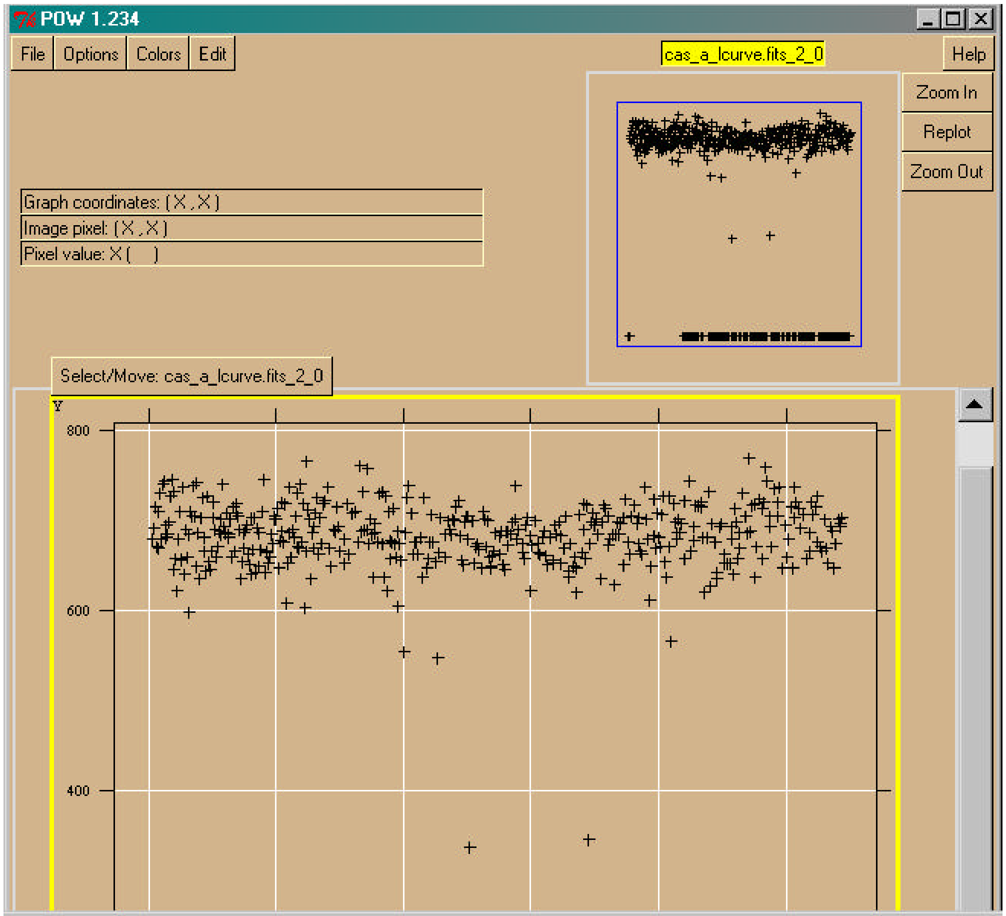


Figure 6

- Next, we will obtain a plot of the spectrum. Start by closing all of the Fv windows. Then, in your BASH window, type:
  fhisto cas_a_reg.fits cas_a_spectrum.fits energy 10 lowval=100 highval=10000

- Again, FTOOLS will repeat your inputs and return a prompt. Go to your desktop and open Fv. Find the output file you just created, **cas_a_spectrum.fits**, select it and click the 'Open' button. (cas_a/primary/cas_a_spectrum.fits)

- In the 'Summary….' window that appears, click on 'Plot' under the 'View' heading. A window labeled 'Select Plot Columns' will pop up. Like before, click on X in the left hand column and then on the X button under the 'Axis' heading. Click on Y in the left hand column and then on the Y button under the 'Axis' heading. Finally, click on 'Go'.

- A window will appear, containing an image. This is a plot of a spectrum of Cas A! (See Figure 7.) You can use the scroll bar to try to view more of the image. Also, clicking on 'Edit' and then 'Choose Graph Size' will allow you to set the dimensions of the graph.

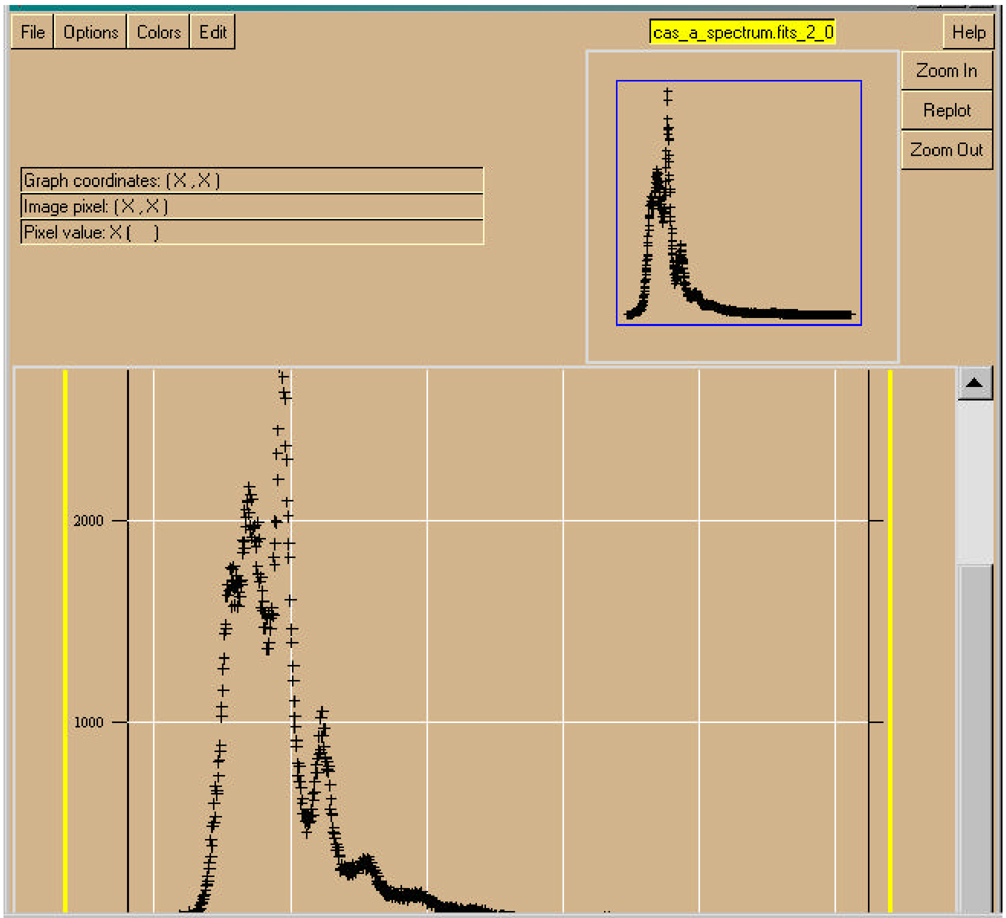


Figure 7