Background and Purpose

In an effort to learn more about black holes, pulsars, supernovas, and other high-energy astronomical events, NASA launched the Chandra X-ray Observatory in 1999. Chandra is the largest space telescope ever launched and detects "invisible" X-ray radiation, which is often the only way that scientists can pinpoint and understand high-energy events in our universe.

Computer aided data collection and processing is an essential facet of astronomical research using space- and ground-based telescopes. Every 8 hours, Chandra downloads millions of pieces of information to Earth. To control, process, and analyze this flood of numbers, scientists rely on computers, not only to do calculations, but also to change numbers into pictures. The final results of these analyses are wonderful and exciting images that expand understanding of the universe for not only scientists, but also decision-makers and the general public.

Although computers are used extensively, scientists and programmers go through painstaking calibration and validation processes to ensure that computers produce technically correct images. As Dr. Neil Comins so eloquently states[1], “These images create an impression of the glamour of science in the public mind that is not entirely realistic. The process of transforming [i.e., by using computers] most telescope data into accurate and meaningful images is long, involved, unglamorous, and exacting. Make a mistake in one of dozens of parameters or steps in the analysis and you will get inaccurate results.”

The process of making the computer-generated images from X-ray data collected by Chandra involves the use of "false color." X-rays cannot be seen by human eyes, and therefore, have no "color." Visual representation of X-ray data, as well as radio, infrared, ultraviolet, and gamma, involves the use of "false color" techniques, where colors in the image represent intensity, energy, temperature, or another property of the radiation. Scientists use different "false colors" to highlight different properties of the astronomical object being studied. Ultimately, it is important that anyone viewing these images understands that "false color" image processing is being used and the object would not have this appearance if viewed by the naked human eye.

The purpose of this activity is to take students “gently” through the steps of data and image processing with actual data from the Chandra X-ray Observatory. Students will develop that data shown in the image, and also, the "false colors" used to display the image. The data for this activity have undergone some pre-analysis by Chandra scientists for student manageability purposes, but the activity retains the basic principles of data analysis.

Materials

1. Student Handout Sheet
2. Calculator
3. Colored Pencils (with at least five different colors for each student group)

Objectives

1. The student will use data collected from the Chandra X-ray Observatory to calculate the average pixel intensity of X-ray emissions from a supernova remnant. (A pixel is any of the small discrete grid squares that together constitute an image).
2. The student will order average pixel intensity levels into range levels and associate image colors to each level to create an image of a supernova remnant.
3. The student will interpret a "false color" image formed from real data and develop explanations as to why scientists employ computers to process and analyze astronomical data.

[1] Comins, N.F. (2001). *Heavenly Errors*, Columbia University Press, New York.

Preparation

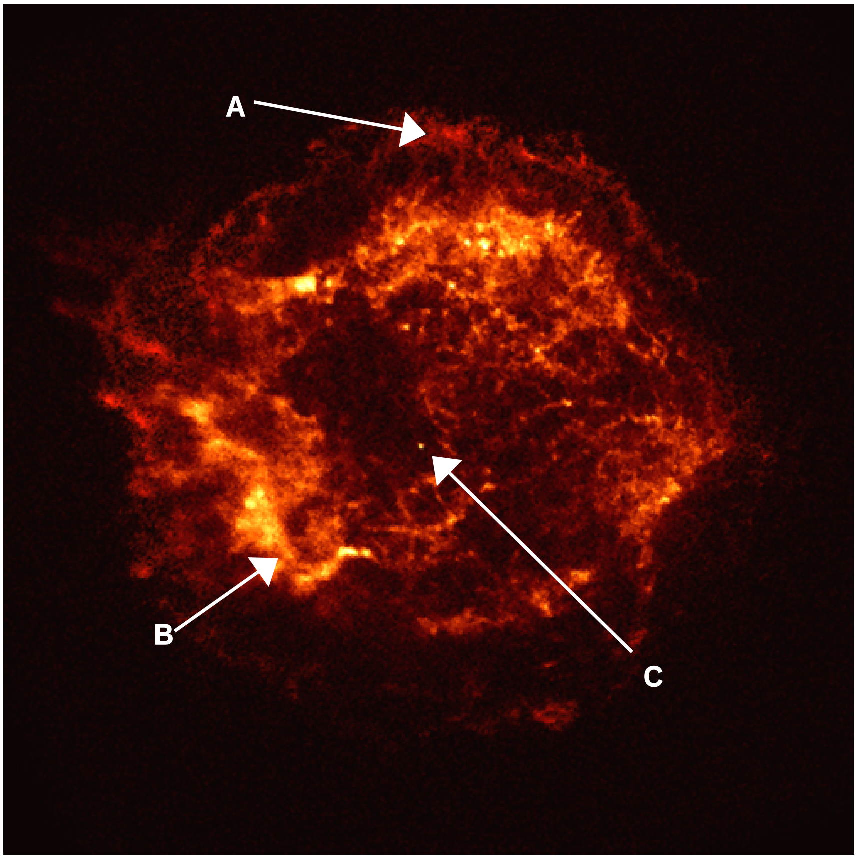
1. Before conducting this activity, the students should be introduced to and understand the mission and operation of the Chandra X-ray Observatory. Significant introductory resources are available at the Chandra web site (http://chandra.harvard.edu). Specifically, the following areas of the web site concern the objectives of this activity.
   a. The Chandra Mission
      http://chandra.harvard.edu/about/axaf_mission.html
   b. Data Collection Instruments on Chandra
      http://chandra.harvard.edu/about/science_instruments.html
   c. Chandra Images and False Color
      http://chandra.harvard.edu/photo/false_color.html
2. In the activity, the students will develop an image for the supernova remnant Cassiopeia A (Cas A). Prior to conducting the activity, the students should be exposed to the basic components of supernova remnants. There are several images of supernova remnants, including Cas A, at the Chandra web site (http://chandra.harvard.edu/photo/category/snr.html). Also, below is an image and feature discussion of Cas A that the instructor should review before conducting the activity.
3. One of the most challenging parts of the activity for the students is assigning colors to intensity ranges (Task B, steps 2 and 3 – see the student handout sheet). This process is called "binning" and commonly occurs in image processing. Binning is extremely important to see image features. In the activity, students choose their own colors and intensity ranges and are instructed to have the teacher check their binning before coloring the image. **To make these steps easier**, the instructor may wish to have pre-assigned colors and intensity ranges instead of having the students do this.
4. One of the main purposes of this activity is to show how numerical data from Chandra is converted to images of astronomical objects. A "Chandra Chronicles" article, titled "A River of Data Flows Through the CIAO Waterworks (http://chandra.harvard.edu/chronicle/0401/ciao_data.html)," discusses how computers assist Chandra scientists in converting numerical data to graphical images. The article includes pictures of the data received from Chandra, as well as a discussion of the software used to convert the data into images. Before conducting the activity, the teacher may find this background information helpful when explaining the activity to the students. The teacher may also want the students to read this information before starting the activity.
5. Some of the data are intentionally missing. Again, this is a realistic challenge confronted by scientists. Depending on student ability you may use a variety of techniques ranging from estimation to statistical techniques to handle these data omissions.

Image Interpretation

For the activity, the students will develop an image of Cassiopeia A (Cas A), the first astronomical object detected by the Chandra X-ray Observatory. The following information provides more information on Cas A obtained from the Chandra web site (http://chandra.harvard.edu/photo/0237/index.html).

In 1680, the British astronomer John Flamsteed observed a bright star that was never seen again. Evidence indicates that this bright star was the explosion that produced Cas A. The Chandra image below shows the 320-year-old remnant of a massive star that exploded to form the supernova remnant Cas A. Located in the constellation Cassiopeia, it is 10 light years across and 10,000 light years from Earth. The observed expansion rate and the observed size of the supernova remnant, give an estimate of the age of about 320 years, near the same time that Flamsteed observed the bright star. The distance to Cas A is approximately 10,000 light years, so the explosion really occurred 10,319 years ago. When astronomers talk about such events, they are more interested in the age of the remnant as we see it, which is important for understanding its evolution. They take for granted that the actual event occurred earlier because of light travel time.

The instrument that collected the data for this image is the advanced charge-coupled device (CCD), which uses electronic equipment to detect photons. The Advanced CCD is composed of many tiny electronic cells, each of which records a buildup of charge to measure the amount of X-ray radiation striking it. The image below was made with the Advanced CCD with a 5000 second exposure time on August 19, 1999. More information on the Advanced CCD can be found at http://chandra.harvard.edu/about/science_instruments2.html.



In the image, two shock waves are visible: a fast outer shock (Arrow A) and a slower inner shock (Arrow B). The inner shock wave is believed to be due to the collision of the ejecta from the supernova explosion with a circumstellar shell of material, heating it to a temperature of ten million degrees. The outer shock wave is analogous to an awesome sonic boom resulting from this collision. The small bright object near the center (Arrow C) may be the long sought neutron star or black hole that remained after the explosion that produced Cas A

This false color image of Cas A shows the brightness of the X-rays, where yellow reveals the areas with the most intense X-ray emission.

After the Activity

1. By reviewing various "false color" schemes used by different groups, the students will get an idea about how the same data may be represented differently. A class discussion on the type of color

schemes used may enhance the students' understanding of how different color styles may allow for varied interpretation.

2. The students should also develop an understanding of how the "artist's impression" of the supernova remnant may vary among groups. If possible, the teacher should show the drawings from the different groups and compare them to some of the images of Cas A made by Chandra Scientists found at http://chandra.harvard.edu/photo/0237/index.html.

3. This activity provides a good introduction for student use of the SAOImage DS9 software. This software was developed by the Harvard-Smithsonian Center for Astrophysics (CfA) to first, acquire "raw" Chandra data, and then, to form and analyze "false color" images. The software and data are available for student use at the Chandra Education Data Analysis Software and Activities web site (http://chandra-ed.harvard.edu). If the students have not already done so, they may want to read "Chandra Chronicles" article, titled "A River of Data Flows Through the CIAO Waterworks (http://chandra.harvard.edu/chronicle/0401/ciao_data.html)." As mentioned earlier, this article discusses how computers assist Chandra scientists in converting numerical data to graphical images, and specifically, discusses the use of the SAOImage software.

Alignment of Performance Activity with National Standards

Specific skills and knowledge demonstrated by the activity	Alignment with Project 2061 Benchmarks for Scientific Literacy	Alignment with National Science Education Standards
The student will use data collected from the Chandra X-ray Observatory to calculate the average pixel intensity of X-ray emissions from a supernova remnant.	4A-The Universe (9-12) #3: Increasingly sophisticated technology is used to learn about the universe. Visual, radio, and X-ray telescopes collect information from across the entire spectrum of electromagnetic waves…	Standard B-Physical Science: Interactions of Energy and Matter #2: Electromagnetic waves result when a charged object is accelerated or decelerated. Electromagnetic waves include radio waves (the longest wavelength), microwaves, infrared radiation (radiant heat), visible light, ultraviolet radiation, X-rays, and gamma rays. The energy of electromagnetic waves is carried in packets…
The student will order average pixel intensity levels into range levels and associate image colors to each level to will create an image of a supernova remnant.	4A-The Universe (9-12) #4: Mathematical models and computer simulations are used in studying evidence from many sources in order to form a scientific account of the universe.	Standard A-Inquiry (9-12)-Use of Technology and mathematics to improve investigations and communications: A variety of technologies, such as hand tools, measuring instruments, and calculators, should be an integral component of scientific investigations. Mathematics plays an essential role in all aspects of an inquiry. For example, …graphs are used for communicating results
The student will interpret an image formed from real data and develop explanations as to why scientists employ computers to process and analyze astronomical data.	11B-Models (9-12) #2 Computers have greatly improved the power and use of mathematical models by performing computations that are very long, very complicated, or repetitive. Therefore computers can show the consequences of applying complex rules or of changing the rules. The graphic capabilities of computers make them useful in the design and testing of devices and structures and in the simulation of complicated processes.	Standard A-Inquiry (9-12)-Understandings About Scientific Inquiry: Scientists rely on technology to enhance gathering and manipulation of data. New techniques and tools provide new evidence to guide inquiry and new methods to gather data, thereby contributing to the advance of science.

The Scenario

You and your partner have just discovered a brilliant new supernova remnant using the Chandra X-ray Observatory. The Director of NASA Deep Space Research has heard of your discovery and wants a report of your results in her office in 45 minutes. Unfortunately, your computer crashed fatally while you were creating an awesome image of the supernova remnant from the numerical data. Because the NASA director always wants to see cool images (not numbers) of newly discovered objects, you and your partner will have to create, by hand, an image of the supernova remnant.

To create the image, you and your partner will have to use "raw" data processed from the Chandra satellite. You have tables of the data, but during the excitement of the computer crash, you spilled soda over some of the information and will have to recalculate some values.

In addition to the graph, you and your partner will have to prepare a written explanation of your discovery and answer a few of the Director's questions.

Your Tasks

Before you are ready to present your findings to the NASA director, you will need to complete the following three tasks.

Task A: Calculations

1. Your mission is to turn "boring" numbers into a super-cool picture. Before you can make the image, you will need to make some calculations.
2. The raw data for the destroyed "pixels" (grid squares containing a value and color) are listed in Table 1. Before making the image, you will need to fill in the last column of Table 1 by calculating average X-ray intensity for each pixel.
3. After you have determined average pixel values for the destroyed pixels, write the numerical values in the proper box (pixel) of the attached grid. Many of the pixel values are already on the grid, but you have to fill in the blank pixels. This is the grid in which you and your partner will draw the image.

Task B: Coloring the Image

You and your partner will need to complete the following steps in coloring the image. **Important Note**: read all the instructions carefully before you start coloring!

1. You are allowed to use five and only five colors in drawing your image.
2. Each of the five colors will represent a range of intensity values. You and your partner should select the range of intensities assigned to each color. Fill in these range values and associated colors on the legend at the bottom of the image grid sheet.
3. Hint: as you assign colors to ranges, it is best to pick colors that are “close” to each other as you move from one range to another. For example, in the range with the lowest intensities you may assign the color red. In the next lowest range, you would then assign the color orange, rather than indigo. Before proceeding, have the instructor check you assigned colors.
4. Using colored pencils, shade in the grid using your color legend.

Task C: Preparing the Presentation

1. On the back of the image, write a detailed description (1-2 paragraphs) of the prominent features of the supernova remnant. Be sure to describe how the image shows a neutron star, a fast outer shock wave, and a slower inner shock wave.
2. Include an artist’s impression drawing of what the actual supernova remnant would “look” like.
3. The NASA director has the following specific questions about your findings. Answer these questions on the back of the image.
   a. In the table, some of the data were missing. In 3-4 sentences, describe how you “handled” these missing data in making your calculations and coloring your image.
   b. Because your computer crashed, you had to draw the image by hand. In 3-4 sentences, explain why would it have been easier to use a computer? (In your answer, consider that the Chandra satellite actually sends millions of data from each observation and how long it would take to process millions of data by hand)

Table 1. "Raw" data of the newly discovered supernova remnant collected from the Chandra X-ray Observatory.

Missing Grid Coordinate	Number of X-ray Photons Detected					Average Number of Photons
	Observation 1	Observation 2	Observation 3	Observation 4	Observation 5	
A4	39	40	40	42	42	
B6	59	61	62	60	58	
B7	62	71	missing	63	missing	
B8	64	68	71	71	72	
C3	50	54	52	50	54	
C6	33	missing	missing	31	38	
C10	64	63	61	64	missing	
D2	41	missing	missing	missing	43	
D6	104	missing	105	108	108	
D7	140	144	142	141	137	
D10	62	50	57	50	52	
E7	41	43	43	36	40	
E8	214	210	210	210	214	
F2	missing	49	49	47	47	
F4	153	missing	154	155	156	
F6	148	135	missing	missing	130	
F8	152	141	147	145	144	
G2	49	51	48	50	missing	
G4	130	123	missing	missing	124	
H2	51	49	53	50	50	
H3	34	25	38	31	26	
H4	115	114	missing	128	123	
H6	95	97	missing	missing	missing	
H8	115	115	115	113	112	
H10	73	83	missing	80	81	
I3	missing	39	35	37	42	
I5	58	69	54	missing	65	
I9	68	77	80	81	missing	
J6	46	49	55	missing	48	
J7	61	69	79	74	54	

Supernova Remnant
Image Grid

	A	B	C	D	E	F	G	H	I	J	K
1	0	1	1	1	1	1	1	1	1	1	1
2	2	5	35		48				46	18	7
3	23	36		35	30	27	21			13	0
4		43	24	8	216				54	21	3
5	36	58	37	44	36	20	33	105		23	4
6	32				12		18		24		17
7	24		32			17	12	126	64		21
8	18		36	237			155		22	74	6
9	16	75	38	34	26	12	14	21		37	4
10	8	71			42	23	64		31	16	2
11	3	3	2	1	0	0	2	0	1	0	0

Legend

Average number of photons					
Color					

SAMPLE
OF COMPLETED IMAGE

Supernova Remnant
Image Grid

	A	B	C	D	E	F	G	H	I	J	K
1	0	1	1	1	1	1	1	1	1	1	1
2	2	5	35	42	48	48	50	51	46	18	7
3	23	36	52	35	30	27	21	31	38	13	0
4	41	43	24	8	216	155	126	120	54	21	3
5	36	58	37	44	36	20	33	105	62	23	4
6	32	60	34	106	12	138	18	96	24	50	17
7	24	65	32	141	41	17	12	126	64	67	21
8	18	69	36	237	212	146	155	114	22	74	6
9	16	75	38	34	26	12	14	21	77	37	4
10	8	71	63	54	42	23	64	79	31	16	2
11	3	3	2	1	0	0	2	0	1	0	0

Legend

Average number of photons	< 40	40-80	81-120	121-160	>160
Color					

SAMPLE
OF COMPLETED IMAGE