Chandra X-ray Observatory
From Pixels to Images: De-Coding Starlight
(Grades 5-8)

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 to 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 interpret a "false color" image formed from real data.

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

3. The student will develop explanations as to why scientists employ computers to process and analyze astronomical data.

Preparation

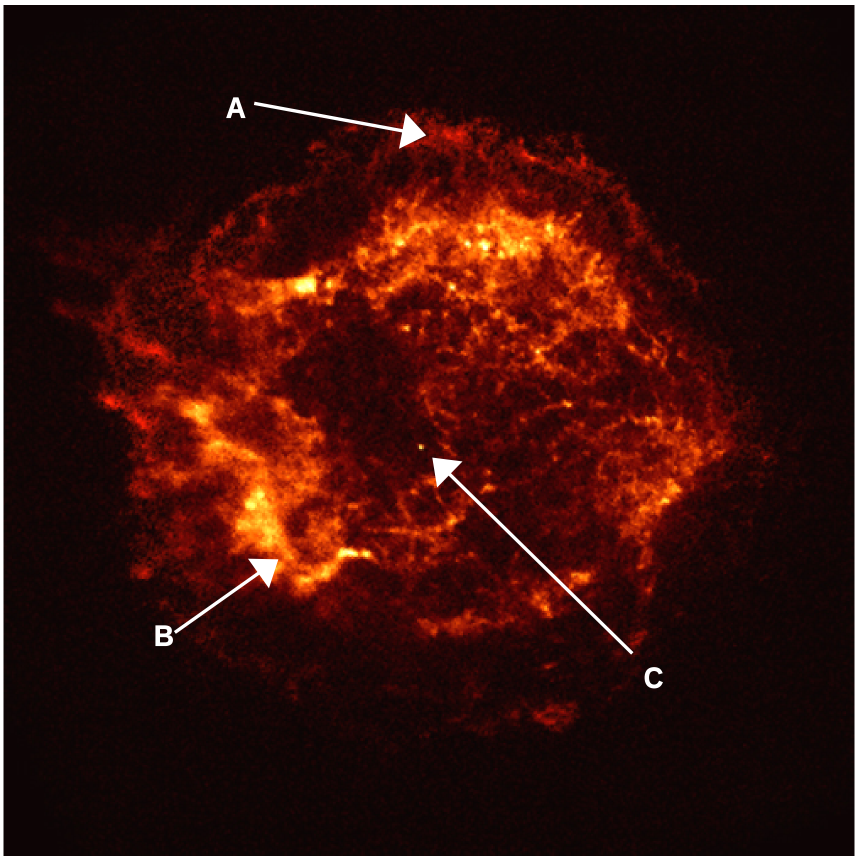
1. Before conducting this activity, the students should be introduced to and understand the mission and operation of the Chandra X-ray Observatory. Significant introductory resources are available at the Chandra web site (http://chandra.harvard.edu). Specifically, the following areas of the web site 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). Before 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 teacher should review before conducting the activity.
3. 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 assisting the students during the activity. Please note that the article is probably beyond the reading level of most middle school students, and therefore, would not make a suitable reading assignment for most middle school students.
4. The data the students are analyzing are the number of X-ray "photons" from the supernova remnant that are detected by Chandra. A photon is an individual packet of electromagnetic energy that makes up electromagnetic radiation. A discussion of how X-ray photons are produced can be found at http://chandra.harvard.edu/xray_astro/xrays.html.
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 just over 10,000 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. The students should 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.

2. 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).

Alignment of Performance Activity with National Standards

Author's Note: these standards are for middle school level. This page will need to be revised to reflect the middle school level. This page serves as a reminder to alter these standards as appropriate.

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.	3: The Nature of Technology (6-8) A: Technology and Science #2: Technology is essential to science for such purposes as access to outer space and other remote locations, sample collection and treatment, measurement, data collection and storage, computation, and communication of information.	Content Standard B-Physical Science: Transfer of Energy #1: Energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, sound, nuclei, and the nature of a chemical. Energy is transferred in many ways.
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.	11: Common Themes (6-8) B: Models #2: Mathematical models can be displayed on a computer and then modified to see what happens.	Content Standard A-Inquiry (5-8)-Abilities Necessary to Do Scientific Inquiry #3: Use appropriate tools and techniques to gather, analyze, and interpret data. The use of tools and techniques, including mathematics, will be guided by the question asked and the investigations students design. The use of computers for the collection, summary, and display of evidence is part of this standard. Students should be able to access, gather, store, retrieve, and organize data, using hardware and software designed for these purposes.

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 interpret an image formed from real data and develop explanations as to why scientists employ computers to process and analyze astronomical data.	11: Common Themes (6-8) B: Models #3: Different models can be used to represent the same thing. What kind of a model to use and how complex it should be depends on its purpose. The usefulness of a model may be limited if it is too simple or if it is needlessly complicated. Choosing a useful model is one of the instances in which intuition and creativity come into play in science, mathematics, and engineering.	Content Standard A-Inquiry (5-8)-Understandings About Scientific Inquiry: #3: Mathematics is important in all aspects of scientific inquiry. #4: Technology used to gather data enhances accuracy and allows scientists to analyze and quantify results of investigations.

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. Using colored pencils, shade in the grid using the color legend. Match the value in the grid to the color range shown on the legend and color the grid squares according to the legend.

Task C: Preparing the Presentation

1. Draw an picture of what the actual supernova remnant would “look” like. In your drawing, include and label the neutron star, a fast outer shock wave, and a slower inner shock wave.
2. 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 2-3 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 2-3 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)

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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 1	Observation 1	Observation 1	Observation 1	
C3	50	54	52	50	54	
E8	214	210	210	210	214	
F6	148	135	missing	missing	130	
H10	73	83	missing	80	81	
I5	58	69	54	missing	65	

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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		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		23	4
6	32	60	34	106	12		18	96	24	50	17
7	24	65	32	141	41	17	12	126	64	67	21
8	18	69	36	237		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		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

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 per sec	< 40	40-80	80-120	120-160	>160
Color					

SAMPLE
OF COMPLETED IMAGE