Decoding Starlight: From Pixels to Images

Decoding Starlight is a classroom activity that helps students better understand the scientific practices associated with imaging. The activity combines data analysis with image creation and interpretation. Students work through the activity tasks without the aid of automation, thereby facilitating understanding of both how computers normally conduct the analysis and why scientists use computers for imaging. This article first discusses some fundamentals of how scientists and technicians create astronomical images and how imaging is a scientific process. The article then introduces the basics of the activity and how *Decoding Starlight* can be used in the classroom. Finally, the article concludes by presenting suggested next steps to further deepen student understanding of image analysis and evaluation.

Some Imaging Fundamentals

Astronomers, geophysicists, and many other scientists use imaging widely in their daily routines. Scientists employ images to achieve greater understanding of our universe, and also to engage students as well as the public in the scientific enterprise. In this way, imaging creates both scientific knowledge and increases scientific literacy. The *Decoding Starlight* activity uses data collected from NASA's Chandra X-ray Observatory, a spacecraft and telescope system that has been orbiting Earth since 1999, and helps students learn the fundamental processes of imaging that are common to many scientific disciplines.

Representative color

The Chandra X-ray Observatory gathers information about high-energy astronomical phenomena. From the data collected by the observatory, scientists and technicians have created literally thousands of images that are all available on the Chandra website (http://chandra.harvard.edu). The observatory collects information from X-rays, a type of light invisible to the humans. The question then arises: how are images of X-ray light made, and specifically, how are these images made so that they are scientifically meaningful?

Chandra images are made by using what is commonly called false color, but what the mission education and public outreach office prefers to call *representative color*. Representative color is commonly used to depict light that our eyes cannot detect, such as radio, infrared, ultraviolet, gamma, and of course, X-rays. Furthermore, representative color is often used to enhance images made from visible light, such as the images made from data collected by the Hubble Space Telescope.

Representative colors are selected by scientists and technicians to highlight important details. Additionally, representative colors are chosen as an analog to light that we observe with our eyes. It is often the case in Chandra images that lower-energy (soft) X-rays are colored red, moderate energy X-rays are colored yellow, and higher-energy (hard) X-rays are colored blue. Such a color scheme is representative of the visible light spectrum, where red light has lower photon energy, yellow light has moderate photon energy, and blue light has higher photon energy.

Scaling

Scientists and technicians also need to define the scaling scheme when they develop representative color images. A fundamental scheme is linear scaling, where different photon energies are equally divided among the different colors. The Chandra X-ray observatory can detect photon energies from about .1 to 10 keV (kiloelectron-volts, where 1 keV equals about 1.6×10^{-16} Joules). Therefore, a linear scheme using three colors (e.g., red, yellow, and blue) would subsequently divide photon energy ranges into three essentially equal parts (~.1 to 3.3 keV is red, 3.3 to 6.7 keV is yellow, and 6.7 to 10 keV is blue). Sometimes scientists and technicians call these equal divisions: bins (think of three laundry hampers, where you would sort white clothes into one hamper, light colors into another, and dark colors into the third). Scientists and technicians often call this scaling/color combination the *binning* scheme.

Imaging as a Scientific Process

Data collection and processing are essential facets of astronomical research using both space- and ground-based telescopes. Often the final results of these analyses are images that scientists use to communicate among themselves, as well as with the general public. Many of these images involve observations lasting a few hours up to a few days or more. These observations therefore generate millions of data points from which the images are created. In practice, scientists and technicians use computers to do calculations, and to change measured and calculated numbers into images.

A tremendous amount of scientific understanding and effort goes into creating these computer-generated images. As Comins (2001) states, "these images create an impression of the glamour of science in the public mind that is not entirely realistic...the process of transforming 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 images" (p. 76). However, imaging is not just an essential skill for astronomers, but something which is practiced by many scientists (e.g., meteorologists' use of infrared images of clouds; neurologists' use of magnetic resonance images).

The process of scientific imaging is an excellent example of the science and engineering practices recommended for inclusion into the Next Generation Science Standards (National Research Council, 2011), including the use of mathematics, information and computer technology, and computational thinking. Therefore, it is important that when our students view these images, they understand the fundamental processes scientists are using to create them (e.g., representative color and scaling), as well as the meanings scientists are trying to convey through these images.

Removing the Veil

Decoding Starlight: From Pixels to Images is an activity created to take students through the steps of data and image processing with actual data from the Chandra X-ray Observatory. The data are from observations made of Cassiopeia A (or Cas A for short), a supernova remnant of what once was a massive star (also known as a Type II supernova). Supernova remnants can emit an abundance of X-rays and Cas A was Chandra's extended source calibration image (e.g., one of the first images observed by the observatory to verify that both spacecraft and instrumentation were functioning properly; see Figure 1). Over time, Chandra has made several detailed observations of Cas A that have greatly expanded our understanding of supernovas and stellar nucleosynthesis, which is the generation and distribution of elements from carbon to plutonium. Cas A is the youngest supernova remnant in the Milky way and you can learn more about this remnant and nucleosynthesis at the Chandra website (http://chandra.harvard.edu/photo/2011/casa).

Decoding Starlight is easily scaled to various grade levels and the author has personally used the activity with 5th grade students, undergraduates, and every grade in between. The underlying purpose of this activity is to engage students in the fundamentals of imaging, including basic data analysis, assignment of representative color and scaling schemes, generation of an image by hand, and creating an analog artist's representation to help communicate their understanding. For classroom manageability purposes, the data for *Decoding Starlight* have undergone some pre-analysis by Chandra scientists, but the activity retains the basic principles of data analysis. You can download a description of the *Decoding Starlight* activity and the necessary materials for classroom use at http://chandra.harvard.edu/edu/formal/imaging/index.html. The main features of the activity are highlighted below.

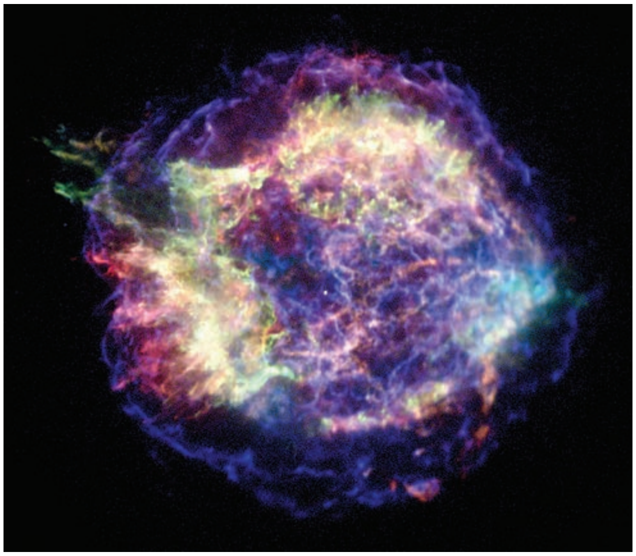


Figure 1.Cassiopeia A (Cas A) is a 325-year-old remnant produced by the explosive death of a massive star located about 11,000 light years from Earth. This image was created using representative color.

Credit: NASA/CXC/MIT/UMass Amherst/M.D.Stage et al.

The Scenario

The *Decoding Starlight* activity has students assume the role of scientists who have just discovered a new supernova remnant. The students are told that they are expected to present this discovery to a NASA official very soon, but unfortunately, their computer has crashed. In order to create an image for the presentation, the students need to reanalyze some of the data and create an image using paper and pencil.

The Tasks

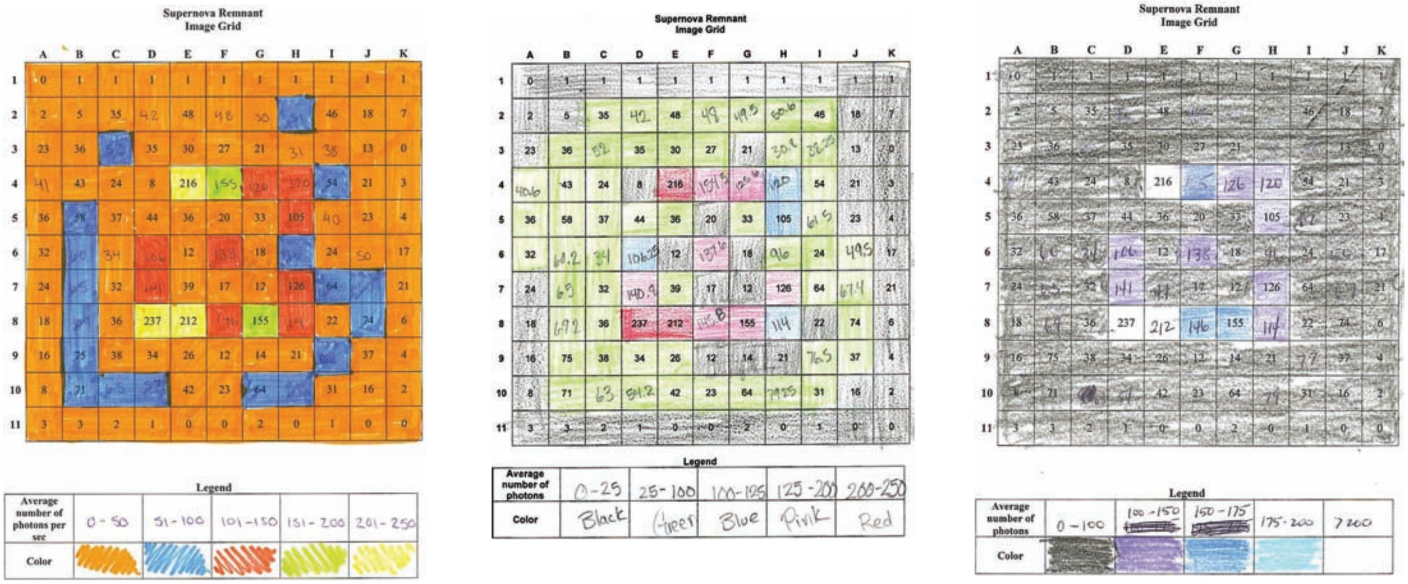
Students need to complete three major tasks in *Decoding Starlight*:

a. recalculate some values that have been lost in the computer crash,

b. determine the binning scheme to be used to color the image, and

c. prepare the image and the associated presentation.

The activity is flexible in many ways by supporting a variety of instructional modes and grade levels. For example, the teacher may specify a certain method for recalculating missing values, such as using a simple arithmetic average among numbers. However, advanced students can use more robust calculations (e.g., areal or running average techniques). Furthermore, the activity has both a middle and high school version. The middle school version of *Decoding Starlight* has much fewer values that require recalculation.



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	120	170	54	21	3
5	36	58	37	44	36	20	33	105	40	23	4
6	32	60	34	106	12	138	18	[illegible]	24	50	17
7	24	65	32	141	39	17	12	126	64	[illegible]	21
8	18	[illegible]	36	237	212	146	155	[illegible]	22	74	6
9	16	75	38	34	26	12	14	21	[illegible]	37	4
10	8	71	63	[illegible]	42	23	64	[illegible]	31	16	2
11	3	3	2	1	0	0	2	0	1	0	0

Legend

Average number of photons per sec	0 - 50	51 - 100	101 - 150	151 - 200	201 - 250
Color	🟧	🟦	🟥	🟩	🟨

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	49	49.5	50.16	46	18	7
3	23	36	52	35	30	27	21	30.8	38.25	13	0
4	40.6	43	24	8	216	159.5	126.6	120	54	21	3
5	36	58	37	44	36	20	33	105	61.5	23	4
6	32	60.2	34	106.25	12	137.6	18	96	24	49.5	17
7	24	69	32	140.9	39	17	12	126	64	67.4	21
8	18	69.2	36	237	212	145.8	155	114	22	74	6
9	16	75	38	34	26	12	14	21	76.5	37	4
10	8	71	63	54.2	42	23	64	79.25	31	16	2
11	3	3	2	1	0	0	2	0	1	0	0

Legend

Average number of photons	0-25	25-100	100-125	125-200	200-250
Color	Black	Green	Blue	Pink	Red

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	[illegible]	48	[illegible]	[illegible]	[illegible]	46	18	7
3	23	36	[illegible]	35	30	27	21	[illegible]	[illegible]	13	0
4	[illegible]	43	24	8	216	[illegible]	126	120	54	21	3
5	36	58	37	44	36	20	33	105	[illegible]	23	4
6	32	[illegible]	[illegible]	106	12	138	18	[illegible]	24	[illegible]	17
7	24	[illegible]	32	141	[illegible]	17	12	126	64	[illegible]	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	[illegible]	[illegible]	42	23	64	79	31	16	2
11	3	3	2	1	0	0	2	0	1	0	0

Legend

Average number of photons	0 – 100	100 – 150	150 – 175	175 - 200	> 200
Color	■	🟪	🟦	🟦	

Examples of student work on the *Decoding Starlight: From Pixels to Images* activity.

(left to right)

Figure 2.This example represents a linear scaling and complementary color scheme.

Figure 3. This example represents a quasi-logarithmic scaling and complementary color scheme.

Figure 4. This example represents a quasi-exponential scaling and gradual color scheme.

Decoding Starlight is similarly flexible in allowing a variety of binning schemes. For example, students can pick a linear, logarithmic, or squared scaling method. If students use linear scaling (equal range of photon counts for each bin; which may be the preferred scaling technique for lower grade levels), the image looks quite different than when they use logarithmic scaling (more bins associated with lower photon count ranges) or squared scaling (more bins associated with higher photon count ranges). Students can also specify different color schemes, such as using complementary color transitions to sharply delineate different bin ranges, or a gradual color transitions to provide smoothness to the different bin ranges. With lower grade levels, teachers may wish to have pre-assigned representative color and binning schemes; however if you pre-assign schemes to students, I recommend having students select from more than one because this will allow for a richer class discussion when sharing results. Figures 2, 3 and 4 are examples of students' work with various representative color and binning schemes.

Planning to Use *Decoding Starlight*

Be sure to read the teacher's guide section of *Decoding Starlight* (http://chandra.harvard.edu/edu/formal/imaging/index.html) to gain insights about how to prepare and use the activity in your classroom. For example, you may wish to introduce your students to the basic components that are commonly found in supernova remnants prior to conducting the activity. In a Type II supernova remnant that results from a massive stellar explosion, common components that can often be imaged are the

- stellar remnant (a neutron star or black hole),
- slow inner shock wave, and
- fast outer shock wave.

Students can resolve each of these components in the image of Cas A that they create; however, because they are doing this by hand, the resolution will be far less detailed than in the Chandra images. If you introduce your students to supernovas before conducting the activity, the Chandra website contains many images and explanations of supernova remnants other than Cas A (http://chandra.harvard.edu/photo/category/snr.html). Be sure to use Type II supernova remnants, which are from explosions of massive stars. Type Ia supernova remnants have some different features because they result from explosions of stars that are about the same mass as our Sun and are accreting material from a companion star. Alternatively, you may wish to have the students complete *Decoding Starlight* prior to any discussion of supernovas. In this way, the activity and the drawings created by your students would be a platform for engagement and introduction.

Analyzing Data and Generating Images with Computers

Decoding Starlight provides an introduction for students' use of the SAOImage ds9 software. This software was developed by the Harvard-Smithsonian Center for Astrophysics (CfA) to first, acquire Chandra data, and then, to form and analyze computer-generated images. The software and data are ***free*** and available for student use at the Chandra Education Data Analysis Software and Activities web site (http://chandra-ed.harvard.edu). The ds9 software can be run on either on the Windows or Mac operating systems. Although not required for successful use of the software, conducting *Decoding Starlight* in your classroom prior to doing computer-assisted analysis can deepen your students understanding about imaging processes and increase their chances for conducting meaningful investigations. Furthermore, the activity provides an opportunity for students to learn about the fundamentals of a scientific practice that spans several disciplines.

References

Comins, N. F. (2001). *Heavenly errors: Misconceptions about the real nature of the universe.* New York: Columbia University Press.

National Research Council. (2011). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas.* Committee on a Conceptual Framework for New K-12 Science Education Standards Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, D. C.: The National Academies Press.

About the Author

Doug Lombardi is a doctoral candidate in Educational Psychology at the University of Nevada, Las Vegas. His research is on climate change education and the role of critical evaluation in reappraising plausibility judgments and conceptual change. He has appreciable experience working in NASA education enterprises and has been a teaching resource agent for the agency's Chandra X-ray Observatory since 2001. Doug is also a project facilitator at the Regional Professional Development Program, serving as a science education specialist and the program's internal evaluator. He is a licensed physics and mathematics teacher, with 12 years experience in a variety of educational settings. Doug can be reached at lombardi.doug@gmail.com.