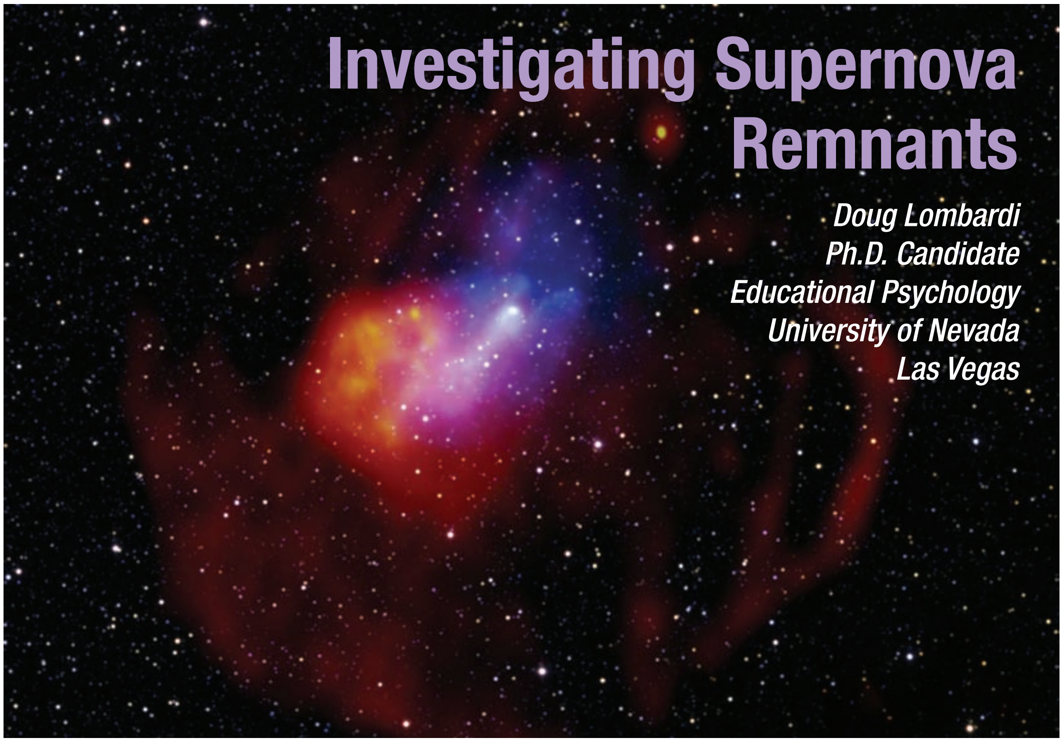

Investigating Supernova Remnants

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Carl Sagan (1980) said that "if you wish to make an apple pie from scratch, you must first invent the universe" (p. 218). With that idea, he linked pie ingredients (e.g., apples, flour, butter, water, etc.) to basic atomic structure (carbon, oxygen, hydrogen, etc.) and ultimately to the Big Bang. *Investigating Supernova Remnants* is a classroom activity concerned with an intermediate point in this cosmic process. Specifically, how stars and their remnants are the source for almost all of the chemical elements, as well as their distribution throughout the universe. The activity itself is concerned with how we can identify different types of supernova remnants based on their chemical signature. To better understand the two main types of supernovas, the article first provides an overview of the features of these astronomical phenomena and how these supernovas contribute to scientific understanding and the scientific process. The article then introduces the *Investigating Supernova Remnants* activity and the option of conducting the activity using the freely available ds9 imaging software. In the article wrap-up, it is discussed how this imaging software can be used to engage students in conducting scientific investigations using data collected by NASA's Chandra X-ray Observatory.

Types of Supernovas

Much scientific research has been conducted on two types of supernovas. Type Ia supernovas are the complete annihilation of a remnant from a medium mass star (i.e., a star with a mass on the order of our own Sun), which is accreting material from a nearby companion star. Type II supernovas are another type that involve the core collapse of massive stars (i.e., much more massive that the Sun).

Type Ia Supernovas. For much of its existence, nuclear fusion in a star's core exerts an outward pressure that essentially counterbalances the inward force induced by gravitational attraction of the star's mass. Fusion of hydrogen to helium occurs in a star's core during the early stages of its existence and fusion of helium to carbon and/or oxygen characterizes the latter part. At this later stage, the star is commonly referred to as a red giant due to cooling and expansion of the star's outer layers. Stellar cores that are up to 1.4 times as massive as our Sun, transition into a white dwarf remnant after most of the core helium has fused. White dwarves are created because a lesser thermal pressure in the star cannot overcome gravitational forces and the core collapses. As the core material becomes tightly packed, a degeneracy pressure builds due to filling of electron energy levels. This electron degeneracy pressure then counterbalances the pressure induced by gravitational attraction and the white dwarf remnant is stable. Our Sun is destined to end its existence as a white dwarf.

The white dwarf stage is not the end for all medium mass stars. Some explode as a Type Ia supernova. To result in an explosion, a white dwarf must be in a contact binary system, which means that the dwarf is pulling material from its nearby companion star. This happens when the companion has reached the red giant stage after the white dwarf has formed. As the white dwarf pulls material from the companion star onto itself (a process that scientists call accretion), the mass of the white dwarf grows. Accretion may cause the mass of the dwarf to increase to a value greater than 1.4 times the Sun's mass, which in turn, causes the remnants' internal pressure to increase, core temperatures to rise, and unsustainable nuclear fusion to occur. The white dwarf undergoes a thermonuclear explosion and is completely destroyed.

Type II Supernovas. In massive stars (i.e., from about eight times as massive as our Sun or greater) that reach the red giant stage, internal core temperatures are hot enough that elements heavier than carbon and oxygen are created in the core. This forms elements such as neon, magnesium, silicon, sulfur, nickel, and iron. As iron builds in the core, it fuses into even heavier elements; however, rather than releasing energy, fusion of iron into heavier elements absorbs energy. A critical value is reached when the iron in the star's core reaches about 1.4 times our Sun's mass. At this value, more energy is required for fusion than the star has available and thermal radiation pressure from the star is catastrophically reduced. The result is a nearly instantaneous core collapse and a rebounding explosion called a Type II supernova. The energy produced by the explosion's shockwave creates elements heavier than iron (e.g., gold, yttrium, uranium) as the shockwave interacts with the star's outer layers. A stellar remnant of very dense matter (called a neutron star), or a singularity (called a black hole) are also produced from the core collapse.

How Do Scientists Know?

The Chandra X-ray Observatory measures X-ray light from many high-energy astronomical phenomena, including supernova remnants. Chandra has greatly increased our understanding of the universe, including characterizing important differences between Type Ia and II supernovas. If scientists are just observing light, the following questions arise.

- How do they know the type of supernova remnant they are observing?
- How do scientists determine the cause of the remnant when the event occurred hundreds or thousands of years ago?
- What effect do the different types of supernovas have on the distribution of elements throughout the cosmos?

Answering such questions about "cause and effect relationships by seeking the mechanisms that underlie" a phenomena are an important crosscutting concept that spans all of science and something that is essential for our students to know in order to achieve scientific literacy (National Research Council, 2011, p. 4-2).

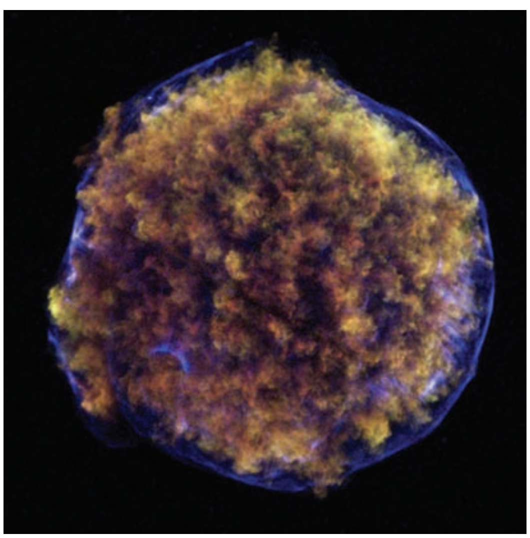
Supernova Remnants Activity

Investigating Supernova Remnants is an activity that helps students to deepen their understanding about cause and effect by understanding the underlying mechanisms that characterize supernovas. The activity is available for download at http://chandra.harvard.edu/edu/formal/snr/. *Investigating Supernova Remnants* engages students in an investigation of whether a supernova is a Type Ia or Type II by looking at the element distribution within the remnant. This activity is appropriate for high school and undergraduate students.

Teachers have two options for using *Investigating Supernova Remnants* in their classrooms. In the first option, students conduct the analysis with the SAOImageds9 software, which is freely available at the Chandra Education Data Analysis Software and Activities web site (http://chandra-ed.harvard.edu). The ds9 software can be used on either on the Windows or Mac operating systems. Students can download data collected from the Chandra X-ray Observatory and use ds9's sophisticated suite of analysis tools to understand the chemical nature of supernova remnants, as well as other astrophysical properties.

Baselining Known Remnants

The first thing that students do in *Investigating Supernova Remnants* is to determine the chemical composition of two events that serve as the baseline for further comparisons. The first remnant is from a supernova that was documented by Renaissance astronomer Tycho Brahe (commonly known as a Tycho's Supernova Remnant; see Figure 1). This remnant resulted from a Type Ia Supernova resulting from an explosion and complete destruction of a white dwarf. Tycho's Supernova Remnant has undergone many observations via the Chandra X-ray Observatory, with more information found at http://chandra.harvard.edu/photo/2011/tycho/. The second baseline remnant is SNR G292.0+1.8 (see Figure 2), has an unglamorous name based on its catalog coding, but nevertheless has been an important object for gaining "textbook" understanding of supernovas, specifically those that are rich in oxygen content. SNR G292.0+1.8 resulted from a Type II supernova and more information about this event can be found at http://chandra.harvard.edu/photo/2007/g292/.



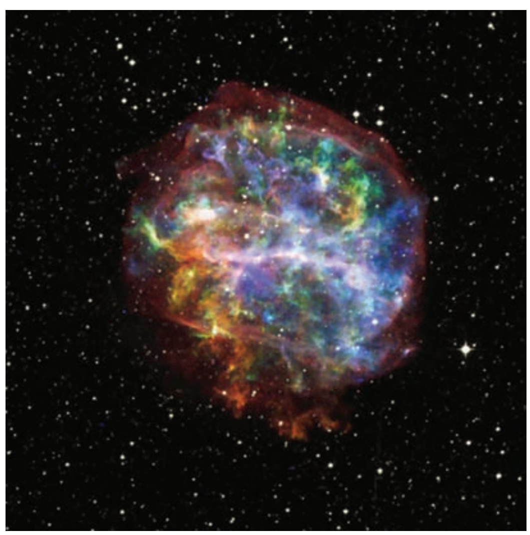


Figure 1 (left). An image of Tycho's Supernova Remnant, which was formed by a Type Ia supernova of a white dwarf located about 13,000 light years from Earth.

Credit: NASA/CXC/Chinese Academy of Sciences/F. Lu et al.

Figure 2 (right). An image of SNR G292.0+1.8, a remnant of a Type II supernova formed by the explosion of a massive star located about 20,000 light years from Earth.

Credit: X-ray: NASA/CXC/Penn State/S.Park et al.; Optical: Pal.Obs. DSS

To determine the chemical compositions of Tycho's Supernova Remnant and SNR G292.0+1.8, students look for peak emission lines in energy plots that either (a) they generate using the ds9 imaging and analysis software or (b) are provided in the pencil and paper version of the activity (see

Figures 3 and 4). Energy plots represent the spectrum of different X-ray photon energies collected by Chandra during an observing run and provide a chemical "fingerprint" of remnants. *Investigating Supernova Remnants* includes a database of different photon energies and their elements that students can use as they look up peak emission lines that they can identify on the graph.

Figure 3. Bremsstrahlung Spectrum of Tycho's SNR

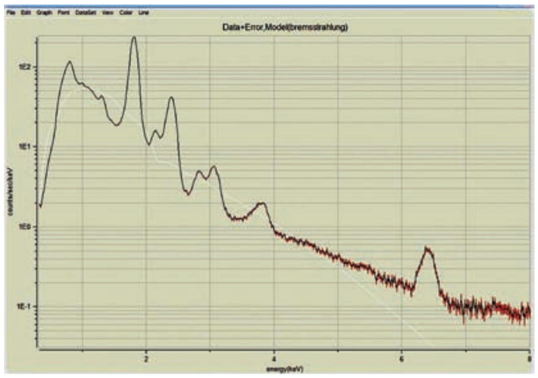
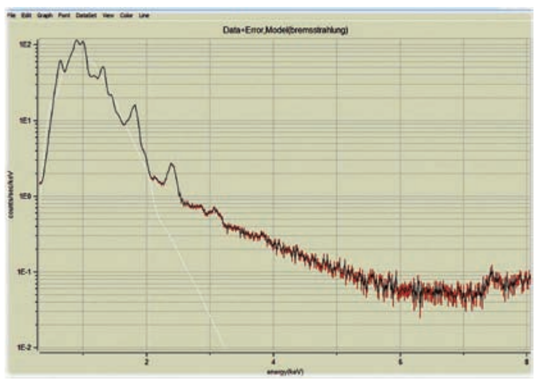


Figure 4. Bremsstrahlung Spectrum of G292.0+1.8



The peaks produced by the elements are referred to as emission lines, the greater the peak, the stronger the emission line (See Figures 3 and 4). To determine relative strength of the peaks, the X-ray spectra the emission lines are superimposed on top of a large curve that is also drawn as white lines on Figures 3 and 4. This curve is produced by the acceleration of electrons as they are deflected by positively charged atomic nuclei and is called Bremsstrahlung (breaking) radiation. The distribution of photon energies due to Bremsstrahlung radiation is called a continuous spectrum. Peak emission lines that spike above the Bremsstrahlung curve correspond to the ejection of K and L shell electrons knocked out of atoms in collisions with the high-energy electrons. The energies of these emission lines can be used to identify the elements in plasma rich environments, such as supernova remnants.

Beyond the Baseline

Once students have identified the chemical structure of Tycho's Supernova Remnant and SNR G292.0+1.8—the known Type Ia and Type II remnants, respectively—the activity pushes students to examine five mystery remnants. The purpose of this extension is to have students use the information they have gained in the two baseline remnants to make inferences about what types of supernovas the mystery remnants represent. In other words, which of the supernova remnants look chemically similar to Tycho's and may be Type Ia, and which look similar to SNR G292.0+1.8 and may be Type II? Again, the spectral plots of these mystery remnants and associated extension questions are included in the *Investigating Supernova Remnants* activity.

Developing Student Scientists

Investigating Supernova Remnants is an excellent platform for launching students into conducting scientific investigations using freely available data, which in large part, may have not been analyzed by astronomers. Students can conduct this activity in pencil and paper mode with hard copies of X-ray spectra; however, this is activity is most powerful for students if they use the ds9 imaging analysis software. This software allows the user to download a toolbox onto their desktop and remotely access dedicated Linux servers which process the analysis commands.

The ds9 image analysis software allows educators, students, amateur astronomers and the general public to perform X-ray astronomy data analysis using data sets from the Chandra X-ray Observatory, the ds9 image display program, and astrophysical software analysis tools. The program uses the same analysis process that an X-ray astronomer would follow in analyzing the data from a Chandra observation. The download instructions to install the ds9 toolbox on your desktop are located athttp://chandra-ed.harvard.edu/install.html. The introduction at http://chandra-ed.harvard.edu/learning_ds9overview.htmldescribes the overview and purpose of the software.

Almost all of the Chandra observations are freely available online at http://cxc.harvard.edu/cda/public.html. These data are generally released to the public after about one year from the observation period to allow the proposing scientific team a "first crack" at the information. However, even though scientists have had a first look opportunity, much of the data may not have been involved in the scientific analysis. Therefore, there are many data that are unexplored. This presents a wonderful opportunity for students to provide a unique analysis of astronomical information and the potential for students to do some meaningful science. By using ds9, which is the same imaging analysis software used by astronomers, and the wealth of data that has been collected by the Chandra X-ray observatory, students can actively engage in the scientific process. This in turn will increase their learning of phenomena, such as supernova remnants, which are essential for understanding the material composition of our universe.

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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.