Teacher Guide for Estimating the Age of Supernova Remnants:

Overview:

The dates for some historical supernovas (SNRs) are well known – such as Tycho's supernova observed and recorded in 1572 and the Kepler supernova event 32 years later in 1604. If a supernova event occurred within recorded history, the date is reasonably established. Sometimes, as with the Cassiopeia A (Cas A) supernova remnant, the date is not known.

For additional information, the Chandra chronicle below discusses historical supernovas and gives a table listing 9 SNRs with additional information.
http://chandra.harvard.edu/chronicle/0406/historical_snr/

For the Cas A remnant, there are several possibilities for the date of the event: John Flamsteed may have observed it in 1680, it may have been recorded in medieval poetry on the birthday of King David II in 1629, and there is evidence within the Greenland Ice Core Science Project H-2 core that a possible date could be 1667.
The URL below is a page from the background information for the Ice Core Records – From Volcanoes to Supernovas investigation and is a summary of the evidence for the possible dates for the Cas A SNR.
http://chandra.si.edu/edu/formal/icecore/summarizing.html

An approximate date for Cas A can also be estimated by calculating the expansion rate of the remnant itself. Mathematical extrapolations from several different features within the remnant converge on a date of 1681 – plus or minus 19 years – so any of the possible dates listed above are all possibilities. There is no definitive date for the Cas A supernova event. The Chandra ds9 image analysis software is one method of mathematically determining the expansion rate and therefore the age of the Cas A supernova.

The Chandra ds9 image analysis software allows educators and students to perform X-ray astronomy data analysis using data sets from the Chandra X-ray Observatory, and the ds9 image display program and 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. Ds9 allows the user to download a toolbox and remotely access dedicated Linux servers which process the analysis commands and return the results to the user. The download instructions to install the ds9 toolbox on your desktop are located at http://chandra-ed.cfa.harvard.edu/install_2014.html. The introduction at http://chandra-ed.harvard.edu/learning_ds9overview.html describes the overview and purpose of the software and gives a short summary of the Chandra mission. The tutorial for using the ds9 software is located at http://chandra-ed.harvard.edu/learning_ds9.html.

NOTE: It is not necessary to read the tutorial before beginning the activities and investigations. All ds9 educational activities are constructed to use one or two specific software tools, and complete instructions to use the tools are given within the individual activities. Since computers are not always available as an option, a paper and pencil version of this investigation is also provided that includes screen shots of the necessary images from ds9.

Teacher Guide for Estimating the Age of Supernova Remnants:

Estimating the Age of Supernova Remnants is a completely self-contained activity. The student handout contains a brief introduction; download instructions for the ds9 software, and a step by step procedure to determine the age of the Cassiopeia A (Cas A) supernova remnant (SNR). All necessary equations and conversion factors are provided.

As stated in the overview, students do not need to read the ds9 tutorial or have any prior knowledge of the ds9 software to use this activity. All necessary instructions are included within the activity, including download and installation instructions. The software is downloadable to desktops and laptops in either a Windows or Mac environment.

If you want your students to have some prior knowledge of the ds9 software, you may consider the three following basic activities which introduce the software and imaging.

The Decoding Starlight: From Pixels to Images High School Version is a pencil and paper activity that uses Chandra data from Cas A to give students an idea of how photon intensity is converted into images and does not use ds9.
http://chandra.harvard.edu/edu/formal/imaging/highIndex.html

The 3-Color Composite Images activity is a short, completely self-contained activity that guides students through the process of merging 3 images (red filter – soft X-rays, green filter – medium X-rays, blue filter – hard X-rays) into one composite image using ds9 and ImageJ software.
http://chandra.si.edu/edu/formal/age_snr/3color_ds9.html

In the openFITS Create Images from Raw Data activity, students learn how to smooth the data, remove artifacts, and use colorize, hue and color curves to produce their own unique images of any of the 22 objects they choose. The objects range from pulsars, to supernovas to galaxies, to Sagittarius A – the black hole in the center of the Milky Way Galaxy. http://chandra.harvard.edu/photo/openFITS/

If computers are not an option, this activity has both a ds9 version, and a pencil and paper version that incorporates screen shots from the ds9 software. Students perform the same calculations and answer the same questions with either version of this activity.

The answer key gives the answers and shows all of the calculations. It is important that the students discuss their individual or group results as there will be variations in the answers. Also, the answers will be an approximation only. The answers will differ from the current range of probable dates for the event of ~334 to ~384 years ago. The student calculations will give answers of ~625. However, this is the same order or magnitude, and when dealing with astronomical distances and timeframes, that is perfectly acceptable. This is the opportunity to discuss orders of magnitude, and the assumptions and approximations within computer and mathematical models that affect the outcome of calculations. Reading the Summarizing the Evidence for Dating the Cas A Supernova from the Ice Core Records materials mentioned above describes other models used to determine astronomical dates. http://chandra.si.edu/edu/formal/age_snr/answer.html

Assessment:
The following Rubric can be used to assess student understanding of the physics content and calculations in this activity.

Task Specific Scoring Rubric for <u>Estimating the Ages of Supernova Remnants</u>

Content Understanding	Communication
4pts- Students have correctly calculated an age of ~625 years for the Cas A supernova event using the ds9 data, appropriate mathematical equations and conversions correctly. 3 pts- Students have calculated an age of ~625 + /- 100 years for the Cas A supernova event using ds9 data, the appropriate mathematical equations and conversions correctly. 2 pts- Students have calculated an age for the Cas A supernova event using the ds9 data correctly, but there are some inaccuracies using the mathematical equations and conversions. 1 pt- Students have calculated an age for the Cas A supernova remnant event, but the ds9 data was analyzed incorrectly and there are some inaccuracies using the mathematical equations and conversions. 0 pts- Incomplete or missing	4 pts- Students describe results in detail using correct terminology. Information is clearly understood by the listener or reader and does not sound as if it was merely copied off the web site. 3 pts- Students describe results in general terms using correct terminology. Information can be understood by the listener or reader and in most cases, does not sound as if it was merely copied off the web site. 2 pts- Students describe results with little detail and some terminology may be incorrect. Information may be unclear to the listener or reader and may sound as if it was copied from the web site. 1 pt- Students describe results, but much of the terminology is incorrect. Information is vague and/or confusing to the listener or reader and may sound as if it was copied from the web site. 0 pts- Incomplete or missing

Extensions and Resources:

Students can use this same method to determine the distances to other supernova remnants. In the student handout, the Obs IDs for G11.2-0.3 and Tycho's SNR are given as suggestions and several resources are listed that provide additional information in determining the ages of supernova events.

SpaceMath@NASA introduces students to the use of mathematics involved with scientific discoveries. Through press releases and articles, Space Math explores how many kinds of mathematics skills come together in exploring the Universe. The Chandra website has several math related problem sets posted as part of this program at: http://chandra.harvard.edu/edu/formal/math/

The Chandra Studies an Expanding Supernova Shell (**problem #314**) involves students using a millimeter ruler and a sequence of images of a gaseous shell observed between 2000 and 2005 to calculate the speed of the material ejected by Supernova 1987A. The student handout is located at http://chandra.harvard.edu/edu/formal/math/index.html More information about the SpaceMath@NASA program is available at http://spacemath.gsfc.nasa.gov

Connections to the Standards:

Below are the connections for the Estimating the Age of Supernova Remnants activity to the Next Generation Science Standards (NGSS), the National Science Education Standards (NRC), and Benchmarks for Literacy Project 2061.

Next Generation Science Standards (NGSS)
http://www.nextgenscience.org/search-standards-dci

Performance Expectations:

HS-PS3 Energy

HS-PS3-1. Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.

HS-PS3-2. Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).

HS-PS4. Waves and their Applications in Technologies for Information Transfer

HS-PS4-2. Evaluate questions about the advantages of using a digital transmission and storage of information.

HS-PS4-5. Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.

Science and Engineering Practices:

Analyzing and Interpreting Data:
Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. (**HS-PS3-1**)

Using Mathematics and Computational Thinking:
Use mathematical representations of phenomena to describe explanations. (**HS-PS3-1**)

Obtaining, Evaluating, and Communicating Information:
Communicate technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically). (**HS-PS4-5**)

Developing and Using Models:
Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system. (**HS-PS3-2**)

Disciplinary Core Ideas:

PS3.A: Definitions of Energy

Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. (**HS-PS3-1**), (**HS-PS3-2**)

PS3.B: Conservation of Energy and Energy Transfer

At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. (**HS-PS3-2**)

Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. (**HS-PS3-1**)

The availability of energy limits what can occur in any system. (**HS-PS3-1**)

PS4.A: Wave Properties
Information can be digitized (e.g., a picture stored as the values of an array of pixels); in

this form, it can be stored reliably in computer memory and sent over long distances as a series of wave pulses. (**HS-PS4-2**), (**HS-PS4-5**)

PS4.C: Information Technologies and Instrumentation
Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world (e.g., medical imaging, communications, scanners) and in scientific research. They are essential tools for producing, transmitting, and capturing signals and for storing and interpreting the information contained in them. (**HS-PS4-5**)

Cross Cutting Concepts:

Systems and System Models
Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models. (**HS-PS3-1**)

National Science Education Standards (Grades 9-12)
http://www.nap.edu/openbook.php?record_id=4962&page=173

Content Standard A – Science As Enquiry:

1. Use Technology & 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. The use of computers for the collection, analysis, and display of data is also a part of this standard. Mathematics plays an essential role in all aspects of an inquiry. For example, measurement is used for posing questions, formulas are used for developing explanations, and charts and graphs are used for communicating results.

2. Understanding about Scientific Enquiry: Scientists conduct investigations for a wide variety of reasons. For example, they may wish to discover new aspects of the natural world, explain recently observed phenomena, or test the conclusions of prior investigations or the predictions of current theories. Scientists rely on technology to enhance the 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 accuracy and precision of the data, and therefore the quality of the exploration, depends on the technology used.

Content Standard E – Science And Technology:

1. Understandings about science and technology: Science often advances with the introduction of new technologies. Solving technological problems often results in new scientific knowledge. New technologies often extend the current levels of scientific understanding and introduce new areas of research.

Benchmarks For Science Literacy Project 2061 (Grades 9-12)
http://www.project2061.org/publications/bsl/online/index.php?home=true

1. The Nature of Science

• Science is based on the assumption that the universe is a vast single system in which the basic rules are everywhere the same and that the things and events in the universe occur in consistent patterns that are comprehensible through careful, systematic study. **1A/H1***

• In science, the testing, revising, and occasional discarding of theories, new and old, never ends. This ongoing process leads to a better understanding of how things work in the world but not to absolute truth. **1A/H3bc***

• Sometimes, scientists can control conditions in order to obtain evidence. When that is not possible, practical, or ethical, they try to observe as wide a range of natural occurrences as possible to discern patterns. **1B/H3***

• Scientists often cannot bring definitive answers to matters of public debate. There may be little reliable data available, or there may not yet be adequate theories to understand the phenomena involved, or the answer may involve the comparison of values that lie outside of science. **1C/H9**** (**SFAA**)

2. The Universe

• 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; computers handle data and complicated computations to interpret them; space probes send back data and materials from remote parts of the solar system; and accelerators give subatomic particles energies that simulate conditions in the stars and in the early history of the universe before stars formed. **4A/H3**