Teacher Guide for Analyzing X-Ray Pulses from Stellar Cores:

Overview:

The Analyzing X-Ray Sources from Stellar Cores investigation examines and compares two end products of stellar evolution – GK Per and Cen X-3 – to determine if these stellar cores are white dwarfs and/or neutron stars by calculating the periods of X-ray pulses recorded by the Chandra X-Ray Observatory. This investigation uses the ds9 image analysis software package. Ds9 allows the user to download a toolbox onto their desktop and remotely access dedicated Linux servers which process the analysis commands. There is also a pencil and paper version of this investigation if computers are not an option.

This investigation is an application of several basic physics equations and topics encountered in introductory physics and physical science classes, including Newton's Universal Law of Gravitation and centripetal acceleration. Analyzing X-Ray Sources from Stellar Cores is also useful after the study of stellar evolution in an astronomy classroom. A complete background and introduction to stellar evolution is located at http://chandra.harvard.edu/edu/formal/stellar_ev/story/. More stellar evolution resources are listed in the resource section of this guide.

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 investigation 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 desktop are located at http://chandra-ed.cfa.harvard.edu/install_2014.html. The introduction at http://chandra-ed.harvard.edu/learning_ds9overview.html provides an overview of the software and 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 each activity and investigation is also provided that include screen shots of the necessary images from ds9. The only additional materials required are pencils and rulers.

Teacher Guide for the Analyzing X-Ray Pulses from Stellar Cores Investigation:

Ds9 Version:

The Analyzing X-Ray Sources From Stellar Cores investigation student handout includes a brief introduction to light curves, white dwarfs and neutron stars; as well as the download instructions for the ds9 software and a step by step procedure to analyze GK Per and Cen X-3. All necessary equations, conversion factors and constants are provided. The student handout is completely self-contained and includes all information students need to complete the investigation.

As stated in the overview, students do not need to read the ds9 tutorial or have any prior knowledge of the ds9 software to perform this investigation. All necessary instructions for downloading and using the software is included within the investigation. 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 ds9 software and astronomical 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.
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 image 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/

Pencil & Paper Version:
If computers are not an option, the Analyzing X-Ray Pulses from Stellar Cores investigation also has 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. No materials are required other than the student handout.

Ds9 Version: http://chandra.harvard.edu/edu/formal/stellar_cores/ds9.html
Pencil & Paper Version: http://chandra.harvard.edu/edu/formal/stellar_cores/paper.html

Assessment:

The answer key http://chandra.harvard.edu/edu/formal/stellar_cores/answer.html provides the solutions to the mathematical calculations and the identity of the objects GK Per and Cen X-3. Note that some mathematical answers may vary.

The following rubric can be used to assess student understanding of the Analyzing X-Ray Pulses from Stellar Cores investigation.

Task Specific Scoring Rubric

Content Understanding	Communication
4pts- Students have correctly calculated the centripetal acceleration and the acceleration due to gravity for both stellar cores, and correctly identified GK Per as a white dwarf and Cen X-3 as a neutron star. 3 pts- Students have correctly calculated the centripetal acceleration and the acceleration due to gravity for both stellar cores, and correctly identified GK Per as a white dwarf and Cen X-3 as a neutron star. 2 pts- Students have calculated a reasonable centripetal acceleration for both stellar cores, but the stellar cores were not correctly identified. There may be some inaccuracies in the calculations as well as poor understanding of the physics involved. 1 pt- Students have calculated a centripetal acceleration and have incorrectly identified the stellar cores. The calculations are incorrect and there is little or no understanding of the physics involved. 0 pts- Incomplete or missing	4 pts- Students completely and accurately describe the data analysis method and mathematical procedure and reasoning for identifying the stellar cores. 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 completely and accurately describe the mathematical procedure. Reasoning includes a correct discussion of centripetal acceleration and the acceleration due to gravity. 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 their calculations and reasoning for identifying the stellar cores, but some of the terminology is 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 their calculations and identification of the stellar cores, 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

Additional Resources:

Mathematics Resources:

SpaceMath@NASA introduces students to the use of mathematics in today's 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/. Some Chandra math problems that use basic physics calculations and topics are:

Problem **#314** – Chandra Studies an Expanding Supernova Shell – students calculate the speed of the material ejected by Supernova 1987A with a millimeter ruler and a sequence of images of a gaseous shell observed between 2000 and 2005.

Problem **#417** – Estimating the Size and Mass of a Black Hole – students use a simple formula to estimate the size of a black hole located 3.8 billion light years from Earth, recently studied by NASA's Chandra and Swift satellites.

Problem **#390** – X-Rays From Hot Gases Near the Black Hole SN1979c – students use two functions to estimate the size of a black hole from the gas emitting X-rays which is flowing into it.

Problem **#285** – Chandra Sees the Most Distant Cluster in the Universe – students work with kinetic energy and escape velocity to determine the mass of a distant cluster of galaxies by using information about its X-ray light emissions.

Problem **#144** – Exploring Angular Size – students examine the concept of angular size and how it relates to the physical size of an object and its distance. A Chandra satellite X-ray image of the star cluster NGC-6266 is used, along with its distance, to determine how far apart the stars are based on their angular separations.

Physics Resources:

Here. There. Everywhere is a series of topics each with 3 images that represent the topic from daily experience, the natural world, and the universe. The images show how knowledge of familiar processes is applied to understand similar behaviors on grander scales, and in very different environments. The laws of physics are universal, and the physical processes that underlie our daily experiences are on constant display in the natural world – as well as extend to the stars and galaxies within the universe.

This series helps students better understand cosmic phenomena by looking and studying what they experience on a daily basis, because what happens here, happens there, and happens everywhere. The **Here. There. Everywhere.** Series is located at: http://hte.si.edu/topics.html

Astronomy Resources:

Podcasts:

White Dwarfs: http://chandra.si.edu/resources/podcasts/by_category.html?catid=17
Neutron Stars: http://chandra.si.edu/resources/podcasts/by_category.html?catid=18

AAVSO: The American Association of Variable Star Observers (AAVSO) has an entire variable star curriculum for educators as well as amateur astronomers, and an archive of variable stars; including GK Per.
The Variable Star Astronomy curriculum is located at http://www.aavso.org/education/vsa. Scroll down to Chapter 11 (Variable Stars, Light Curves, and Variability).
Scientific information for GK Per is located at:
http://www.aavso.org/vsots_gkper

References:

The Encyclopedia of Astrobiology, Astronomy, and Spaceflight - Cen X-3:
http://www.daviddarling.info/encyclopedia/C/Centaurus_X-3.html

Wikipedia: http://en.wikipedia.org/wiki/Centaurus_X-3 (Information on Cen X-3)

Connections to the Standards:

Below are the connections for the Star Formation and U/HLXs in the Cartwheel Galaxy investigation 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-PS2 Motion and Stability: Forces and Interactions

HS-PS2-4: Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between 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:

Asking Questions and Defining Problems
Evaluate questions that challenge the premise(s) of an argument, the interpretation of a data set, or the suitability of a design. (**HS-PS4-2**)

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-PS2-4**)

Using Mathematics and Computational Thinking
Use mathematical representations of phenomena to describe explanations. (**HS-PS2-4**)

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**)

Disciplinary Core Ideas

PS2.B: Types of Interactions
Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. (**HS-PS2-4**)

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, and 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:

Patterns:
Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. (**HS-PS2-4**)

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. Formulate and Revise Scientific Explanation and Models Using Logic & Evidence Student inquiries should culminate in formulating an explanation or model. Models should be physical, conceptual, and mathematical. In the process of answering the questions, the students should engage in discussions and arguments that result in the revision of their explanations. These discussions should be based on scientific knowledge, the use of logic, and evidence from their investigation.

3. 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.

4. Communicate and Defend a Scientific Argument
Students in school science programs should develop the abilities associated with accurate and effective communication. These include writing and following procedures, expressing concepts, reviewing information, summarizing data, using language appropriately, developing diagrams and charts, explaining statistical analysis, speaking clearly and logically, constructing a reasoned argument, and responding appropriately to critical comments.

Content Standard D – Earth and Space Science

1. The Origin and Evolution of the Universe
Early in the history of the universe, matter, primarily the light atoms hydrogen and helium, clumped together by gravitational attraction to form countless trillions of stars. Billions of galaxies, each of which is a gravitationally bound cluster of billions of stars, now form most of the visible mass in the universe.

Content Standard E – Science and Technology:

1. Communicate the Problem, Process and Solution:
Students should present their results to students, teachers, and others in a variety of ways, such as orally, in writing, and in other forms—including models, diagrams, and demonstrations.

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

- Eventually, some stars exploded, producing clouds containing heavy elements from which other stars and planets orbiting them could later condense. The process of star formation and destruction continues. **4A/H2ef**
- 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**