Teacher Guide for Star Formation and U/HLXs in the Cartwheel Galaxy:

Overview:

The Star Formation and U/HLXs in the Cartwheel Galaxy investigation examines and compares the Cartwheel Galaxy in optical and X-ray bands to determine the sources of the ultra and hyperluminous X-rays (U/HLXs) in the galaxy. 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.

The unusual shape of the Cartwheel Galaxy is most probably the result of a collision with one of the smaller nearby galaxies several hundred years ago. The collision produced compression waves within the galaxy which triggered bursts of massive star formation. When the most massive of these stars collapse as supernovas, neutron stars and black holes are formed. Some of these neutron stars and black holes are in binary systems, and have become powerful sources of X-rays as they accrete material from nearby companion stars.

Ultraluminous X-ray sources (ULXs) are extragalactic objects that are located outside the nuclei of their host galaxies. The characteristics of their X-ray emission are consistent with accreting black holes; however their X-ray luminosities exceed the maximum theoretical limit for a stellar mass black hole of ~3 to ~80 solar masses formed through the collapse of massive stars. These luminosities have been interpreted as evidence of a new class of intermediate mass black holes with masses between ~100 - 100,000 solar masses. The brightest of these objects, the hyperluminous X-ray sources, have luminosities that cannot be easily explained without the existence of intermediate mass black holes.

Students investigate the U/HLXs in the Cartwheel galaxy and determine the sources for these objects.

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. 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 each activity and investigation is also provided that include screen shots of the necessary images from ds9.

Teacher Guide for the Cartwheel Galaxy Investigation:

The Star Formation and U/HLXs in the Cartwheel Galaxy investigation student handout includes a brief introduction to the Cartwheel Galaxy and its neighboring galaxies, the download instructions for the ds9 software, and a step by step procedure to download and analyze the ultra and hyperluminous X-ray sources (U/HLXs) in the Cartwheel Galaxy.

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 are within the activity, including downloading the software. 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 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/

If computers are not an option, the Cartwheel Galaxy investigation also has a pencil and paper version that incorporates screen shots from the ds9 software. Students will perform the same calculations and answer the same questions with either version.

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

Assessment:

The answer key http://chandra.harvard.edu/edu/formal/cartwheel/answers.html gives the quantitative and qualitative answers to the questions in the investigation. Note that some answers will vary depending upon individual student reasoning and interpretation of the data.

The following rubric can be used to assess student understanding of the Star Formation and U/HLXs in the Cartwheel Galaxy investigation.

Task Specific Scoring Rubric

Content Understanding	Communication
4pts- Students have correctly calculated the size of the ring, the distance the Cartwheel Galaxy has moved, and correctly answered the 4 questions in the conclusion and analysis section. 3 pts- Students have correctly calculated the size of the ring, the distance the Cartwheel Galaxy has moved, and correctly answered at least 3 of the 4 questions in the conclusion and analysis section. 2 pts- Students have calculated the size of the ring, the distance the Cartwheel Galaxy has moved, and answered at least 2 questions in the conclusion and analysis section. There may be some inaccuracies in the calculations. 1 pt- Students have calculated the size of the ring and the distance the Cartwheel Galaxy has moved; however the answers to the questions in the conclusion and analysis section are not complete and there are inaccuracies. 0 pts- Incomplete or missing	4 pts- Students completely and accurately describe their reasoning for identifying the U/HLX sources with 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 completely and accurately describe their reasoning for identifying the U/HLX sources with 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 their reasoning for identifying the U/HLXs sources 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 reasoning for identifying the H/HLX sources, 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 Additional Resources:

At the end of the investigation students are given the option of repeating this analysis with two additional star formation galaxies:
1. The Antennae: Chandra Locates Mother Lode of Planetary Ore in Colliding Galaxies
http://chandra.harvard.edu/photo/2004/antennae/
2. M82: Images From Space Telescopes Produce Stunning View of Starburst Galaxy
http://chandra.harvard.edu/photo/2006/m82/index.html

Students can also analyze the spectra of the Cartwheel, Antennae, and M82 galaxies with the ds9 software. Instructions for analyzing spectra are in the X-Ray Spectroscopy and Supernova Remnants investigation at http://chandra.harvard.edu/edu/formal/snr/ds9.html

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 similar 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.

Photo Album and Podcasts:
Podcast of The Antennae is located at:
http://chandra.harvard.edu/resources/podcasts/by_category.html?page=2&catid=21
Podcast of M82 is located at:
http://chandra.harvard.edu/resources/podcasts/by_category.html?page=5&catid=21
Photo Album Cartwheel Galaxy: http://chandra.harvard.edu/photo/2006/cartwheel/
Photo Album M82 Galaxy: http://chandra.harvard.edu/photo/2011/m82/
Photo Album Antennae Galaxy: http://chandra.harvard.edu/photo/2010/antennae/

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-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.

HS-ESS1: Earth's Place in the Universe

HS-ESS1-1: Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun's core to release energy in the form of radiation.

Science and Engineering Practices:

Developing and Using Models:
Develop a model based on evidence to illustrate the relationships between systems or between components of a system. (**HS-ESS1-1**)

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**)

Engaging in Argument from Evidence:
Evaluate the claims, evidence, and reasoning behind currently accepted explanations or solutions to determine the merits of arguments. (**HS-PS4-5**)

Disciplinary Core Ideas:

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**)

ESS1.A: The Universe and Its Stars
The star called the sun is changing and will burn out over a lifespan of approximately 10 billion years. (**HS-ESS1-1**)

Cross Cutting Concepts:

Cause and Effect
Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (**HS-PS4-5**)

Scale, Proportion, and Quantity
The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. (**HS-ESS1-1**)

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. 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**