Teacher Guide: ***Pulsating Variable Stars & the Hertzsprung-Russell (H-R) Diagram***

Pulsating Variable Star and H-R Diagram Activity Summary:

The traditional Hertzsprung-Russell (H-R) diagram activity is a plot of the nearest and brightest stars. This activity is an extension of the traditional plotting activity, and begins with an H-R diagram with enough bright and nearby stars plotted to define the shape and location of the main sequence, and the location of the giant and white dwarf branches. The activity is part of the *Variable Star Astronomy* (formerly *Hands-On Astrophysics*) curriculum developed by the American Association of Variable Star Observers (AAVSO) in Cambridge, MA. There are other versions of the activity and they will be described in the "Using the Variable Star/H-R Diagram Activity Materials in the Classroom" section below. The traditional H-R diagram plotting activity shows the different branches of the diagram and the location of giants, supergiants and white dwarfs – all part of the evolutionary track involving main sequence stars. However, it presents a rather static view of stellar evolution.

The emphasis of this activity is the plotting of four types of intrinsic pulsating variable stars – Cepheids, RR Lyraes, Miras and Semiregulars. These variable stars can be thought of as representing transition stages for some stars as they evolve from the main sequence and "move" to other branches of the H-R diagram. These variable stars occupy regions on the H-R diagram known as instability strips, and plotting their variability as they transition from one evolutionary stage to another gives a better perspective of stellar evolution as a continuously changing process. This is further emphasized by plotting these pulsating variables at both maximum and minimum brightness to show how much they vary in brightness and temperature as they transition through the instability strips.

Using the Background Information (8 pages):

The student handout includes all information necessary for completing the H-R diagram plotting activity. Teachers may use the background information for their own edification, or download all or part of the information for student use depending on individual classroom needs. The first 2 pages of the background information provides a description of the H-R diagram – including absolute magnitude, temperature, spectra, stellar classification, luminosity, and the major branches. The remaining 6 pages describe variable stars and light curves, cataclysmic and intrinsically pulsating variable stars, and H-R diagram instability strips. The background information includes links for additional in-depth information on stellar evolution. All Chandra stellar evolution materials can be accessed on the Chandra website at http://chandra.harvard.edu/edu/formal/index.html.

Using the Variable Star/H-R Diagram Activity Materials in the Classroom:

The 7-page *Student Variable Star H-R Diagram Activity* handout provides all the information necessary for completing the activity – including the H-R diagram worksheet. The three sets of questions on page 4 are for the purpose of determining if students have a basic understanding of the H-R diagram, and the two sets of questions on page 6 are a discussion of their results. Answers will vary; however, students should have answers comparable to the following:

Before the activity:

1.) Plotting both the brightest and the nearest stars are necessary to see a normal or typical distribution of the stellar population, and the same distribution and percentage of stars on the individual branches would be seen from any position within the Milky Way Galaxy as there is no preferred view of the galaxy. This is the basis of the cosmological principle – that the universe is homogeneous and isotropic over large scale distances – the assumption that observers on Earth do not occupy a unique location within the universe.
2.) Main sequence stars have a specific relationship based on mass – the most massive stars have the brightest absolute magnitudes (luminosities) and highest surface temperatures, and the least massive stars have the dimmest absolute magnitudes and lowest surface temperatures. That relationship only holds for the main sequence – other branches have no specific relationship. As stars transition from the main sequence to other regions on the diagram, there are various tracks that they follow, and there are areas for which specific combinations of stellar luminosities and temperatures does not exist. Other stellar evolution stages and/or objects, such as supernovas, neutron stars and black holes are too extreme to be plotted on the H-R diagram.
3.) The answers will vary – from the introduction students will know that the pulsating variables occupy specific regions of instability so they will be able to reasonably predict the locations.

NOTE: A completed H-R diagram answer key with the plotted variables and a separate H-R diagram answer key with plotted variables and the branches labeled are provided.

After the activity:

1.) Various answers depending on the responses to question 3 above.

2.) The Cepheids, RR Lyaes and the Miras are grouped fairly closely together; however, the two Semiregulars are not. Students should understand that variable stars are classified from their light curves and think about why the two Semiregulars are not together. Semiregular stars are giants and supergiants so there is a large range in mass, which can lead to different evolutionary tracks along the H-R diagram.

This activity focuses on plotting pulsating variable stars. The student H-R diagram worksheet has bright and nearby stars already plotted. If you would prefer your students to plot the bright and nearby stars themselves before plotting the variable stars, a blank H-R diagram and the star data tables are available separately to download. The variable star data tables list the stars, spectral class, absolute magnitude and distance in parsecs. The distances are included because all the absolute magnitudes were calculated from parallax and apparent magnitude measurements by the HIPPARCOS mission. This allows for consistency for the absolute magnitude values. Another version of this activity on the AAVSO website lists the distance in parsecs but not the absolute magnitudes – the students have to calculate the absolute magnitudes using the parallax measurement and the distance modulus. All versions of the H-R diagram activity, including information for teachers, are part of the *Variable Star Astronomy (VSA)* curriculum posted on the AAVSO website: chapter 9 entitled *The Life of a Star*. *Variable Star Astronomy (VSA)* can be accessed at http://www.aavso.org/education/vsa.

Supporting Classroom Activities, Materials, and Resources:

Stellar Life Cycles Activity and Card Set

The Chandra E/PO office has developed an activity with a scoring rubric that is useful as a post assessment for the *Pulsating Variable Stars and the H-R Diagram* activity. It is designed to be used as either a pre or a post assessment activity to determine student understanding of stellar evolution. The image set for the activity includes images of the different stages of stellar evolution, light curves and H-R diagrams. (HTML, PDF and PowerPoint (PPT) versions) Educators can request as many classroom sets of the Stellar Life Cycle cards as necessary.

Stellar Life Cycles Page:
http://chandra.harvard.edu/edu/formal/stellar_cycle/
The Stellar Life Cycles Card Sets Request Form:
http://chandra.harvard.edu/edu/request_special.html
Stellar Cycles Assessment Activity:
http://chandra.harvard.edu/edu/formal/stellar_cycle/task_desc.html
Teacher Guide and Answer Key:
http://chandra.harvard.edu/edu/formal/stellar_cycle/guide.html
Scoring Rubric: http://chandra.harvard.edu/edu/formal/stellar_cycle/rubric.html

Chandra is designed to observe X-rays from high-energy regions of the universe – including cataclysmic variables (supernovas, novas), and X-rays from binary systems such as the pulsating red giant Mira A and its white dwarf companion Mira B. As a result, the American Association of Variable Star Observers (AAVSO) and the Chandra X-Ray mission have collaborated with variable star observations and educational materials in their mutual quest to understand stellar processes and evolution. Two other activities and investigations from the *Variable Star Astronomy* materials, enhanced with extensions and flash versions, are posted on the Chandra website.

Stellar Heartbeats is an introductory activity designed to familiarize students with the magnitude scale and the Julian Day by estimating the changing magnitude of a variable star using comparison stars, plotting a light curve and determining the period. There are HTML, Flash, PDF, and PowerPoint versions.
http://chandra.harvard.edu/edu/formal/variable_stars/activity1a.html

A Variable Star in Cygnus uses a set of photos of the variable star W Cyg. By using actual images of W Cyg students learn how to estimate the changing magnitudes of a variable star with actual comparison stars against a background of the real sky. Students then plot a light curve and determine the period. There are HTML, Flash, PDF, and PowerPoint versions.
http://chandra.harvard.edu/edu/formal/variable_stars/activity2a.html

Chandra Chronicles Articles describing how the AAVSO amateur observers assisted the Chandra X-Ray Observatory for two observing campaigns of the variable star SS Cygni:
Backyard Astronomers Trigger Multi-satellite Observing Campaign on SS Cygni
http://chandra.harvard.edu/chronicle/0101/aavso.html
Astronomers Team Up for Chandra Observations of SS Cygni
http://chandra.harvard.edu/chronicle/0300/aavso.html

Connecting to the National Science Education Standards and Benchmarks:

NATIONAL SCIENCE EDUCATION STANDARDS (Grades 9-12)
http://www.nap.edu/openbook.php?record_id=4962&page=173

1. CONTENT STANDARD A – SCIENCE AS INQUIRY

Formulate and revise scientific Explanations and Models Using Logic and 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.

Understandings about Scientific Inquiry:
5. Scientific explanations must adhere to criteria such as: a proposed explanation must be logically consistent; it must abide by the rules of evidence; it must be open to questions and possible modification; and it must be based on historical and current scientific knowledge.

3. CONTENT STANDARD D – EARTH AND SPACE SCIENCE

The Origin and Evolution of the Universe
3. Stars produce energy from nuclear reactions, primarily the fusion of hydrogen to form helium. These and other processes in stars have led to the formation of all the other elements.

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)

4. THE PHYSICAL SETTING

THE UNIVERSE

• The stars differ from each other in size, temperature, and age, but they appear to be made up of the same elements found on earth and behave according to the same physical principles. 4A/H1a

• 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

11. COMMON THEMES

B. Models

• A mathematical model uses rules and relationships to describe and predict objects and events in the real world. 11B/H1a*

• A mathematical model may give insight about how something really works or may fit observations very well without any intuitive meaning. 11B/H1b

The behavior of a physical model cannot ever be expected to represent the full-scale phenomenon with complete accuracy, not even in the limited set of characteristics being studied. The inappropriateness of a model may be related to differences between the model and what is being modeled. 11B/H5** (SFAA)

C. Constancy and Change:

• Graphs and equations are useful (and often equivalent) ways for depicting and analyzing patterns of change. 11C/H4

• The present arises from the conditions of the past and, in turn, affects what is possible in the future. 11C/H6*

• It is not always easy to recognize meaningful patterns of change in a set of data. Data that appear to be completely irregular may be shown by statistical analysis to have underlying trends or cycles. On the other hand, trends or cycles that appear in data may sometimes be shown by statistical analysis to be easily explainable as being attributable only to randomness or coincidence. 11C/H9** (SFAA)

THE NATIONAL COUNCIL OF TEACHERS OF MATHEMATICS STANDARDS (Grades 9-12)

http://www.nctm.org/resources/content.aspx?id=12630

STANDARD 2: Algebra

Use mathematical models to represent and understand quantitative relationships.

• Draw reasonable conclusions about a situation being modeled.

STANDARD 5: Data Analysis and Probability Standard

Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them:

• Understand histograms, parallel box plots, and scatterplots and use them to display data.