

Star Evolution and Gamma Ray Sources

By Matt Laird and Heather Murphy

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Subject:

STEM

Physics

Chemistry

Earth and Space

Grade:

9th to 12th grade students.

Time:

3 Class Periods of 55 minutes each.

Standard(s): *These performance expectations have been directly taken from the Next Generation Science Standards website at <https://www.nextgenscience.org/>.*

Big Idea 1: Objects and systems have properties such as mass and charge. Systems may have internal structure.

HS-ESSI-3: Communicate scientific ideas about the way stars, over their life cycle, produce elements.

HS-PS1-8: Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion and radioactive decay

Big Idea 2: Fields existing in space can be used to explain interactions.

HS-PS2-5: Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.

HS-PS3-5: Develop and use a model of two objects interacting through electrical or magnetic fields to illustrate the forces between objects and the changes in energy of the object due to the interactions.

HS-PS4-4: Evaluate the validity and reliability of claims in published material of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.

Connections to Prior Learning:

- Electromagnetic Spectrum (See Multiwavelength Astronomy: Lesson Plan)
- HAWC Detector (See Cosmic Gamma Rays: Lesson Plan)
- Observing Radiation (See Multiwavelength Astronomy: Lesson Plan)

Concept/Topic to Teach:

- Sources of Electromagnetic Radiation
- Star Life Cycle
- Gamma-Ray Emitters

- Detecting Objects in Space: HAWC

Specific Objectives: Student will be able to:

- Describe and differentiate the various celestial objects that inhabit the universe.
- Explain Gamma-Ray emitters and how the HAWC observatory models them.
- Interpret star life cycle and evolution and apply it to solve a problem.
- Explain the purpose of multiple wavelength analysis in Astronomy.

Lesson Relevance:

- Communicate scientific ideas about the universe and its features both galactic and extragalactic.
- Construct how the star celestial objects evolve and change.
- Interpret how astronomers determine information about the universe.
- Understand how an observatory (HAWC) collects and models data.
- Appraise the importance of using different tools and instruments to understand the universe.

Cross Curriculum Connections:

- Physics: Nuclear Physics
- Chemistry: Nuclear Chemistry
- Astronomy: Life Cycles of Stars
- Engineering: Observatories and Telescopes in different Spectrums
- Earth and Space: The variety of celestial objects

Required Materials:

- “Life Cycle of a Star” Google Slides Presentation
- “Gamma-Ray Sources” as seen by HAWC Google Slides Presentation
- “Guess What” Card Game
- Computer with Projector
- Access to Streaming Service like YouTube

Technology:

- HAWC

Modification/Accommodation(ELL/IEP students):

- Students could be given access to the ‘Guess What’ cards to assist in the association of the images with the vocabulary.
- Pair down the amount of object to more simple categories (Just galaxies instead of Blazar, Starburst, ect.)

- Additional time for the assignment.
- Guided notes/Printed Google Slides Presentation.
- Reduction of Assignment (choose one EM spectra).
- Provide list of useful Vocabulary.
- Pairing with strong anchor student for project work.

Reteach/Extensions(*struggling/advanced students*):

- Reteach: Focusing on connecting vocabulary with images.
- Extension: Assign other distinguishing features of celestial objects.
- Extension: The expansion set to 'Guess What' to incorporate celestial objects not explicitly covered.

Instructional Procedure: Engage

Heading: The Size of the Universe

Goal of the Day

- Students will be able to compare and contrast the scale of the observable universe.

Advance Preparation:

- Prepare video for viewing.
- Prepare questions to ask class after video viewing.

Background Information (*Lesson Introduction*):

The universe is unimaginably large and populated by an unimaginable assortment and variety of stars, planets, black holes, and other things we haven't discovered yet. The YouTube video succinctly demonstrates the size of the universe. This allows students to grasp the vastness of space.

Procedure/Strategies:

- *Engage*: (5 min): Watch the video: *The Observable Universe (accurately scaled zoom out from Earth)* on YouTube (<https://www.youtube.com/watch?v=HiN6Ag5-DrU>) or another video-streaming service.

Key Vocabulary and Academic Vocabulary:

- Universe: Everything observable – planets, stars, galaxies, light and even the vacuum between these entities.

Assessment: Formative:

Brief classroom discussion on the content of the video. Did the students find it interesting? Were they surprised by the scale of the observable universe?

Resources:

Equinox1989. "The Observable Universe (Accurately Scaled Zoom out from Earth)." *YouTube*, YouTube, 9 Sept. 2012, www.youtube.com/watch?v=HiN6Ag5-DrU.

Instructional Procedure: Explore

Heading: Life Cycle of a Star

Goal of the Day

- Students will be able to communicate scientific ideas about the mass of a star and the stages of a star's lifetime.

Advance Preparation:

- Share 'Life Cycle of a Star' Google Sheet with class
- Copy 'Life Cycle of a Star' Graphic organizer for students Note: This document can be customized for the needs of your students, by increasing or decreasing the number of empty cells.

Background Information (Lesson Introduction):

Field interaction

A field force is capable of acting through space, producing an effect even when there is no physical contact between the objects involved. Many of the celestial objects display observable characteristics of these field interaction.

Stars, within their lifespan, are a notable field force interaction between the pressure of the molecules pushing apart (nuclear force, and thermal energy) and the gravitational field pulling the star together. This interaction is dependent on the mass of the star. The mass determines when the star will contract and expand, and what the final stage of the star will be.

Smaller mass stars will contract to become white dwarf stars. Massive mass stars will further contract, always falling short of balancing gravity, until they become supernova explosions. For massive stars, nuclear burning will not proceed beyond the peak stage of iron formation, because these reactions would cost energy. The end of the thermonuclear life will result in an onion-like structure of shells of different compositions. The shells from the inside out are composed of mostly one type of element; iron, silicon, oxygen, carbon, helium, and finally, hydrogen.

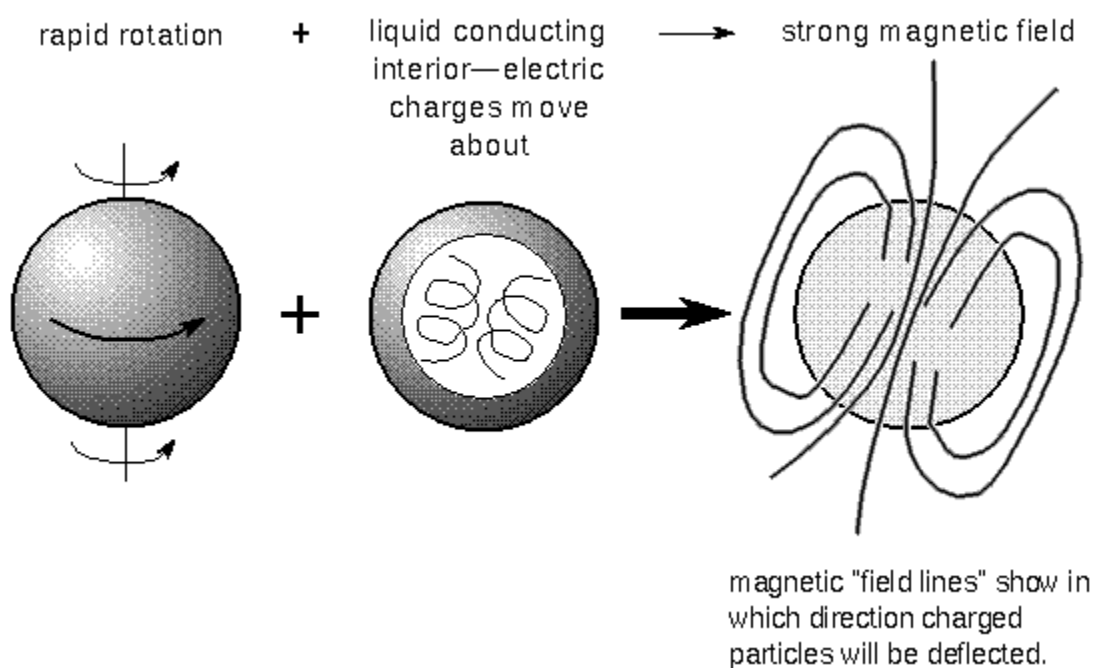
In the collapsing star the density increases to the point that competition between the attractive nuclear and the repulsive Coulomb force leads to a "bounce Back" that sends a outward-moving shock wave, starting the supernova explosion.

The enormous explosion of a supernova causes the interstellar medium (ISM) to expand outward generating shock waves of ISM that play a role in heating and enriching galaxies with material.

Once a massive star has produced a supernova it is known as a supernova remnant (SNR) and the star is known as a Neutron Star. Neutron Stars are observed to have magnetic fields. These observations are due to the field force interaction between an electric field and a magnetic field. An electric field can produce a magnetic field and a changing magnetic field can produce an electric field.

One such neutron star is a pulsar. Pulsars are remarkable because they emit pulses over a finite frequency range. These pulses seem consistent, but in fact are slowing down as the pulsar spins down. The spin-down is related to the magnetic field at the poles of this dipole star. Pulsars with strong magnetic fields (young pulsars) spin-down relatively fast, whereas pulsars with low magnetic fields (aged stars or stars in binary systems) spin-down very slowly.

Magnetars are rare neutron stars with magnetic fields between 100 to 1,000 times stronger than other neutron stars. A magnetar is a product of a fast spinning dynamo effect. This effect is produced when the convection and rotation energy transfers the kinetic energy into magnetic field energy. These strong magnetic fields cause electric fields. Both types of field cause photons to propagate at different speeds depending on their polarization. The magnetic field can also influence the electrons within the atmosphere of the star causing them to squeeze into needle-like shapes.



Graphic: Planetary Science. Astronomynotes.com

Some stars have companion stars called binary systems. When there is a binary system the two celestial objects' field forces interact. If the binary system, for example, involves a white dwarf the gravitational waves interact with the angular momentum, resulting in the slow spiral toward each other. Eventually, the two stars will contact each other in a supernova explosion. Just as the binary system that involved a white dwarf star, a binary system that has a pulsar is slowing down due to the loss of angular momentum to gravitational waves.

When looking for examples of field force interactions one need look no farther than to our Sun or outside our galaxy for dramatic examples of stellar beauty.

Nuclear reaction equations (notation) Isotope

A nuclear reaction involves the nucleus of atoms, whereas, a normal chemical reaction involves the electrons of atoms. There are several types of particles involved in nuclear reactions. The basic types are: alpha (α) a positively charged helium isotope (${}^4_2\text{He}$), Beta (β) a

negatively charged electron (${}^0_{-1}\text{e}$), Gamma (γ) pure energy (${}^0_0\gamma$), neutrons (${}^1_0\text{n}$), positrons a positively charged electron (${}^0_{+1}\text{e}$), and protons (${}^1_1\text{H}$). The symbols for these particles are written in a standardized format with the Mass Number superscript and the Atomic Number as a subscript. An equation such as this: ${}^2_1\text{H} + {}^3_1\text{H} \rightarrow {}^4_2\text{He} + 2 {}^1_0\text{n} + (1.69 \times 10^9 \text{kJ per mole of } {}^4_2\text{He})$ states that there is a deuterium (mass of 2 amu, atomic number 1) collided with a tritium (mass of 3 amu, atomic number 1). The products of this reaction produces a helium atom (mass of 4 amu, atomic number 2), a neutron particle (mass of 1, atomic number 0), and energy.

Procedure/Strategies:

- Bell ringer (5 min): (Check for prior knowledge and misconceptions.) *What is the life cycle of a star?*

-Direct Exploration (45 min): Explore: Life Cycle of a Star

Share the Google Sheet document 'Life Cycle of A Star' with your students. Handout copies of the student version of the 'Life Cycle of A Star' Graphic organizer. Students should fill in the Graphic Organizer using the 'Life Cycle of a Star' document.

Once the graphic organizers have been checked for completeness bring up the 'Life Cycle of a Star' on the projector and have the students take turns explaining each stage.

Key Vocabulary and Academic Vocabulary:

- Active galactic nuclei (AGN): A galaxy that the center of the galaxy emits radiation more powerful than the rest of the galaxy.
- Asteroid: An astronomical object orbiting the sun that does not resemble a planet-like disc.
- Binary System: Two stars rotating around a common central mass.
- Black Dwarf: The stage after white dwarf where the star is no longer emitting any radiation.
- Black Hole: Very dense compression, at the end of a massive star's life.
- Blazar: An AGN with a jet of electromagnetic energy facing Earth.
- Comet: Composed of ice with a rocky core and frequently a tail.
- Dwarf Planet: A planetary-mass object that is neither a true planet nor a natural satellite.
- Isotope: An atom with the same number of protons but different numbers of neutrons.
- Gas Giant: Planets with large amounts of ammonia and methane ice with a rocky or metallic core.
- Magnetar: A neutron star that has a very strong magnetic field.
- Main Sequence Star: 90% of the stars including our Sun. Hydrogen in the core is converted into Helium by Nuclear Fusion.
- Meteoroid: A small rock or metallic body in space that are significantly smaller than an asteroid.
- Moon: An astronomical body that orbits a planet.
- Nebula: A nebula is a giant cloud of matter.
- Neutron Star: A celestial object of very small radius and very high density, composed predominantly of closely packed neutrons.
- Pulsar: A neutron star with a beam of electromagnetic radiation visible when it rotates toward Earth.

- Pulsar Wind Nebula: Nebula inside a Supernova powered by a central pulsar.
- Red Giant: A star without enough mass to continue nuclear fusion beyond He production.
- Starburst: A galaxy under a high rate of star formation (100 times faster than the milky way galaxy).
- SuperGiant: A star with enough mass to continue fusion reaction creating larger atoms (Fe)
- Supernova: A supergiant star exploding, triggered by reignition of Fusion or Gravitational collapse.
- Supernova Remnant: Remains of an exploded star within a supernova
- Terrestrial Planet: Rocky planet with small amounts of ice.
- White Dwarf: A small to medium collapsed star no longer undergoing nuclear fusion.
- X-Ray Binary System: Two stars; one normal star and one collapsed star rotating around a common center of mass that emits x-rays.

Assessment: Formative:

Students should have their graphic organizer completed prior to the end of the class period.

Resources:

AstroMeV, astromev.in2p3.fr/?q=aboutus/gamma-ray-binaries.

“Active Galactic Nucleus.” *Wikipedia*, Wikimedia Foundation, 26 Apr. 2019, en.wikipedia.org/wiki/Active_galactic_nucleus.

Conover, Emily. “New Sky Map Charts Previously Unknown Gamma-Ray Sources.” *Science News*, 4 May 2016, www.sciencenews.org/article/new-sky-map-charts-previously-unknown-gamma-ray-sources.

“HAWC.” *HAWC*, www.hawc-observatory.org/.

“Multiwavelength.” *Goddard Space Flight Center*, NASA, 15 Feb 2018, https://asd.gsfc.nasa.gov/archive/mwmw/mmww_images.html.

“Nebula.” *Wikipedia*, Wikimedia Foundation, 9 July 2019, en.wikipedia.org/wiki/Nebula.

“Pulsar.” *Wikipedia*, Wikimedia Foundation, 7 July 2019, en.wikipedia.org/wiki/Pulsar.

Rosswog S. and Bruggen M. (2007). *Introduction to High-Energy Astrophysics*. Cambridge. New York. NY.

Slane, Patrick. “Pulsar Wind Nebulae.” *Handbook of Supernovae*, 2016, pp. 1–21., doi:10.1007/978-3-319-20794-0_95-1.

Strobel N. "Magnetic field" *Astronomy notes*. (2019).

<https://www.astronomynotes.com/solarsys/s7.htm>. Accessed July 17, 2019.

"Supernova Remnant." *Wikipedia*, Wikimedia Foundation, 25 June 2019, en.wikipedia.org/wiki/Supernova_remnant.

Instructional Procedure: Explain

Heading: Gamma Ray Sources

Goal of the Day

- Students will be able to evaluate the claims of different frequencies of electromagnetic radiation have when encountering different matter.
- Student will be able to understand the images HAWC generates from the sky and relate those images to the significance maps produced from the data collected.
- Students will be able to justify the observation of Gamma-Ray emitting objects in the universe.

Advance Preparation:

- Students should have 'Life Cycle of a Star' Graphic Organizer from previous lessons so they can add to them.
- 'Gamma Ray Sources as seen by HAWC' Google Sheets presentation should be prepared for presentation via a projector.
- Any additional supplemental material such as guided notes or printouts of note should be prepared.

Background Information (Lesson Introduction):

"The High Altitude Water Cherenkov Observatory (HAWC) is a large Gamma-Ray observatory in the mountains of central Mexico that collects Gamma-Ray shower data. The HAWC Collaboration team analyzed the data and creates light curves (Modeling Gamma Ray Data Lesson) and significance maps (Gamma-Ray sources as seen by HAWC) as well as other astronomy and astrophysics research. HAWC primarily detects Gamma-Rays between 100 GeV and 50 TeV. "

"HAWC consists of large metal tanks, 7.3 m wide by 5 m high, containing a light-tight bladder holding 188,000 liters of water. Inside are four photomultiplier tubes (3-8" and 1-10" high QE). High-energy particles striking the water result in Cherenkov light that is detected by the photomultiplier tubes. HAWC uses the difference in arrival times of the light at different tanks to measure the direction of the primary particle. The pattern of light allows for discrimination between primary particles (hadrons) and gamma-rays. From this, scientists can map the sky using gamma-rays. "

"Given HAWC's energy range level, it can image very energetic sources in the sky. Its measurements contribute to Gamma-Ray Astronomy, Cosmic-Ray Astronomy, and Particle Physics. HAWC studies galactic sources at high energies, galactic diffuse emissions, transient emissions from active galactic nuclei and the Crab Nebula, Gamma-Ray bursts, and

Cosmic-Rays at TeV energies. The particle physics applications include identifying the existence of dark matter, testing Lorentz invariance, extragalactic background light attenuation, and searching for massive relic particles such as tau neutrinos.”

“This lesson covers the variety of categories of Gamma-Ray emitters in the universe that HAWC observes. Namely, these include Supernova Remnants, Pulsars, Pulsar Wind Nebulas, X-Ray Binary Systems, and Active Galactic Nuclei such as Blazars. These are all discussed in this lesson, additionally see the speaker notes for links to information. It should be noted that the majority of the discussion is still very theoretical. Many of the ideas presented are still in the works and some questions still do not have answers.” (HAWC)

Procedure/Strategies:

- *Bell ringer* (5 min): *What type of object does the HAWC observatory image? Can you think of an example?*

-Direct Instruction (45 min): Explain: Presentation on Gamma Ray Sources as seen by HAWC

Key Vocabulary and Academic Vocabulary:

- Active Galactic Nuclei (AGN): A galaxy that the center of the galaxy emits radiation more powerful than the rest of the galaxy.
- Binary System: Two stars rotating around a common central mass.
- Black Hole: Very dense compression, at the end of a massive star's life.
- Blazar: An AGN with a jet of electromagnetic energy facing Earth.
- Gamma-Ray: a penetrating electromagnetic radiation arising from the radioactive decay of atomic nuclei.
- HAWC: The High Altitude Water Cherenkov Observatory
- eV (Electron Volt): The amount of kinetic energy gained or lost by a single electron accelerating from rest through an electric potential difference of one volt in a vacuum.
- Extragalactic: Originating outside of our Galaxy.
- Galaxy: A gravitationally bound system of stars, stellar remnants, interstellar gas, dust, and dark matter.
- Nebula: A nebula is a giant cloud of matter.
- Particle: A minute portion of matter.
- Pulsar: A neutron star with a beam of electromagnetic radiation visible when it rotates toward Earth.
- Pulsar Wind Nebula: Nebula inside a Supernova powered by a central pulsar.
- Supermassive Black Hole: The largest type of black hole, containing a mass of the order of hundreds of thousands to billions of times the mass of the Sun.
- Supernova: A supergiant star exploding, triggered by reignition of Fusion or Gravitational collapse.
- Supernova Remnant: Remains of an exploded star within a supernova
- Relativistic: Accurately described only by the theory of relativity, or related to the speed of light.
- X-Ray Binary System: Two stars; one normal star and one collapsed star rotating around a common center of mass that emits x-rays.

Assessment: Formative:

Question and Answer section post direct instruction with classroom. Emphasize on the students knowledge of basic understanding of the different Gamma-Ray emitters. An example question would be: *What is the difference between a Pulsar and a Blazar?*

Resources:

AstroMeV, astromev.in2p3.fr/?q=aboutus/gamma-ray-binaries.

“Active Galactic Nucleus.” *Wikipedia*, Wikimedia Foundation, 26 Apr. 2019, en.wikipedia.org/wiki/Active_galactic_nucleus.

Conover, Emily. “New Sky Map Charts Previously Unknown Gamma-Ray Sources.” *Science News*, 4 May 2016, www.sciencenews.org/article/new-sky-map-charts-previously-unknown-gamma-ray-sources.

“HAWC.” *HAWC*, www.hawc-observatory.org/.

“Multiwavelength.” *Goddard Space Flight Center*, NASA, 15 Feb 2018, https://asd.gsfc.nasa.gov/archive/mwmw/mmww_images.html.

“Nebula.” *Wikipedia*, Wikimedia Foundation, 9 July 2019, en.wikipedia.org/wiki/Nebula.

“Pulsar.” *Wikipedia*, Wikimedia Foundation, 7 July 2019, en.wikipedia.org/wiki/Pulsar.

Slane, Patrick. “Pulsar Wind Nebulae.” *Handbook of Supernovae*, 2016, pp. 1–21., doi:10.1007/978-3-319-20794-0_95-1.

“Supernova Remnant.” *Wikipedia*, Wikimedia Foundation, 25 June 2019, en.wikipedia.org/wiki/Supernova_remnant.

Instructional Procedure: Explore**Heading: Guess What****Goal of the Day**

- Students will be able to explore their understanding of objects in the universe with an interactive astronomy version of Guess What (or Celebrity). Students will challenge each others understanding of the subject material.

Advance Preparation:

- Divide the class into partners of two.
- Print out Guess What cards.
- Students will need their notes from previous lessons.
- A privacy divider constructed between the two partners.
- Score sheet.
- Prizes (Homework pass).

Background Information (Lesson Introduction):

See background information from previous portions of this lesson.

Procedure/Strategies:

Activity: Explore: (45 min):

Game Rules

'Guess What' is a two player game where players use differential yes or no questions to isolate a hidden celestial object. The first player to guess the other players hidden celestial object wins.

Players should erect a divider between them, such as a book on end or some cardboard. Each player should layout the 16 celestial object cards in front of them so that the opposite player can not see them. Each player will randomly select the name of the object they will be from a separate stack of name cards. This card represents the object your opponent has to guess and the object you have to answer questions about.

The youngest player goes first, beginning by asking the other player a characteristic of one of the 16 celestial object cards (both players have the same 16 card). Example: "Is your celestial object currently undergoing nuclear fusion?". Students are encouraged to have their notes out, to help guide both questions and answers.

If they say, "yes," the asking player flips over all of the card without nuclear fusion. If they say, "no," the asking player flips over the cards that are actively undergoing nuclear fusion. Through the process of elimination, players will eventually be able to "guess" the name of the opponents celestial object.

Once a game is over, the players rotate partners. The students with the most victories at the end of the class period wins a prize (homework pass, EC, ect.)

An expansion pack is available, that includes other celestial objects not included in this lesson directly, so that this activity can also be as a review game.

Alternate Game: Celestial Celebrity**Game Rules**

A game for the whole class. Players randomly select a Guess What card without seeing it then attach it to their forehead (with tape or some other adhesive). Players then use differential yes or no questions to ask other players (who also have Guess Who cards attached to them) to determine what celestial object they are.

Once correctly determined they return and replace their object with another and continue the game. At the end of the class period, the student with the most correct guesses wins a prize.

Key Vocabulary and Academic Vocabulary:

- Active galactic nuclei (AGN): A galaxy that the center of the galaxy emits radiation more powerful than the rest of the galaxy.
- Asteroid: An astronomical object orbiting the sun that does not resemble a planet-like disc.
- Binary System: Two stars rotating around a common central mass.
- Black Dwarf: The stage after white dwarf where the star is no longer emitting any radiation.

- Black Hole: Very dense compression, at the end of a massive star's life.
- Blazar: An AGN with a jet of electromagnetic energy facing Earth.
- Comet: Composed of ice with a rocky core and frequently a tail.
- Dwarf Planet: A planetary-mass object that is neither a true planet nor a natural satellite.
- Gas Giant: Planets with large amounts of ammonia and methane ice with a rocky or metallic core.
- Magnetar: A neutron star that has a very strong magnetic field.
- Main Sequence Star: 90% of the stars including our Sun. Hydrogen in the core is converted into Helium by Nuclear Fusion.
- Meteoroid: A small rock or metallic body in space that are significantly smaller than an asteroid.
- Moon: An astronomical body that orbits a planet.
- Nebula: A nebula is a giant cloud of matter.
- Neutron Star: A celestial object of very small radius and very high density, composed predominantly of closely packed neutrons.
- Pulsar: A neutron star with a beam of electromagnetic radiation visible when it rotates toward Earth.
- Pulsar Wind Nebula: Nebula inside a Supernova powered by a central pulsar.
- Red Giant: A star without enough mass to continue nuclear fusion beyond He production.
- Starburst: A galaxy under a high rate of star formation (100 times faster than the Milky Way galaxy).
- SuperGiant: A star with enough mass to continue fusion reaction creating larger atoms (Fe)
- Supernova: A supergiant star exploding, triggered by reignition of Fusion or Gravitational collapse.
- Supernova Remnant: Remains of an exploded star within a supernova
- Terrestrial Planet: Rocky planet with small amounts of ice.
- White Dwarf: A small to medium collapsed star no longer undergoing nuclear fusion.
- X-Ray Binary System: Two stars; one normal star and one collapsed star rotating around a common center of mass that emits x-rays.

Assessment: Formative: Students will be testing each other's knowledge of material with an informal game.

Acknowledgements

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