## Lesson Question

* How can we detect gamma and cosmic rays, in the pursuit of locating their sources?

## Lesson Big Ideas

* Gamma rays and cosmic rays are different yet related.
* Radiation from gamma rays and cosmic rays can be detected using technologies and tools governed by scientific principles.
* Computers play a vital role in the data collection, storage, and analysis of large and complicated data sets.

## Lesson Introduction

Gamma rays are often mentioned but not extensively studied in the classroom due to their high energies and the difficulty involved in detecting/observing them. Scientists have developed the ability to indirectly observe cosmic gamma rays within the last 50 years. Sophisticated computer programs have been created and refined to collect, store, and interpret the data collected. In order to successfully use computer programs, simulations, and generated plots, an at least basic understanding of the scientific concepts that drive the data are required. So how are we able to detect gamma rays? What else are we able to detect, and what can we do with this information?

Gamma rays are created by astronomical objects within the galaxy and greater universe. However, these photons of energy are not the only thing created. Cosmic rays, charged particles (and neutrinos) are also created and accelerated in active galaxies, supernova remnants, pulsars, and pulsar wind nebulae before being ejected into the universe. Gamma rays, as chargeless particles, will travel in a straight line from the source to Earth; cosmic rays, as charged particles, will be deflected by the various magnetic fields found within the universe. To some extent, a food analogy makes the most sense to describe this difference. In the Engage phase of this lesson, students will try to locate a bag of freshly-popped popcorn by smell and by sight. While almost everyone in the classroom will be able to smell the popcorn, not everyone will be able to see the popcorn. However, those that see the popcorn will be able to place it quicker than those that can only smell it. Similarly, cosmic rays are pervasive in the universe - they leave a source and are deflected several times until the source can no longer be traced (smell of popcorn). Meanwhile, gamma rays will travel in a straight line; while harder to detect they can be relatively easily traced back to the source (sight of popcorn).

Understanding how cosmic rays (including gamma rays) travel from source to the Earth, students will be able to explore how the particles from outer space change and are eventually detected here on Earth. First, students will learn of Cherenkov Radiation. Many people are quick to make the statement, “nothing travels faster than the speed of light” but fail to add the very important “in a vacuum” at the end. The devil is in the details, for particles can travel faster than the speed of light *in water* (or any medium), and create the light version of a sonic boom. When objects travel faster than the speed of sound, a shockwave and “boom” can be felt; when charged particles travel faster than the speed of light (in water), a bluish hue - photons of light are given off. When many particles undergo this “optical boom”, the blue can be detected with human eyes. However, when detecting particles that have traveled from outer space, the numbers are too few to be detectable by sight. Instead, students are introduced to photomultiplier tubes (PMTs), which are able to pick up a single photon of light. PMTs work using the photoelectric effect, which is a great reminder to students that light can truly be thought of as a series of particles.

It is this point in the Explore phase of the lesson that students take what they have learned and begin to apply it to the High-Altitude Water Cherenkov (HAWC) Gamma-Ray Observatory project. After viewing a short video that describes the project and illustrates the experimental set-up, students will examine simulated events from HAWC. These events, cosmic ray or gamma ray, are displayed on a map of the observatory, with color and size of the PMT markers indicating the timing and number of particles (respectively) in the event. Students will work collaboratively to organize the events into two groups - cosmic ray (otherwise referred to as proton or hadron) events and gamma ray (otherwise referred to as photon) events based on visible patterns they see in the data. Some students may argue that a third group, “uncertain” is needed because not enough information has been provided to completely sort all of the events. Students obtain additional information in the Explain phase about how gamma rays and cosmic rays interact with Earth’s atmosphere to form air showers. Knowing how gamma ray produced air showers differ from cosmic ray produced air showers will allow students to solidify their groupings of events and hopefully eliminate the “uncertain” group.

Within HAWC, the computer programs used to collect and store data automatically removes most cosmic ray “noise”, only storing the gamma ray signals, as detected by the air showers. Students connect the reason for this back to the Engage phase - gamma rays can be traced back to the source. HAWC is able to reconstruct the gamma ray air showers and trace them back to the original photon that created them. Then, knowing photons are unaffected by magnetic fields, HAWC can trace the photon(s) back to the source that created them and map gamma ray signals to coordinates within the universe. In the Extend phase, students will examine real HAWC data of (up to) 18 locations in the universe. 9 locations are of HAWC-detected gamma sources; the other 9 are randomly chosen alpha stars of constellations. Students will use two types of data to play a game of “gamma source or no gamma source”. First, students will examine count maps - these are maps were each pixel is color-coded to match the number of particles that HAWC has detected from that location. Many students will struggle to see patterns in this “raw” data, which is why HAWC uses significance maps to determine how similar/different the location is from an expected gamma source. Students examine these significance maps, and recognize how computer programs are able to input more data and compute more complex data analysis than our eyes can do (i.e. look for simple patterns).

Finally, in the Evaluate phase students read a 2016 space.com article discussing the release of HAWC’s first publicly-available sky map, which identifies and locates 40 high-energy gamma sources in the universe. Students make connections between this article and the activities they completed in the lesson to think of the process that scientists go through to collect and analyze data to detect gamma rays. With an appreciation of gamma-ray astronomy, students construct an explanation/answer supported with evidence, to the lesson question, “how can we detect gamma and cosmic rays, in the pursuit of locating their sources?” This explanation will serve as a formative assessment to gauge student understanding of this introductory lesson.

## Intended Learning Outcomes

*Students will be able to …*

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1. Define and differentiate between gamma rays and cosmic rays.
2. Describe Cherenkov Radiation.
3. Identify how Photomultiplier Tubes are used to detect photons.
4. Use the differences in air showers from gamma and cosmic rays to sort cosmic events.
5. Discuss how the use of computer (modeling) can improve data analysis of large or complicated data sets.

## Teaching Time: 2 Class Period (assuming 55 minute periods)

## Materials, Resources, and Advanced Preparation Needed

* There is a [classroom-ready presentation](https://docs.google.com/presentation/d/1i38nD7-9HqV-D9VJjJBDUSTUuI00rBz6EIZOFTRovI4/edit?usp=sharing) that accompanies this lesson. There are also several materials that should be printed or posted in advance.
  + The [simulated event cards](https://docs.google.com/document/d/1zvAssKNiSn14IwuAAc9B6etXOIylye8hjR6MkXxTkEQ/edit?usp=sharing) used in the Explore/Explain phases should be printed in color and may be laminated for future use.
* This lesson explores the High-Altitude Water Cherenkov (HAWC) Gamma-Ray Observatory. Teachers may want to acquaint themselves with the project by visiting their [website](https://www.hawc-observatory.org/).

## NGSS Connections

### Performance Expectations may include:

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

* [**HS-PS1-8**](http://www.nextgenscience.org/pe/hs-ps1-8-matter-and-its-interactions)**:** 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.
  + [Clarification Statement: Emphasis is on simple qualitative models, such as pictures or diagrams, and on the scale of energy released in nuclear processes relative to other kinds of transformations.]
  + [Assessment Boundary: Assessment does not include quantitative calculation of energy released. Assessment is limited to alpha, beta, and gamma radioactive decays.]
* [**HS-PS4-3**](http://www.nextgenscience.org/pe/hs-ps4-3-waves-and-their-applications-technologies-information-transfer)**:** Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.
  + [Clarification Statement: Emphasis is on how the experimental evidence supports the claim and how a theory is generally modified in light of new evidence. Examples of a phenomenon could include resonance, interference, diffraction, and photoelectric effect.]
  + [Assessment Boundary: Assessment does not include using quantum theory.]

### Lesson Subcomponents may include

*The subcomponents listed below have been directly taken from the NGSS Appendices webpage at* [*https://www.nextgenscience.org/resources/ngss-appendices*](https://www.nextgenscience.org/resources/ngss-appendices)*.*

#### SEP: Science & Engineering Practices

* **Developing and Using Models**
  + Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.
  + Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations.
  + Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.
* **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.
  + Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible.
  + Evaluate the impact of new data on a working explanation and/or model of a proposed process or system
* **Constructing Explanations and Designing Solutions**
  + Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students’ own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.
  + Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion.

#### DCI: Disciplinary Core Ideas

* **PS1.A: Structure of matter & PS1.C: Nuclear processes**
  + The sub-atomic structural model and interactions between electric charges at the atomic scale can be used to explain the structure and interactions of matter, including chemical reactions and nuclear processes. Repeating patterns of the periodic table reflect patterns of outer electrons. A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy to take the molecule apart
* **PS1.B: Chemical reactions**
  + Chemical processes are understood in terms of collisions of molecules, rearrangement of atoms, and changes in energy as determined by properties of elements involved.
* **PS4.B: Electromagnetic radiation**
  + Both an electromagnetic wave model and a photon model explain features of electromagnetic radiation broadly and describe common applications of electromagnetic radiation.

#### CCC: Crosscutting Concepts

* **Patterns**
  + Students observe patterns in systems at different scales and cite patterns as empirical evidence for causality in supporting their explanations of phenomena. They recognize classifications or explanations used at one scale may not be useful or need revision using a different scale; thus requiring improved investigations and experiments. They use mathematical representations to identify certain patterns and analyze patterns of performance in order to reengineer and improve a designed system.
* **Systems and System Models**
  + Students can investigate or analyze a system by defining its boundaries and initial conditions, as well as its inputs and outputs. They can use models (e.g., physical, mathematical, computer models) to simulate the flow of energy, matter, and interactions within and between systems at different scales. They can also use models and simulations to predict the behavior of a system, and recognize that these predictions have limited precision and reliability due to the assumptions and approximations inherent in the models. They can also design systems to do specific tasks.

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## Instructional Phases

### Engage: *(*15 *minutes)*

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| **Phase Summary:**  Students are introduced to gamma and cosmic rays through an analogy about the senses. Students make connections between the senses (sight and smell) and gamma and cosmic rays by reading and discussing an article. |

**Student Steps:**

**Note:** These student steps have been put into a classroom-ready [presentation](https://docs.google.com/presentation/d/1i38nD7-9HqV-D9VJjJBDUSTUuI00rBz6EIZOFTRovI4/edit#slide=id.p) to help keep the teacher and students organized and on topic during this lesson.

1. Students enter the classroom and notice a strong popcorn odor. Naturally, students sniff at the smell to try to place it, but struggle to identify the origin of the smell.
2. Students are informed by the teacher that the smell is coming from a bag of microwave-popped popcorn that was left in the classroom (in plain view, but not an obvious location). Students try to locate the source of the smell, now using their eyes to locate the container as well.
3. Students have a short discussion about locating objects with different senses. Students recognize that their smelling sense is strong, but since the smell spreads out and doesn’t move in a straight line it’s sometimes difficult to locate the source. However, they seeing sense provides a direct line-of-sight to the object (once they knew what they were looking for).
4. Students learn about cosmic rays and gamma rays by reading an [article](https://drive.google.com/open?id=1FYyNTpsakvom_QPokDU8C2JyztcN8L6ErbS4w_wl3FA). Through a short discussion with a partner, students come to the conclusion that cosmic rays are similar to the sense of smell (does not travel in a straight line) while gamma rays are similar to the sense of sight (does travel in a straight line).

### Explore: *(*25 *minutes)*

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| **Phase Summary:**  Students are introduced to Cherenkov Radiation through a short video, and learn how photomultiplier tubes (PMTs) are used to detect the radiation. Students are also introduced to the High-Altitude Water Cherenkov Gamma-Ray Observatory (HAWC Observatory) through another video. Students practice separating cosmic ray and gamma ray events based on what they know at this point (gamma rays are similar to sight - straight line, while cosmic rays are similar to smell - spread out). |

**Student Steps:**

1. Students watch a [short video](https://www.youtube.com/watch?v=_Kf2f_9MfPc) on Cherenkov radiation (SciShow Space, 2016). In this video, students learn that “nothing travels than the speed of light” is incorrect (by omission), and that high-energy particles *can* travel faster than the speed of light in water.
   * **Note:** The video discusses a situation (nuclear reactors) where enough Cherenkov Radiation is produced to be detected by the human eye. Students will also need to be quickly introduced to photomultiplier tubes (PMTs), which are able to electrically detect small amounts of Cherenkov Radiation. PMTs use the photoelectric effect in their operation, so students will be able to see that in this instance, light is being treated as a particle (over a wave).
2. Students watch a second [video](https://www.youtube.com/watch?v=Ch1hF9RBHVw) on the HAWC Observatory (Gizmodo, 2018). Students are introduced to how the PMTs are used to measure Cherenkov Radiation to detect gamma rays from the universe.
   * **Note:** This lesson focuses on HAWC, the data it collects, and the results it publishes. For more information about the project, the science behind it, and results, please visit their [website](https://www.hawc-observatory.org/) (HAWC Collaboration, 2018b).
3. Students each receive one [simulated event card](https://docs.google.com/document/d/1zvAssKNiSn14IwuAAc9B6etXOIylye8hjR6MkXxTkEQ/edit?usp=sharing) that the teacher has cut out (and laminated for future use) (HAWC Collaboration, 2018a). Students move around the room to show their card to classmates and try to form two groups; those events which are cosmic ray events and which are gamma ray events.
   * **Note:** The event cards show the HAWC Observatory water tanks, with three PMTs inside. The color indicates the timing of the particles (blue = beginning; red = ending). The size of the marker indicates how many particles struck (big = many; small = few). Finally, there is a blue star that indicates the “center” of the event.
   * **Note:** This is a preliminary grouping; students will learn the answer later. If students are truly stuck, they may form a third group, of those events which students are unsure about.

### Explain: *(*25 *minutes)*

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| **Phase Summary:**  Students are provided a summary of air showers, which provide the bridge between gamma and cosmic rays and the particles that actually reach the ground to be detected. Students use this additional (new) information to finalize their event card groupings (gamma ray events and cosmic ray events). Students have a whole-class discussion about gamma rays, cosmic rays, and air showers. |

**Student Steps:**

1. Students are introduced to air showers through the [supplementary lesson slides](https://docs.google.com/presentation/d/1i38nD7-9HqV-D9VJjJBDUSTUuI00rBz6EIZOFTRovI4/edit#slide=id.g3e554ed9ae_0_8). These air showers (and their particles) are how ground-based observatories are able to detect cosmic and gamma rays. The PMTs detect photons of light - but these photons (emitted through Cherenkov Radiation) only come from *charged* particles. There are many charged particles that could be emitting this radiation, and the PMTs cannot distinguish between them. However, based on the geometry of the event (i.e. how many and where particles were detected), scientists can differentiate between cosmic ray (sometimes called hadronic or proton) showers and gamma ray (sometimes called photon) showers.
2. Students use the added information to revisit their event card groupings. Students group by event (cosmic ray or gamma ray), and dissolve the “uncertain” group if necessary. Once students have their groupings, the teacher reveals the final results (using the number or letter on each card and comparing it to the [answer key](https://docs.google.com/document/d/1zvAssKNiSn14IwuAAc9B6etXOIylye8hjR6MkXxTkEQ/edit?usp=sharing)).
   * **Note:** If a break in the lesson (due to time constraints) has occurred since the first round of groupings, the teacher can reassign the event cards and redo the activity (call the previous attempt “practice”). This will alleviate any stress in having students retain their cards and claims (cosmic ray v. gamma ray) from one day to the next
3. Students have a whole-class discussion about gamma ray and cosmic ray events, including the difficulties in differentiating between the two.

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| **Question** | **Expected Student Response** | **Teacher’s Note** |
| How easy is it to distinguish between cosmic ray showers and gamma ray showers? Support with evidence from the activity. | *Not easy at all! Some are easy to differentiate, but some look identical. Some events have a lot more hits than others; this made it easier to tell. Events with few hits were harder to differentiate.* | The amount of hits and location of hits also depends on the energy of the source (higher energies will have more particles) and the direction/angle of the source (straight down from zenith versus at an angle). |
| Should we have kept “uncertain” group? | *Maybe. Some events we were still unsure about. There were other events that looked really similar, but one was a gamma ray and one was a cosmic ray.* | These event cards were made from *simulated* data, so the designations of gamma ray or cosmic ray events are certain. However, when examining *real* data, (and working backwards), there are some events that look too similar to be able to differentiate between cosmic ray and gamma ray events. So, with *real* data, there may be several “uncertain” events. |
| How would the use of computers improve this sorting activity? | *The computers can work with a lot more data and find patterns faster than humans. We can look at one at a time, but computers can look at more and compare them.* | The HAWC Observatory has computer programs that separates out background radiation from cosmic and gamma ray showers. |
| Would it be possible to get “hits” (activated PMTs) when there was no actual event (i.e. shower)? What might this look like? | *Maybe. If just one particle interacts with a PMT, just one blip would happen. The events we looked at had lots of “blips” (color and size of the PMT markers), so a LOT of particles at one time.* | Natural background radiation occurs everywhere all the time. This radiation can result in the random stray particle interacting with the PMTs and generating a very small signal. But, this background noise is easily sorted and the computer throws out these readings. |
| Why are gamma rays harder to detect than cosmic rays? | *Gamma rays are neutral - they do not interact with the PMTs. Cosmic rays are charged - they will interact with the PMTs and create a signal. Both don’t reach the ground, and so we need the air showers to detect them.* | Another complication (thinking of smell v. sight), is that cosmic rays are constantly interacting with the atmosphere from every direction. This creates a cosmic background radiation (*not* the same thing has cosmic microwave background radiation) that is “noise” to the HAWC Observatory. Gamma ray showers will occur at the same time as this cosmic ray noise, and computers are used to help separate signals. |
| Why would we want to separate gamma ray showers from cosmic ray showers? | *We can trace back gamma rays to their source; cosmic rays we cannot trace back because they are deflected by magnetic fields.* | This is an important connection back to the Engage Phase, and is expanded upon in the next instructional phase. |

1. **EXTENSION:** Students may sort additional simulated events by going to the HAWC Observatory [gamma/hadron separation](https://www.hawc-observatory.org/observatory/ghsep.php) page (HAWC Collaboration, 2018a).

### Extend: *(*30 *minutes)*

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| **Phase Summary:**  Students take the search for gamma sources to the sky by looking at HAWC data of several locations in the sky (some gamma sources, some not). Students try to find patterns in the data, and then examine the results from computer-analyzed data, all in an attempt to answer “gamma source or no gamma source?”. |

**Student Steps:**

1. Students search for sources of gamma rays in the known universe by playing the game “[Source or No Source](https://docs.google.com/presentation/d/1u9V8x7tj-_qlZanLFP_MjzibPMjZq5zfo97WcLKtrYM/edit?usp=sharing)”. This game is kinesthetic; students get up and move from one side of the room to the other to play the game. There are student instructions on slide 2.
   * Students start by standing in the middle of the room.
   * The teacher shows a slide, with one image displayed. Students look for patterns in the image and make a claim “source” or “no source”. Students move to the side of the room that represents their claim (i.e. “by the windows is ‘source’ and by the cabinets is ‘no source’.”).
   * Students see a second image of the same location of the sky. Students may stay where they are, or move to the other side of the room if their claim has changed.
   * Students see the last count image and vote again.
   * Before the answer is revealed, three images that show the significance are displayed.
     + **Note:** These significance maps are computer generated. In essence, the computer program takes the data (organized by pixels) and overlays a series of models to find the best fitting model (presence/location of source). First, a model of no source (just background) is overlaid to determine how well the model fits the data. Then, the computer programs overlays a model of a source at a specified location on the data, again to see how well the model fits the data. This is then repeated for every location (pixel) within the map. The significance readings indicate how much improvement was made with this new model (i.e. putting a source there versus not having a source there). The more significant the pixel, the more improvement was made from changing the model (background to source). So, in general, the higher the significance, the higher probability that the data can be described as a gamma ray source at that location.
   * **Note:** There are a total of 18 “sample sources” (nine gamma sources; nine not gamma sources). Students do not need to play all 18 rounds; play as many or little rounds as desired.
2. Students have a whole-class discussion about gamma ray sources and how they are detected.

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| **Question** | **Expected Student Response** | **Teacher’s Note** |
| How good were our eyes were at detecting gamma source? | *We could only see some of the strongest sources. We could see (sometimes) very rough “sources”, but couldn’t narrow it down to coordinates.* | Hit Count Bin Maps are often considered to be somewhat raw data. It is not entirely raw data, as background noise (cosmic rays) and some data sorting has already been done. There is data pixel-by-pixel, but the data can not be expanded to discuss information about the source. |
| How does the use of computers help identify gamma sources? | *The significance maps were able to find patterns our eyes couldn’t. They showed background as grey and actual sources as colors. This made it easy to identify.* | Significance Maps are used because they contained analyzed data. There are several complex computer programs that run to produce these maps, but basically the program looks at not only the pixel in question, but the pixels around it, and the pixel(s) in the other energy bins. The computer puts all of this information together (much more than could be collected with just our eyes) and produces the significance levels - how far away from the null hypothesis the data is. That is, a significance of zero indicates that there is no (statistical) difference from background; the higher the significance goes, the more of a possibility that the data is different from background - i.e. a source. The scale used in the maps are purposefully chosen so that color begins at a significance of 3. 3 sigma is indication of evidence (of something); 5 sigma (in the maps, there is a black contour line at this point) indicates detection. |
| Did all gamma sources look the same (in the significance maps)? What possible conclusions could we make about gamma sources? | *No; some looked like bullseyes (circles), while others looked like smears of colors. When we looked at the significance maps of the bins we saw that some changed shapes based on if it was “low”, “medium”, or “high” - some gamma sources can be more/less energetic than others.* | Some gamma sources are known as point sources (<0.2° in diameter; based on HAWC’s resolution), while others are extended sources. Furthermore, some sources are in close proximity to other sources; this creates a colorful smear with different peaks (sources) in the significance maps. In general, a brighter (significance) source is a stronger source. There will always be more data at the lower energies than at the higher energies because there will be more photons. Scientists working with HAWC use these significance maps as just part of their analysis. As the significance maps are generated, another map is generated that describes the flux (amount of energy) at each location for the modeled source that best fit the data. Some sources will have higher/lower flux values than others, indicating a more/less energetic source. Additionally, sources outside of the galaxy (like Markarian 421 and 501) will have an energy cutoff at higher energies because of photon absorption that occurs in the cosmic microwave background. |

1. **EXTENSION:** Students can further explore gamma sources in the universe by examining significance maps of objects identified in HAWC’s “[2HWC catalog](https://data.hawc-observatory.org/datasets/2hwc-survey/catalog.php)” (HAWC Collaboration, 2018c). Students can also use the coordinate view to enter their own coordinates to search for gamma sources.

### Evaluate: *(*15 *minutes)*

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| **Phase Summary:**  Students reflect on the HAWC project and detecting gamma sources by reading an article that describes the release of HAWC’s first publicly available sky map of high-energy gamma sources. Students make connections between the article and what they have done/learned in this lesson by talking with a classmate before constructing an explanation that answers the lesson question, “how can we detect gamma and cosmic rays, in the pursuit of locating their sources?” |

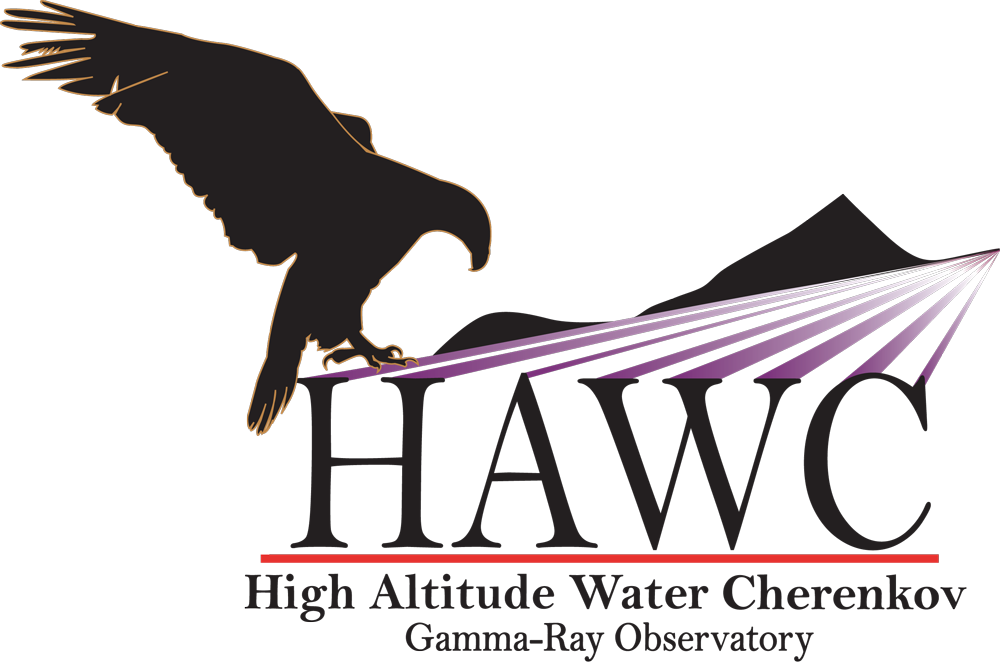
**Student Steps:**

1. Students individually read “[The HAWC Has Landed — Observatory Maps the High Energy Sky](https://www.space.com/32927-hawc-maps-high-energy-sky.html)” (Cofield, 2016). As they read, students should be encouraged to annotate the article by underlining ideas and jotting questions or notes down.
2. Students partner with another student to discuss the article, focusing on how the activities of this lesson culminate to a whole-sky map of gamma sources. Additionally, students discuss the importance of the map (HAWC project) and what can be learned from the information.
3. Students answer the lesson question, as a way to reflect on the lesson. Students use what they have learned and the evidence they have collected to construct a supported explanation/answer. The teacher may chose to collect this explanation as a form of formative assessment.
   * How can we detect gamma and cosmic rays, in the pursuit of locating their sources?

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