## Lesson Questions

* What does the night sky look like in other wavelengths?
* What can we learn about our galaxy and universe by observing in other wavelengths?

## Lesson Big Ideas

* Visible light is only a small portion of the electromagnetic spectrum.
* Information about the universe can be gathered by observing the night sky in different wavelengths.
* Information can be reported in a variety of ways (scales, notation, prefixes, units, etc.) that must be communicated when sharing the information.

## Lesson Introduction

Our eyes are able to gather a lot of information about the world (universe) around us. However, there is a lot that our eyes are not able to detect. The development of technology that allows us to view the world (universe) in these “invisible” lights provides more information that what our eyes alone could gather. Of course, we are discussing the electromagnetic spectrum, of which visible, or optical, light is a very small part of. The world (universe) looks different if viewed in radio waves, microwaves, infrared, ultraviolet, x-rays, or gamma-rays. These portions of the electromagnetic spectrum are all fundamentally the same - it is light, electromagnetic radiation, at different energies (and therefore wavelengths and frequencies).

This lesson focuses on objects that are out of this world and emit light that our eyes alone may or may not detect. Students use a jigsaw method to become experts on one portion of the electromagnetic spectrum. Each student is provided with a picture of the Milky Way Galaxy at their wavelength (radio, infrared, optical, ultraviolet, x-ray, or gamma-ray) and a short description about the wavelength, including what objects emit that wavelength. Students individually use this as a departure point, utilizing internet research to further explore the universe in their assigned wavelength. Students are allowed to tailor their research to what interests them - their only constraint is that they stay within their assigned wavelength. Students then meet in six groups (one for each wavelength) to share and discuss their common wavelength. Once students have become “experts” in their wavelength, the class forms new groups of six students (each of the six wavelengths in one group) to create an entire spectrum of wavelengths. Students take turns sharing their expert knowledge on that wavelength, while the other students compare the wavelength to their own. A whole-class discussion brings all the different wavelengths together to discuss multiwavelength astronomy and how our universe looks similar/different in multiple wavelengths.

The whole-class discussion continues, but shifts focus to examine the electromagnetic spectrum itself (instead of objects that emit it). Students see the plotted electromagnetic spectrum, in terms of energy, through the use of supplementary slides. Through this discussion, students are exposed to several mathematically and scientifically important skills/concepts including logarithmic and linear scales, scientific notation, scientific prefixes, and scientific units. Students are exposed to the electron volt, and compare energies of the electromagnetic spectrum to more “everyday” energies. These energy comparisons allow students to appreciate the size and scale of the electron volt, the energies contained in the electromagnetic spectrum, and the various astronomical objects that emit this energetic light.

At the end of the lesson students focus on one of these astronomical objects, the Crab Nebula (and its associated pulsar) and examine it in different wavelengths. Students read an article that discusses what has been learned about the Crab Nebula in radio waves, infrared, optical light, ultraviolet, and x-rays. Students wonder why gamma-rays were excluded from the article, and discuss with their classmates about why gamma-rays were not included, and what the Crab Nebula might look like in gamma-rays. Students then watch a short video from Fermi that describes the Crab Nebula in gamma-rays, including an interesting flaring phenomenon. Students use the information gathered from this video, as well as other information from the lesson, to complete a summative assignment about multiwavelength astronomy and the electromagnetic spectrum.

## Intended Learning Outcomes

*Students will be able to …*

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1. critically read scientific text to gather information.
2. identify astronomical objects that emit various wavelengths.
3. compare the portions of the electromagnetic spectrum.
4. rank the electromagnetic spectrum in terms of energy.
5. convert between standard form and scientific notation, and/or scientific prefixes.
6. compare logarithmic and linear scales, and discuss which scale better represents the electromagnetic spectrum.
7. construct explanations that utilize evidence and reasoning to support their claim.

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

## Materials, Resources, and Advanced Preparation Needed

* The [jigsaw activity](https://drive.google.com/open?id=1IAeCQB9eLYhAlRZLRntUcPVAptBNulARQTmJL7S-erk) in the Explore/Explain instructional phases include jigsaw cards, that should be printed and given to each student. Teachers may want to assign wavelengths to students based on difficulty or interest. Some examples or things to consider:
	+ Radio astronomy has been around for a while and has a lot of information. Microwaves are also included in this wavelength, so students have a lot of information to work with.
	+ Infrared astronomy has a very student-friendly website (Cool Cosmos) that may help students who need more support.
	+ Optical astronomy is the smallest portion of the electromagnetic spectrum; it is the easiest to observe and one of the oldest fields of multiwavelength astronomy.
	+ X-rays and gamma-rays are the newest fields of astronomy (100 years and 50 years, respectively).
* There are several extension options within the “Extend” instructional phase that allows the teacher to tailor the lesson to several scientific skills (scientific notation, scientific prefixes, plotting logarithmic scales - frequency and/or wavelength, researching missions/experiments, and energy conversions/comparisons). Teachers should read through and gather supplementary lessons/activities if they wish to focus on one (or more) scientific skill introduced in this lesson.

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## 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-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

* **Asking Questions and Defining Problems**
	+ Ask questions
		- that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information.
		- that arise from examining models or a theory, to clarify and/or seek additional information and relationships.
		- to determine relationships, including quantitative relationships, between independent and dependent variables.
* **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.
* **Obtaining, Evaluating, and Communicating Information**
	+ Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions and/or to obtain scientific and/or technical information to summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.
	+ Compare, integrate and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question or solve a problem.
	+ Gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and usefulness of each source.

#### DCI: Disciplinary Core Ideas

* **ESS1.A: The universe and its stars**
	+ Light spectra from stars are used to determine their characteristics, processes, and lifecycles. Solar activity creates the elements through nuclear fusion. The development of technologies has provided the astronomical data that provide the empirical evidence for the Big Bang theory.
* **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

* **Scale, Proportion and Quantity**
	+ Students understand the significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. They recognize patterns observable at one scale may not be observable or exist at other scales, and some systems can only be studied indirectly as they are too small, too large, too fast, or too slow to observe directly. Students use orders of magnitude to understand how a model at one scale relates to a model at another scale. They use algebraic thinking to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth).
* **Energy and Matter**
	+ Students learn that the total amount of energy and matter in closed systems is conserved. They can describe changes of energy and matter in a system in terms of energy and matter flows into, out of, and within that system. They also learn that energy cannot be created or destroyed. It only moves between one place and another place, between objects and/or fields, or between systems. Energy drives the cycling of matter within and between systems. In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved

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## Instructional Phases

### Engage: *(*10 *minutes)*

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| **Phase Summary:**Students watch a short video that highlight the Milky Way Galaxy in optical (visible) light. Students observe how the presence of light pollution can affect the view, and begin to consider what the night sky may look like in other wavelengths. |

**Student Steps:**

1. Students think about the last time they observed the night sky. Students share with a partner what they have seen when they observed the sky (i.e. stars, satellites or the International Space Station, planets, comets, meteor showers, northern lights, etc.).
2. Students watch a [short video](https://www.youtube.com/watch?v=0FXJUP6_O1w) that shows the night sky at different levels of light pollution (National Geographic, 2016). Students observe which objects can be seen in each video, and which objects are only viewable once it is dark enough.
3. Students consider the lesson questions, which are displayed on the board. Students use prior knowledge, what they have observed in the videos, and what they quickly discussed with a classmate to construct initial explanations.
	* What does the night sky look like in other wavelengths?
	* What can we learn about our galaxy and universe by observing in other wavelengths?

### Explore: *(*30 *minutes)*

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| **Phase Summary:**Students individually explore a branch of multiwavelength astronomy, looking at how astronomers observe the sky and objects that emit that wavelength (radio, infrared, visible, ultraviolet, x-ray, gamma-ray). Students discuss their research findings with classmates who were also looking at that particular wavelength. These groups are now “experts” in their wavelength. |

**Student Steps:**

1. Students are assigned a portion of the electromagnetic spectrum (radio wave, infrared, visible, ultraviolet, x-ray, and gamma-ray). Students receive a “[Jigsaw Card](https://docs.google.com/document/d/1IAeCQB9eLYhAlRZLRntUcPVAptBNulARQTmJL7S-erk/edit?usp=sharing)” with their type of light and read a short description of the electromagnetic radiation and view what the Milky Way looks like in that wavelength. Students are directed towards a website, where they conduct open-ended research to learn more about astronomy in that wavelength.
	* **Note:** The websites are designed to serve as a platform from which students can dive deeper into their topic. Students are encouraged to look at other websites that describes their electromagnetic radiation and how it is detected, observed, and studied in astronomy. Students should also look into one (or more) object(s) that interest them that emit their radiation. The teacher will want to monitor students carefully, not only during individual research time, but in the following jigsaw activity so that they are prepared for the multitude of objects/concepts students may discuss as a result of their research.
	* **Note:** Microwaves, for the purpose of this activity, have been combined with radio waves.
2. Students form six groups representing the six portions of the electromagnetic spectrum (i.e. all students in one group have the same radiation). Students discuss their findings, and add information they gain from their group mates to their jigsaw card.

### Explain: *(*30 *minutes)*

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| **Phase Summary:**Students form new groups, so that every person in the group researched a different wavelength. Students take turns sharing their findings with their group mates. Students then have a whole-class discussion on multiwavelength astronomy and make connections back to their jigsaw groups. |

**Student Steps:**

1. Students form groups of six students, so that each of the electromagnetic radiation portions are represented in each group. Students take turns sharing information about their field of astronomy, including any significant findings and objects that emit that wavelength. As students listen to each expert, they organize their information using a [Jigsaw Table](https://docs.google.com/document/d/1WaXvGo1_4eXYe1kYhMIJ2GwvSaLzra0KwHM9CCBHb28/edit?usp=sharing).
2. Students come together as a whole-class to discuss observing the night sky in different wavelengths, using the following questions as guidance.

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| **Question** | **Expected Student Response** |
| What did you learn from the jigsaw activity? | *Student responses will vary.* |
| What are some sources of radio waves? | *Student responses will vary. Possible responses include:**pulsars, quasars, radio galaxies, cosmic microwave background radiation (evidence of Big Bang), the Sun, Jupiter, Milky Way (center), active galaxies, galaxy clusters, supernova remnants* |
| What are some sources of infrared light? | *Student responses will vary. Possible responses include:* *the Sun (and other stars), the Moon, protostars, extrasolar planets, nebulae, quasars, star clusters* |
| What are some sources of optical/visible light? | *Student responses will vary. Possible responses include: planets, moons, meteors, stars, galaxies, star clusters* |
| What are some sources of ultraviolet light? | *Student responses will vary. Possible responses include: interstellar medium, hot young stars, galaxies* |
| What are some sources of x rays? | *Student responses will vary. Possible responses include:**the Sun, neutron stars (and black holes), active galaxies, supernova remnants* |
| What are some sources of gamma rays? | *Student responses will vary. Possible responses include: pulsars, supernova remnants, active galaxies* |
| What is the difference between the different wavelengths? | *The wavelengths and frequencies of the light are different. Some students may also state that the amount of energy is different or that the temperature of the object is different.* |
| Are there astronomical objects that emit light in multiple wavelengths? Why is this important to know when studying astronomy? | *Yes; the Milky Way Galaxy (galaxies in general), the Sun (stars in general), and other objects are seen in multiple wavelengths. It’s important because when we know something produces multiple wavelengths of light we can search for it/confirm it in these lights and study them in more detail.* |
| What are some questions you still have?Is it okay that there are unanswered questions out there? | *Student responses will vary.Yes; we are still studying the universe and learning more each day. Some fields of astronomy (e.g. gamma-ray) are still very new. We are also improving and launching new experiments/observatories each year to answer more questions (and ask new questions).* |

* + **Note:** This discussion is purposefully left rather open ended so that students can guide the discussion wherever their interests and/or research takes them. Furthermore, teachers may use this discussion to highlight different concepts/objects that were either brought previously or will be brought up in the future. The teacher should monitor students during their jigsaw activity carefully to plan for the different objects or concepts students may bring up in the whole class discussion.
	+ **Optional**: Students may engage with [this game](http://herschel.cf.ac.uk/activity/multiwavelength), that allows them to match images from different wavelengths to an optical image of an astronomical object (Herschel Space Observatory, n.d.). This may help facilitate classroom discussion, particularly about how a single object may appear (different) in multiple wavelengths.

### Extend: *(*25 *minutes)*

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| **Phase Summary:**Students have a whole-class discussion about the electromagnetic spectrum. Students use a logarithmic scale of electromagnetic radiation (photon) energies and some “everyday” comparisons to help facilitate and scaffold the discussion. Students may extend the discussion in several ways to focus on scientific notation, scientific prefixes, the electromagnetic spectrum (frequency/wavelength), and energy comparisons/conversions, depending on the goals of the teacher. |

**Student Steps:**

1. Students have a whole-class discussion about the electromagnetic spectrum and the energies of the different radiations. Through the use of [slides](https://docs.google.com/presentation/d/1nNlaT98s_JxYR6MfBXfbkFTf5_g3NGQhoHGUic7jMJ8/edit?usp=sharing), students observe the construction of an energy spectrum to help facilitate their discussion.

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| **Slide** | **Question** | **Expected Student Response** |
| 2 | Why do scientists sometimes use a *logarithmic* scale instead of a *linear* scale? | *Logarithmic scales show the number of zeros before/after the number - so on one scale we can see a really wide range of numbers. We can see both really small numbers and really big numbers. A linear scale would have to be ridiculously long to show the same range of numbers.* |
| What is a benefit of using *scientific notation*? | *Scientific notation is like a shortcut. Instead of counting out and writing each and every zero we can just say how many zeros there are. It makes the numbers shorter and easier to read (and copy/use).* |
| 3 | Where are you seen *scientific prefixes* before? | *In science class - centimeters, milliliters, and kilograms. We have also seen them with computers/phones and data - gigabyte, kilobyte, megabyte.*  |
| Why do scientists sometimes use *scientific prefixes* instead of *scientific notation*? | *If we are using the same order of magnitude over and over again it will get tedious to write “times ten to the \_\_\_”. Instead, if we use prefixes, it’s just a letter to add before the unit.* |
| What are different units of energy? Why might we use electron volts for this activity? | *In physics we use “joules” for energy. In biology/chemistry we use calories; we also use calories for food energy. We use different words for different things/fields, so maybe an electron volt is used to talk about electromagnetic radiation. Maybe the size of the energies mean it makes the most sense to measure in these units.* **Note:** Some students may have seen “[ergs](http://www.dartmouth.edu/~ast15/notes/unitsnote.pdf)” when exploring their field of astronomy. While not the focus of this activity, it may be brought up (Astronomy 15, n.d.).**Note:** The [electron volt](http://www.einstein-online.info/dictionary/electron-volt.html) is often used to discuss very small energies (Einstein Online, 2017). 1 eV = 1.6 x 10**-**19 J = 3.8 x 10**-**23 kcal |
| 4 | What observations can you make about the electromagnetic spectrum and it’s energies? | *Student responses will vary.* |
| 5 | Why do we divide portions of the electromagnetic spectrum into smaller chunks? Do we do this with visible light? Why/why not? | *Some of the portions of the spectrum (especially radio and gamma) are really big - breaking them into smaller chunks help to better describe the wavelengths that are being observed/used. We do divide visible light into the rainbow (red, orange, yellow, green, blue, violet), but the spectrum is already really small compared to the other portions of the spectrum.***Note:** Spectral analysis (like that used in chemistry) divides visible light into smaller chunks to look at the elemental makeup of the light/material. |
| 6 | What observations can you make about how these energies compare to other “everyday” energies? | *Student responses will vary. Most will comment on how small the energies are.* |
| How do the *sizes* of these objects compare? Why might size matter when we are comparing energies? | *All of the objects are really small. But, the photon (electromagnetic radiation particle) is massless - it is the smallest of these small objects. If we wanted to directly compare things we would need to use objects of the same size. Even though these seem like really small energies, if we scaled the system up things would be very energetic.***Note:** A couple comparisons in energies are displayed on slides 7-9, which are at the end of the presentation. The teacher may share these results with students to help generate the desired response(s). |
| How is energy related to temperature? | *As the energy increases, so does temperature. So, some of the most energetic objects in the universe (pulsars, black holes, supernova), are also the hottest.* |

* + **Extension:** Use slide **2** (scientific notation) to further practice the skill of converting to and from scientific notation and standard form.
	+ **Extension**: Use slide **3** (scientific prefixes) to further practice the skill of writing, reading, and converting scientific prefixes (to scientific notation and/or standard form).
	+ **Extension**: Use slide **4** (energy spectrum) to discuss how wavelength and frequency are related to energy. Have students construct a similar (logarithmic) scale that reports wavelength and/or frequency.
	+ **Extension:** Use slide **5** (detailed energy spectrum) to research [specific missions/observatories that observe in different wavelengths](https://imagine.gsfc.nasa.gov/science/toolbox/emspectrum_observatories1.html) (NASA Imagine the Universe, 2013b). Explore why scientists may use ground-based and space-based telescopes (or different techniques) to study one portion of the electromagnetic spectrum.
	+ **Extension:** Use slide **6** (energy comparisons) to talk about scales of energy. Use slides 7 - 9 to directly comparing a couple energies (comparing electrons to everyday objects), and have students calculate their own comparisons.

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

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| **Phase Summary:**Students apply what they have learned about multiwavelength astronomy by reading about the Crab Nebula in different wavelengths. Students consider why gamma-rays are left off of the reading, and watch a short video that supplies some evidence. Students work individually or collaboratively to complete a student guide to reflect on student learning. |

**Student Steps:**

1. Students read about the [Crab Nebula](https://imagine.gsfc.nasa.gov/science/toolbox/multiwavelength2.html) and what can be learned of the object through different wavelengths (NASA Imagine the Universe, 2013a). In the article, students see what the Crab Nebula looks like in radio, infrared, visible/optical, ultraviolet, and x-rays. Students recognize that gamma-rays are not pictured or described.
2. Students work in small groups to discuss possible reasons why gamma-rays were not included in the article. Students also discuss predicts for what the Crab Nebula in gamma-rays would look like, and what scientists could learn from this view. Student groups record their thoughts and predictions to reflect on later.
3. Students watch a [short video](https://www.youtube.com/watch?v=qDhdwgK218E) on the Crab Nebula, as viewed in gamma rays (NASA Goddard, 2011).
4. Students complete the “[Observing the Universe](https://docs.google.com/document/d/1Uvnyh9kUnzlU6SjrJlnm9ShTMluGmVLsFuBIc9VyqnY/edit?usp=sharing)” guide.
	* **Note**: This activity may be done individually or in partners/small groups. This activity may be done as a form of assessment, or students may use additional resources (i.e. the internet) to work on extending their understanding. The teacher should decide what is best for their classroom. The last two questions are the lesson questions - these should be completed individually so students (and teachers) can measure their growth from the lesson by comparing their responses to what students thought at the beginning of the lesson. A proposed answer key may be found [here](https://docs.google.com/document/d/1Nzuz-l5hBS6Lhu0BKH5OcytHPA064hI3dhlq0OJBofA/edit?usp=sharing).

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## Acknowledgements

This lesson was created through the support of Michigan Technological University’s Physics Department. The Physics Department sponsored a *Research Experience for Teachers*, which allowed the author to partner with scientists and post-secondary students working in the Michigan Tech group of the larger HAWC (High-Altitude Water Cherenkov Gamma-Ray Observatory) collaboration on gamma-ray astrophysics. This lesson introduces multiwavelength astronomy and the various energies associated with the electromagnetic spectrum. Another lesson, focusing on gamma-ray astronomy was also created, and can be used as a follow-up to this lesson. Additionally, a third lesson introducing subatomic particles using a simple cloud chamber, can be taught in a variety of science classrooms.

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