Teacher Guide for the Black Holes Instant Pack

Black holes are mysterious objects in the Universe. What are they? How do scientists discover them? In this Teen Astronomy Cafe — To Go! Instant Pack, students learn what black holes are and how astronomers use light to measure distances. Students then analyze photon flux plots and compute light travel distances to determine the duration and brightness of a flare from black hole and the energy it emits. This activity is conducted in a Python Notebook, a web-based interactive computational environment that contains code, text, and plots.

Learning Objectives:

Students will be able to:

- Use an interactive plot to analyze how far light travels relative to the Solar System.
- Interpret a photon flux plot to determine the duration, brightness of a flare and the energy emitted.

NGSS Standards:

Building Towards NGSS Performance Expectations:

- HS-PS4-1: Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.

Disciplinary Core Ideas	**PS4.A: Wave Properties** The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing.
Science and Engineering Practices	**Analyzing and Interpreting Data** Students analyze photon flux plots to determine the size of a flare from a black hole and the energy it emits. **Developing and Using Models** Students use models based on evidence to predict the relationships between black holes and the fate of galaxies. Students use a computational model to generate data to discover how light can be used to measure distance and predict the gravitational effects of black holes and energetic flares. **Using Mathematics and Computational Thinking** Students test simulations of light travel and quasars to make sense of data compared with what is known about these astronomical events today.

	Connections to the Nature of Science: Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena Students explore the natural phenomenon of black holes and quasars, as it relates to the theory of relativity. Students use interactive plots and graphs to measure light travel distances in space.
Cross Cutting Concepts	**Systems and System Models** Computational models are used to simulate light travel distances relative to the scale of the Solar System. **Connections to the Nature of Science: Science Is a Human Endeavor** Technological advances have led to the development of more powerful telescopes, which has influenced the progress of astronomical discoveries including research into black holes.

Suggested Timing:

- Black Hole Phenomenon & Presentation (50 minutes)
- Python intro and how to run a cell (5 minutes)
- Activity 1: What are Black Holes? (15 minutes)
- Activity 2: How Big is the Flare of 3C 279? (20 minutes)
- Activity 3: How Much Energy is in the Flare? (20 minutes)
- Conclusion: How Can Black Holes Change the Fate of Galaxies? (5 minutes)

Black Holes Presentation:

This Teen Astronomy Café — To Go! Instant Pack includes a slideshow presentation that is accompanied by a recorded presentation video. The purpose of the slideshow is to provide the audience with background information on black holes and to excite and motivate learners in the content. A lesson-level phenomenon (below) is suggested to precede the presentation slides and is recommended as a student-driven active learning strategy to initiate curiosity and questioning. Instructions for incorporating the phenomenon are included below.

Black Holes Phenomenon:

1. Black holes are mysterious objects in space that do not emit light. To begin the lesson, set up a Driving Question Board with the lesson question: "How do astronomers discover black holes?"
2. Provide students with time to think about this question and then show them the first image of a black hole, Black Hole Center of Galaxy M87, and the image of the black hole at the center of our galaxy, Sgr A* supermassive black hole.
3. After observing the initial photos, visit the Driving Question Board and the driving question: "How do astronomers discover black holes?" Encourage students to develop questions based on this question and the first images of black holes. The questions will ultimately drive student learning for this activity. (Note: many student questions may be focused towards understanding what a black hole is and what instruments scientists need to make these images.)

4. Students should share their generated questions as a whole class by posting them visibly to the Driving Question Board. The questions can be organized into similar categories and revisited throughout the slideshow presentation and/or Python Notebook.
5. When referring back to the Driving Question Board throughout the activity, students should work as a whole class to answer, refine or ask new questions.
6. At the end of the activity, share additional resources helping students make connections.
    a. Two articles associated with the images of the black holes:
        i. Messier 87 Article
        ii. Sgr A* Article
    b. Video showing Messier 87 viewed from various scales of wavelengths and size
    c. Video summarizing the Quest to take picture of black hole
7. Concluding the activity, there will most likely be questions unanswered on the Driving Question Board. These questions may be similar to the questions scientists are asking today and that are driving future research. Students may investigate these remaining questions independently.
8. Additional Resource: Telescopes Get Extraordinary View of Milky Way's Black Hole

Python Notebook General Information

- Start by going over the operation of a Python notebook: To execute or run a selected cell, click the little play button or hit [Shift + Enter] on your keyboard. Some cells may take a few seconds to render, so be patient!
- If something doesn't seem to be working correctly (e.g., it can't find resources such as tools.ipynb, or the first simulation where students don't have to enter in any values fails), try restarting the notebook (`Runtime → Restart`).
- To run all the cells at once, go to the "`Runtime`" menu and select the option to "`Run all`."

Activity 1: What Are Black Holes?

This section provides background information on black holes. Students and the public are fascinated by black holes. They are regions of space where gravity is so extreme that not even light can escape (i.e., the escape velocity is greater than the speed of light). Escape velocity is the speed an object much reach in order to surpass the gravitational influence of a primary body. This velocity is determined by the mass of the object and distance to the center of this object. For example, a spacecraft much reach a velocity of 11.2 km/s in order to escape Earth's gravity and only 2.4 km/s for the Moon. Each black hole has a boundary where the escape velocity is greater than the speed of light. This boundary is called the event horizon.

Since black holes do not emit light, astronomers find black holes by observing their influence on other objects. A famous project, led by Andrea Ghez (UCLA), began observing stars near the center of our galaxy in 1995. By mapping their orbits, Ghez's team has determined that the stars are orbiting an object with a mass 4.1 million times that of our Sun. This object is too massive to be anything other than a black hole. Ghez, Roger Penrose, and Reinhard Genzel shared the 2020 Nobel Prize in Physics for their research on black holes.

Another technique to find black holes is to observe their surroundings. As gas and dust fall into a black hole, they form an accretion disk. An accretion disk is an orbital flow of matter formed as a disk around a massive astronomical object such as a black hole. The accretion disk reaches very high temperatures and emits radiation across the electromagnetic spectrum. The accretion disk forms outside the black hole's event horizon so this radiation can be observed by astronomers. The most luminous examples of such objects are known as quasars and can be seen at distances of billions of light-years.

Sometimes quasars can flare and produce vast amounts of energy. These flares can reveal details about the size of the black hole. Students will learn to use these flares to explore the properties of black holes.

Activity 1.1: Using Light To Measure Sizes

The speed of light is $3*10^8$ m/s (or 300 million meters per second). This activity gets students thinking about how fast light travels. You can have the students explore what this means by asking students how long it would take for light to travel to the Moon, to Earth from the Sun, etc. This will be explored more in the next activity.

Activity 1.2: Light Travel Distances Relative To the Solar System

Students explore how far light travels in different amounts of time using objects in our Solar System and going out to Proxima Centauri, the nearest star to our Sun. Be sure to point out the scale at the bottom of the first graph (billions of kilometers). The second graph has a different scale: solar systems. The size of our Solar System is 18 billion kilometers (the distance to the heliopause, where the solar wind from our Sun becomes indistinguishable from the interstellar medium). Be sure students catch the change in units!

Activity 2: How Big Is The Flare of 3C 279?

This diagram has no associated activity but is very important to understanding how we use light travel time to measure the size of objects. Think about the object having a very short flare. Light from the near side would reach us first. Light from the far side would reach us later. The difference in those arrival times would tell us the diameter of the object based on how long the light was delayed.

That works well for flares that are very short. Longer flares, however, can complicate the picture! Students will deal with that concept below.

Activity 2.1: Light-Year As A Distance

A light-year is not a unit of time, but of distance. A light-year is the distance light travels in one year. If you multiply the speed of light by the number of seconds in a year, you get $9.46*10^{12}$ kilometers, a light-year.

Activity 2.2: Let's Look At Some Real Data!

This activity looks at data collected by the Compton Gamma Ray Observatory (one of NASA's Great Observatories that operated from 1991 to 2000) while observing the quasar 3C 279. This flare occurred in 1991.

The graph plots the intensity (in units of 10^{-2} photons/second/square meter) of the flare vs the time. The error bars are fairly large and students will have to decide where the flare starts to rise and fall. Different students will get slightly different answers. Dissuade students from believing there is one "right" value.

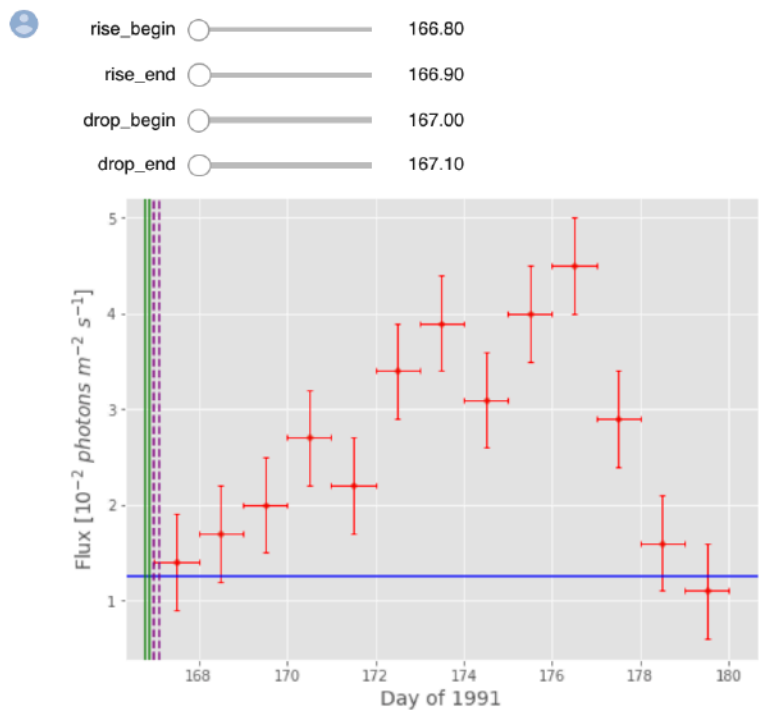

Figure 1: Calculating the rise and fall time of the flare.

Students will calculate the difference between the `rise_begin` and `rise_end` time, to input a value for the `rise_time` into the cell. They will do the same to find the `drop_time`. The rise and fall time of a flare do not have to be the same. Students use the shorter of the two times to calculate the size of the flare in kilometers. \ They can convert that number into how many Solar Systems wide the source is..

Ask students why they use the shorter time instead of the longer time.

Activity 3: How Much Energy Is In The Flare?

Flares from black holes are extremely energetic. This high energy is what makes them visible at such vast distances. If we know how much energy we receive from the flare, we can calculate the total energy output of the flare.

The y-axis of the graph tells us the intensity of the flare. Students can read the peak flux from the graph and enter it into a cell which will convert to photons per second per square meter.

The following cell uses the distance to the quasar to calculate the total energy per second emitted at the peak of the flare.

Students will then calculate how much brighter this flare is than our Sun. As was mentioned earlier, these flares produce copious amounts of power!

Students will then compute how many years it would take our Sun to produce the energy this flare releases in one second. Remember, the flare lasted many days so the flare produces many times this energy in total!

The flare is not only brighter than our Sun, it is brighter than our entire galaxy! The final cell calculates the luminosity of the flare compared to that of the Milky Way galaxy.