Teacher Guide for the Gravitational Lensing Instant Pack

In this Teen Astronomy Cafe — To Go! Instant Pack students will explore the astronomical phenomenon of gravitational lensing. Students will use models to explore techniques astronomers use to determine the mass of a galaxy by examining the lensing effects. Students will understand and predict the effects of changing the physical properties of a lensed and lensing galaxy. 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:

- Model gravitational lensing effects of a nearby galaxy on a distant one.
- Predict how properties, such as the mass of a galaxy, can change the lensing effects.

NGSS Standards

Building Towards NGSS Performance Expectations
HS-PS2-4: Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.

Disciplinary Core Ideas	**HS-PS2.B: Types of Interactions** Forces at a distance are explained by fields (gravitational) permeating space that can transfer energy through space.
Science and Engineering Practices	**Developing and Using Models** Students develop models of a lensed galaxy to illustrate and manipulate relationships between the gravitational field of a nearby galaxy and the mass of a background, more distant galaxy. **Using Mathematical and Computational Thinking** Students use mathematical representations of gravitational lensing phenomena to describe the properties of a foreground lensing galaxy and a background lensed galaxy. **Connections to the Nature of Science: Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena** The theory of relativity is explored as students use simulations to walk through some of the steps astronomers use to determine the total mass of a lensing galaxy.
Cross Cutting Concepts	**Scale, Proportion, and Quantity** Algebraic thinking is used to examine graphical representations and predict the effect of a change in variables between lensed and lensing galaxies.

Suggested Timing

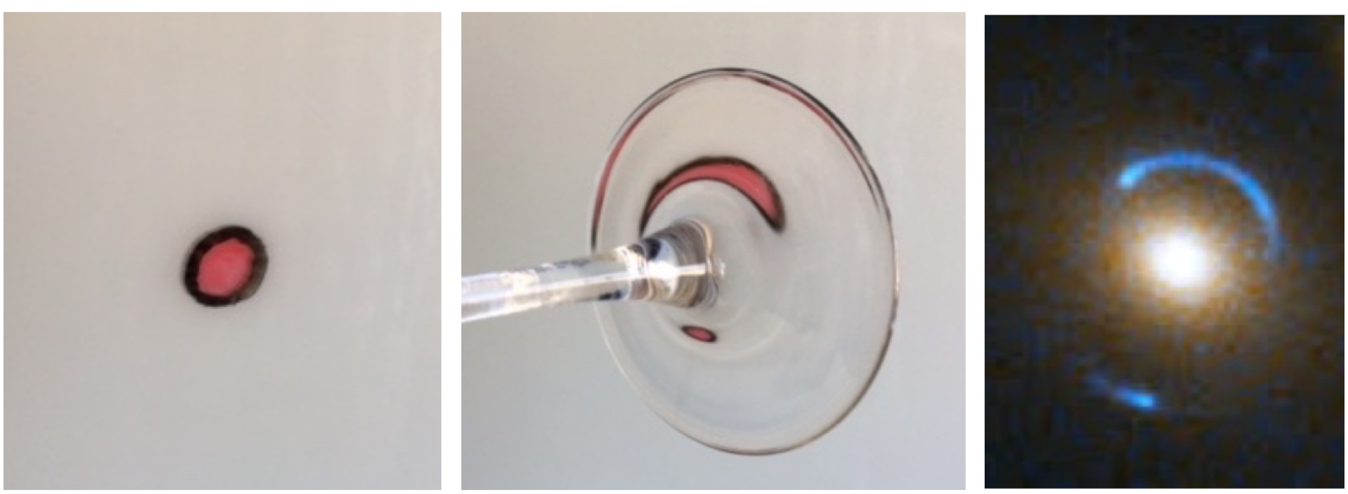
- Gravitational Lensing Presentation & Phenomenon Activity (50 minutes)
- Python Notebook intro and how to run a cell (5 minutes)
- Activity 1: The Lensed Galaxy (15 minutes)
- Activity 2: The Lensing Galaxy (15 minutes)
- Activity 3.1: Matching the Galaxy (20 minutes)
- Activity 3.2: Real Lensed Galaxies (20 minutes)

Gravitational Lensing Presentation

This part of the Teen Astronomy Cafe — To Go! Instant Pack includes a slideshow presentation that is accompanied by a recorded presentation video. The purpose of the slideshow is to provide background information on gravitational lensing to the audience and to excite and motivate the learners about the content. A lesson-level phenomenon is built into these presentation slides and is recommended as a hands-on student-driven learning activity to foster curiosity. Instructions and materials for the phenomenon are included below.

Gravitational Lensing Phenomenon

Materials per student:
- One wine glass with stem
- One marker
- Whiteboard or paper



Credit: A.Bolton/NASA/ESA

Instructions

Observe the Phenomenon

1. Draw a spot, about the size of a dime, on the whiteboard or paper.
2. Center the base of the wineglass on top of the spot.
3. View the spot through the wineglass.
4. Explain to students that what they are observing is similar to a galactic phenomenon called gravitational lensing. Show students an image of gravitational lensing.

Generate Questions

5. Ask students to develop questions about the observed gravitational lensing phenomenon. Strategies for facilitating the development and organization of questions include arranging a Driving Question Board and a driving question such as, "What causes astronomers to observe a distorted galaxy as seen through gravitational lensing?"
6. Student questions can be organized by category and revisited throughout the slideshow presentation and/or Python Notebook.
7. Throughout the investigation, the whole class should reference back to the Driving Question Board to answer, refine or ask new questions.
8. After the investigation, answer any remaining questions on the Driving Question Board and explore a different simulation of gravitational lensing effects as they are applied to a photograph of a city: A Black Hole Visits Baltimore

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 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`."
- Encourage students to alter one parameter at a time as they are learning what each one does.
- To reset each simulation, run the corresponding cell again. This helps when exploring the function of each parameter.

Activity 1: The Lensed Galaxy

This activity focuses on the parameters (physical properties) of the un-lensed galaxy (which we affectionately named "Pat"). Encourage students to experiment with the sliders until they understand the effect of each parameter change. Suggest that students only change one parameter at a time until they understand what that parameter does. Have students discuss with each other how they created their galaxy. For a challenge, have one student create a galaxy and another student try to duplicate the first student's galaxy (the first student should hide their "control panel" of sliders from the second student). Alternatively, the instructor can do a quick formative assessment since this is the first activity: the instructor can display a created galaxy on the board (no parameters visible), and have each individual student or pair try to replicate the instructor's galaxy. Students can work with each other for the remaining activities.

Figure 1: The parameters that students can change in Activity 1.

Activity 2: The Lensing Galaxy

Activity 2 adds a galaxy called Chris which resides between Pat and the observer. Chris is the lensing galaxy and Pat is the lensed galaxy. Students change the parameters of Chris and observe the effect on the image of Pat that is observed by astronomers on Earth. Have students experiment with each parameter until they understand how each parameter alters the observed image. It helps if they only alter one parameter at a time to observe the changes. Similarly to the previous activity, you can have one student create a lensed image and another student try to duplicate it by changing the parameters on their lensing galaxy (Chris).

Figure 2: The parameters the students can change in activity 2.

Activity 3: The Lensed and Lensing Galaxy

Now that the students understand how each of the parameters of Pat and Chris impact the final image, they can put that knowledge to the test! Students can change parameters of both Pat (the lensed galaxy) and Chris (the lensing galaxy). Note: Only Pat is shown. The left image shows Pat before lensing and the right image shows Pat after lensing. Chris is not shown. Although we can frequently see the lensing galaxy, it usually contains large amounts of dark matter that we cannot see!

Activity 3.1: Matching the Galaxy

There are 15 simulated images of lensed galaxies. Students should choose one of them and try to reproduce that image. To do this students can (and probably will need to) change parameters of both the lensed galaxy and the lensing galaxy. Remind the students that the images show the lensed galaxy (Pat) before and after lensing and that the lensing galaxy (Chris) is NOT shown! Remind students that parameters that start with `g_` represent the lensed galaxy (Pat) and they will change the image on the left and right. The parameters that start with `l_` represent the lensing galaxy (Chris). Since the lensing galaxy (Chris) is not shown, changing these parameters will ONLY change the lensed image on the right.

Have students record the values they use to reproduce each image they work on. There are multiple approaches to this section. You can have each student try to produce different images so that each image gets produced at least once. Another approach is to have two (or more) students try to reproduce the same image and compare the parameters they used.

Figure 3: Changing parameters of both the lensed galaxy and lensing galaxy in activity 3.1

Activity 3.2: Real Lensed Galaxies

This activity has the same controls and setup as activity 3.1. In activity 3.2, students attempt to recreate gravitational lenses observed by the Sloan Digital Sky Survey. Using real data is not always as clean as using simulated data!

The instructions on the Python Notebook suggest students can change the value of the parameter `cmap` in the first cell of the activity. Changing `cmap` will change the color palette used to create the gravitational lens. This step is optional as students should be focused on the shape of the lens. Students may find one of the other color pallets more pleasing. If the students change `cmap`, they will have to run that cell and cells 17 and 18 below it for the change to take effect (it is not necessary to run all the cells again). Students can record the values that reproduce the galaxies in the table provided on their student worksheet.

```
[9]  # You can change the last one to change the color of the map.
     myargs = {'interpolation': 'nearest', 'origin': 'lower', 'cmap': cm.magma}
```

Figure 4: Students can change the parameter '`cmap`' to other values such as `cm.magma`, `cm.inferno`, `cm.hot`, or `cm.Blues`.