Astronomers use computers to build mathematical models of gravitational lenses in order to measure the physical properties of the lensing (foreground) and lensed (background) galaxies. In this activity, you will explore how this mathematical model-building works. In this Teen Astronomy Café — To Go Pack, you will use a Python Notebook to interact with simple gravitational lens models and see the computer program that generates the graphics. Python Notebooks are web-based interactive computational environments that contain code, text, and plots.

Pre-Activity Setup: Go to the “Runtime” menu and select the option to “Run all.” Running all helps to ensure a cell was not skipped and all libraries are imported to help the activities work properly. As you work through the Python Notebook, you may also re-run each cell individually.

Activity 1: The first interactive graphic appears at the bottom of the “Activity 1” section. The graphic represents a simple model for the appearance of a distant galaxy without any gravitational lensing. The sliders adjust the numbers that control how the galaxy looks. Each of the sliders represents parameters (physical properties) that are defined in the notebook. See if you can understand what parameter each slider controls by observing how the graphic changes when you adjust the sliders. It is particularly interesting to attempt to reproduce the same image with a partner or small group and then compare the values obtained.

Activity 2: The second interactive graphic appears at the bottom of the “Activity 2” section. The graphic represents the appearance of a gravitationally lensed (background) galaxy. (Note: it does not show the image of the lensing galaxy, only the effect of the lensing galaxy on the lensed galaxy.) The sliders adjust numbers that describe how the mass of the lensing galaxy is distributed. By adjusting the sliders, see if you can understand how changes in the properties of the lens
affect the appearance of the lensed image.

- **Hint 1**: The parameter "l_amp" is called the “Einstein radius,” which changes the overall size of the “Einstein Ring,” and is directly related to the total mass of the lensing galaxy.

- **Hint 2**: You may find it easier to understand the effects if you only change the sliders by small amounts or only change a couple of physical properties at a time.

**Activity 3**: Two more interactive graphics appear at the bottom of Parts 3.1 and 3.2. With these, you can adjust the parameters of both the lensed galaxy and the lensing galaxy.

Choose a few of the simulated images (Part 3.1) and real images (Part 3.2), and see if you can find the combinations of values that reproduce them. You can record the values in this table: